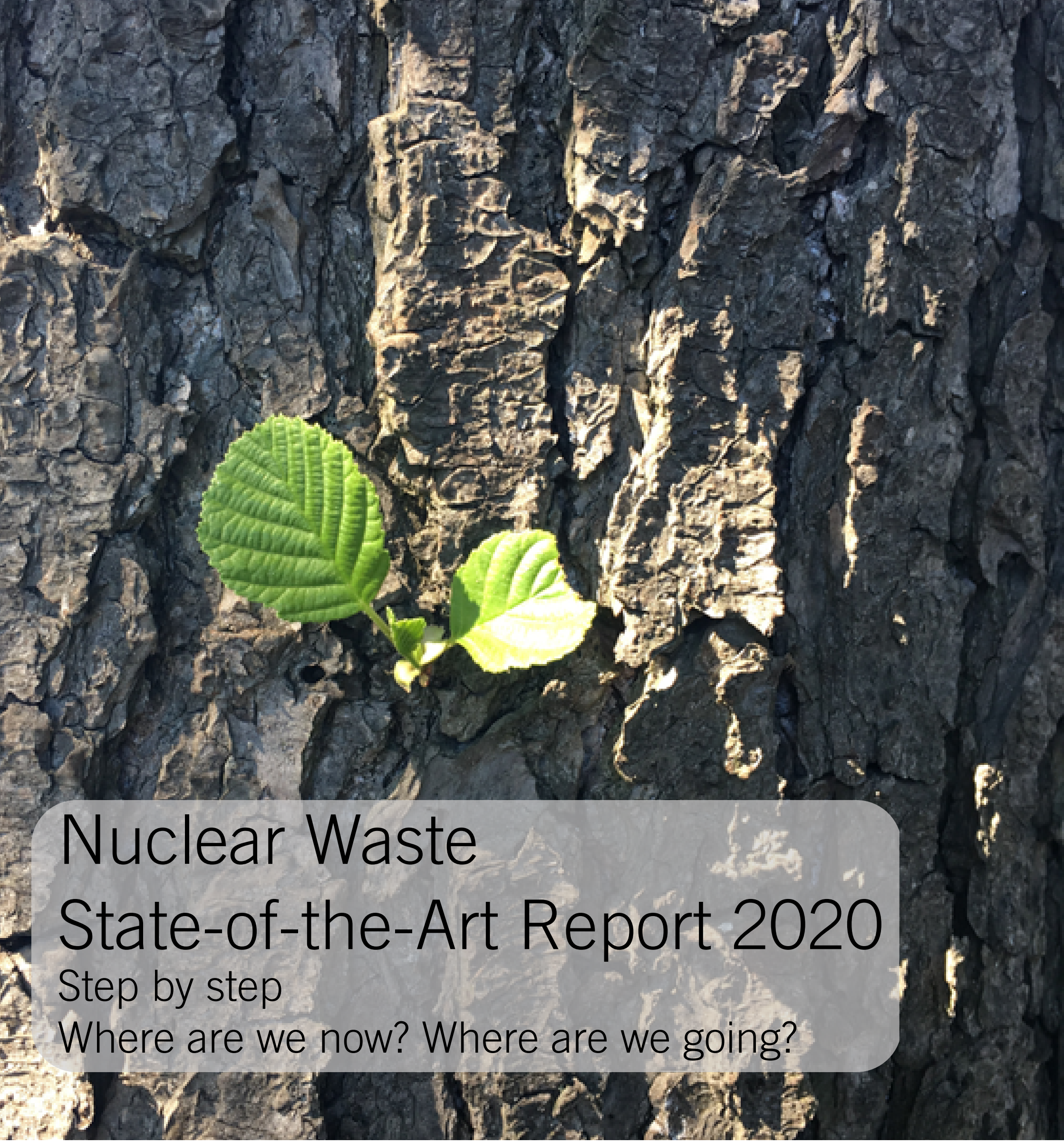

# Nuclear Waste State-of-the-Art Report 2020

## Step by step

## Where are we now? Where are we going?


KÄRNAVFALLSRÅDET
Swedish National Council for Nuclear Waste



SWEDISH GOVERNMENT INQUIRIES
SOU 2020:9

# Nuclear Waste State-of-the-Art Report 2020

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Where are we now? Where are we going?

*Translation of SOU 2020:9*

*The Swedish National Council for Nuclear Waste*

*Stockholm 2020*

SWEDISH GOVERNMENT INQUIRIES

**The Swedish National Council for Nuclear Waste**

(M 1992:A)

Swedish National Council for Nuclear Waste
SE-103 33 Stockholm, Sweden

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Translated into English by Gullers Grupp

# To the Minister and head of the Ministry of the Environment

The Swedish National Council for Nuclear Waste (the national advisor on nuclear waste issues) is an independent scientific committee whose task is to advise the Government on matters relating to spent nuclear fuel, nuclear waste and dismantling of nuclear facilities (M 1992:A the Swedish National Council for Nuclear Waste Dir. 2018:18). In February every other 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 that 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 SOU 2020:9, entitled *Nuclear Waste State-of-the-Art Report 2020. Step by step. Where are we now? Where are we going?*

This report is endorsed by all members and experts of the Swedish National Council for Nuclear Waste.

English versions of the Nuclear Waste State-of-the-Art Reports are also available for the years 1998, 2001, 2004, 2007, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017 and 2018.

Stockholm, 20 February 2020

Carl-Reinhold Bråkenhielm
Chairperson of the Swedish National Council for Nuclear Waste

Tuija Hilding-Rydevik
Deputy Chairperson of the Swedish National Council for Nuclear Waste

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

## Secretariat

Peter Andersson, Executive Director
Johanna Swedin, Scientific Secretary
Evis Bergenlöv, administrative officer

# Content

## Appendix

# PART 1

# 1 Introduction

The Swedish National Council for Nuclear Waste (the Council) publishes its State-of-the-Art Report every other year, as of 2018. This year's report (SOU 2020:9) is divided into two parts:

**Part 1** When the present report is published (February 2020), the issue of a final repository for spent nuclear fuel will be awaiting processing by the Government. The primary objective of the final repository project is that radioactive spent nuclear fuel will be kept separated from future generations for at least 100,000 years. The issue here is how such a complex project should be managed and responded to during a project timeframe spanning multiple generations? How can we ensure the best possible conditions for the success of the project?

Based on a multidisciplinary approach, in this state-of-the-art report the Council considers a number of different issues, which are not only linked to the KBS-3 concept, but rather to all conceivable concepts for the final storage of spent nuclear fuel. They all relate in different ways to the question of what constitutes good technology.

**Part 2** Includes both a report on the Council's work based on the Directive, and a short description of developments in the nuclear waste field in Sweden in 2018–2019.

The focus of this report is on the process that will follow if the Government grants a license for a final repository for spent nuclear fuel.

## 1.1 Chapters of the 2020 State-of-the-Art Report

### 1.1.1 Long-term competence management within the nuclear waste field in seven European countries with commercial nuclear power plants

For a number of years, the Swedish National Council for Nuclear Waste has monitored and drawn attention to the need for long-term competence management within the nuclear power and nuclear waste sectors in Sweden. This chapter constitutes a continuation of this work and sets out a survey that the Council commissioned regarding the current state of competence and national strategies in the nuclear waste sector in six European countries with commercial nuclear power plants, in addition to Sweden. The objective here is three-fold: i) to review the current situation, ii) to gain knowledge on how these issues have been managed in other countries, and iii) to perform an analysis of the situation in Sweden and the six other European countries in the study to discuss how a Swedish strategy for long-term competence development and maintenance may look.

In conclusion the Swedish National Council for Nuclear Waste wishes to propose the following recommendations based on the experiences of the countries included in this study.

- As a matter of urgency, an expert advisory group should be established to analyse the needs for research, education and training to ensure competence in the long term when it comes to implement decommissioning of nuclear power facilities and final nuclear waste repository projects in Sweden.
- This advisory group should investigate the kind of coordination and organisation required to ensure that Sweden is self-sufficient regarding competence and specialist knowledge in implementing the decommissioning and dismantling of nuclear power plants and safe management of nuclear waste. This task should also include an investigation of the conditions required and the consequences of establishing particular institutes or centres of excellence within nuclear technology and radiation protection.

- It is imperative that a national programme is established, for which the government is responsible, for long-term competence management within areas relevant to the decommissioning of nuclear power plants and safe management of nuclear waste.

### 1.1.2 Stepwise licensing and beyond – process and reflections

The previous state-of-the-art report from 2018 included a chapter on stepwise licensing. Stepwise licensing refers to the time until standard operation begins, after which supervision and so-called full evaluations shall be carried out. The chapter in this report contains an overview of the process, all the way through to the final closure, and the Council provides perspectives on this. One challenge is that the experience currently available of stepwise licensing originates from other kinds of nuclear facilities (primarily nuclear power plants), and not final repositories. There is no experience of a project of this length or of building a final repository for spent nuclear fuel that is to be safe and secure in the long term, for at least 100,000 years.

Making sure the stepwise licensing is a tangible process is important, as is being better equipped regarding regulation and transparency throughout the entire period until the final closure. There are a number of question marks when it comes to how current regulation can be adapted to the specific circumstances that apply to the construction and operation of a final repository for spent nuclear fuel. One example is that the construction and operation are to take place in parallel, meaning that using concepts such as standard operation in the same way as for a nuclear power plant is complicated.

### 1.1.3 Modern2020 – the state of art in monitoring

The Council has explored issues of monitoring programmes on many occasions, and has, among other things, described the MoDeRn EU project. This chapter provides an overview of the current state of art based on the subsequent EU project Modern2020, on the latest technologies for supervision and on work on the project regarding participation, primarily with local stakeholders. The period of time in question is until the final closure of a final repository, which may take as long as a century. There are many challenges here, as the supervision must not compromise the functionality of the technical barriers.

The contribution of and interaction with concerned stakeholders (primarily local residents and operators) is a key factor in the realisation of a final repository for spent nuclear fuel and high level waste being successful. For this reason, one Modern2020 work package focused on participation. There are a number of challenges in encouraging public participation. The results of the work package provide no answers on how participation can take place constructively, but instead serve more as a basis for further discussion.

### 1.1.4 Development in barriers – the state of art regarding the integrity of the copper canister

In this chapter the Council explores issues previously raised regarding the canister, based on the latest research. At the end of 2019 the Council participated in a conference on issues relating to the canister, and a doctoral thesis on certain processes has been defended at Aalto University in Helsinki. The Council's conclusions based the latest findings are that there are still a number of research activities that remain to be carried out, primarily regarding the cast iron insert in the copper canisters for spent nuclear fuel, but also regarding details concerning corrosion of copper when exposed to water containing hydrogen sulfide and chloride.

The reason knowledge on primarily the mechanical properties of the cast iron insert is insufficient is that the research was started late, but it has intensified in recent years. This chapter sets out issues that should be prioritised in forthcoming RD&D programmes (where the research should be described even if a license is granted), there should also be clear requirements in any ongoing stepwise licensing from the Swedish Radiation Safety Authority (SSM).

### 1.1.5 Nuclear waste and the public

The chapter looks at public attitudes to, and knowledge on, Swedish nuclear waste. The Council carried out a survey study in late 2018, the objective of which was to expand the basis of assessment of the public's informational needs and how these needs can be satisfied.

The study comprises a representative sample of the adult population of Sweden and demonstrates, amongst other things, that knowledge regarding nuclear waste is at a relatively low level. However, the majority still feel that the nuclear waste issue is important and that Sweden is capable of managing the issue safely. Faith in researchers and experts is high, where as faith in the authorities is lower, and in politicians even lower still. As part of a so-called cluster analysis, a comparison of three different groups is carried out, each containing participants with similar attitudes (i.e. confidence or lack of confidence, and calmness or concern) on the issue. One result of this is that the group comprising recipients who are both lacking in confidence and concerned also demonstrated lower levels of knowledge on nuclear waste.

Citizens' participation in conversations and decisions on the final repository issue is key for a number of reasons. One reason is democratic – that citizen participation strengthens democracy and increases the legitimacy of the decision. It is important that those affected by a decision are involved in the discussions regarding what the right decision would be. And following a potential positive decision, it is important that the municipalities concerned continue to be afforded transparency. The public can also provide the knowledge and experience decision makers lack.

It is vital that citizens are involved and participate in the decision-making process underway and feel that they can be involved in a conversation on the future disposal of nuclear waste.

### 1.1.6 Remembering a final repository

In its previous state-of-the-art reports, the Council has looked at issues of information and knowledge preservation, primarily by reporting on the work of the OECD group *Preservation of Records, Knowledge and Memory (RK&M) across Generations.*

The aim of this chapter is to explore the development work carried out on information preservation for the future and the opportunities for creating common memories relating to a final repository for spent nuclear fuel. The objective here is to demonstrate the broad and multi-faceted nature that is required in this complex work. The chapter provides a short description of institutional memory as a field of research, describing in brief the OECD's development work on information preservation through generations, and sets out some results of an international workshop in Stockholm in spring 2019. Finally, some conclusions and comments are provided on key issues for the continued process in Sweden to establish a final repository for spent nuclear fuel.

## 1.2 Synthesis – nuclear waste and good technology

The concluding chapter of part one aims to provide an overview and establish a number of threads from the mass of information in the previous chapters. This is carried out by stating a range of hallmarks that characterise good technology. Whilst technology is certainly not simply good or evil in itself, it is not value neutral, either. The difference between good, less good and bad/evil technology ultimately depends on its consequences for humans and society. Against this background, the Council proposes a number of different features that, when considered together, could be hallmarks of good technology. Our proposal is that this 'good technology' has the following hallmarks:

– relies on a scientific basis
– requires competence
– is consequence-aware and ready for review action
– is value-aware
– is aware of long-term objectives
– provides transparency through open communication
– requires a comprehensive orientation to the surrounding environment.

First, the different characteristics of good technology are described in a broader context than just the nuclear waste sector. After this is a discussion of 'the good technology' and a final repository for spent nuclear fuel. Finally, the discussion moves to the controllability and steering of the technology. Here, we once again return to the potential for stepwise licensing to steer future technological developments within the nuclear waste sector.

# 2 Long-term competence management within the nuclear waste field in seven European countries with commercial nuclear power plants

## 2.1 Introduction

Sweden is facing a major challenge as a number of nuclear power plants are planned to be decommissioned and both the waste from dismantling and the spent nuclear fuel require management. At the same time, there are also plans to construct and operate an encapsulation plant and a final repository for spent nuclear fuel. All of these activities will require skilled personnel for many decades to come, and there is already concern that demand for this kind of labour force may outstrip supply. For a number of years, the Swedish National Council for Nuclear Waste has monitored and drawn attention to the need for long-term competence management within the nuclear power and nuclear waste sectors in Sweden. This chapter constitutes a continuation of this work and sets out a survey that the Council commissioned regarding the current state of competence and national strategies in the nuclear waste sector in six European countries with commercial nuclear power plants, in addition to Sweden. The objective here is three-fold: i) to review the current situation, ii) to gain knowledge on how these issues have been managed in other countries, and iii) to perform an analysis of the situation in Sweden and the six other European countries in the study to discuss how a Swedish strategy for long-term competence development and maintenance may look.

During the period 2018–2019, SSM reported the problems concerning national short-term and long-term competence management, and an investigation of the issue has been carried out upon a request of the government.[1]

The Council's study was carried out in 2019 with the assistance of Oxford Research AB, Stockholm. The six European countries considered in the study are at different stages in terms of efforts and strategies within the nuclear technology sector, which in turn has consequences for operations related to decommissioning and waste management. Finland is carrying out an expansion of commercial nuclear power, whilst a final repository for spent nuclear fuel is under construction. France and the UK have plans to both build new and decommission commercial nuclear power plants, whilst Belgium, Spain and Germany are planning for decommissioning of commercial nuclear power plants. The survey involved the mapping of the situation regarding competence in the countries, as well as exploring how training, education and research within the nuclear technology and nuclear waste sectors are arranged.

### 2.1.1 Research method

Oxford Research and the Council developed a data collection model with the objective to investigate competence management and national strategies relevant to nuclear waste management. The survey encompasses four key aspects:

- an overview of the countries' existing and planned nuclear technology plants and final repository systems
- an evaluation of the countries' perspectives on their own preparedness regarding short- and long-term competence requirements.
- a description of how the competence management system is organized in each country.
- the conditions required to maintain competence management in each country.

[1] SSM. 2018. Grunden för en långsiktig kompetens-försörjning inom strålsäkerhetsområdet [The basis for long-term competence development within the radiation safety sector].

The survey was carried out by studying material in published reports and on websites, as well as using in-depth telephone interviews with one representative at national authority level in each country. The interviews were carried out in the native language of each representtative. In addition to these interviews, the Council carried out a telephone interview with one representative from the Swedish Radiation Safety Authority (SSM), complemented by written responses, using the same questionnaire as used in the other interviews. The questionnaires with completed responses are available on the Council's website.[2] Additional information has been collected from the SSM's state-of-the-art report.[3]

The materials collected by the Council, in the form of the questionnaire, is only descriptive in nature. In instances where the results are reported qualitatively in the form of figures, they are based on the Council's assessment of the supporting information.

## 2.2 Current state of skills in the sector and appeal of the industry

It is clear from the studies that the nuclear power sector is, on the whole, in a challenging situation in terms of attitudes and values, both politically and publicly. In all countries except Finland, the nuclear power sector is considered unattractive by students planning for their university studies. Finland is clearly investing in the development of commercial nuclear power, which means that the sector is considered as a prospective industry sector of interest for both graduates and professionals. In France and the UK, nuclear power remains a key source of energy, but the sector is not considered appealing, and in France it is seen as somewhat controversial. In other countries the reasons why the sector is considered unattractive vary from a lack of clear political directives and plans (Spain), to a sector characterised by plans for decommissioning, making it uninteresting as a future career opportunity (Belgium, Germany, Spain, Sweden). In general it is considered that the accident in Fukushima in 2011 has had a negative impact on attitudes, whilst the limited carbon dioxide emissions from nuclear power have been put forward in some coun-

[2] The materials for the 2019 study into competence management can be found in reports at: www.karnavfallsradet.se/en/publications (accessed 27 January 2020).
[3] SSM. 2018.

tries to stimulate interest and create a more positive societal attitude. This may influence the attitudes towards nuclear technology-related operations, including nuclear waste management, making them more attractive to students.

It is a problem in many different ways that the nuclear power and nuclear waste sectors are seen as unattractive. Fewer students attend education programs in these sectors, will in the long term, lead to a potential shortage of graduated students and young professionals. At the same time, many countries foresee significant retirements. Furthermore, all countries are at risk of losing more staff to other sectors considered more attractive than nuclear power and nuclear waste management. In the worst-case scenario, this could lead to an acute shortage of staff and skills. Relying on import or purchase of international (specialist) skills does not appear to be a possible way forward as it seems unlikely that other European countries will have an excess of trained staff within the near future.

Figure 2.1 shows diagrams illustrating attitudes towards nuclear power versus the interest of students (expressed in terms of students attending relevant courses and programs) and the level of competence management problems experienced. Each country's rating on the scale is a subjective assessment made by the Council, based on information obtained from the survey. We note a clear positive correlation between attitudes in the society and the student interest to attend university programs related to nuclear power technology and waste management. In this case Finland is unique with its positive societal attitude and high number of students attending such programs, compared to the other six countries. The link between attitudes towards nuclear power and perceived competence management problems (difficulties to attract and maintain educated and experiences workforce) are not as clear cut. Also in this case, the seven countries form two clusters, with Finland constituting its own group with only minor problems experienced. The reasons why the six other countries experience major problems with competence management, independently of societal attitudes regarding nuclear power, may depend on a number of factors. Our interpretation is that negative societal attitudes to nuclear power is a common factor for the countries being unsuccessful in attracting skilled employees. In some countries, attempts are being made to increase the attraction for the sector by promoting the climate advantages (primarily the UK), whilst other countries are investing in research and development of nuclear power technology and/or future nuclear power systems (France, Belgium and the UK, as well as Finland and Spain to a more limited extent). However, the challenges concerning problems with competence management are likely to persist for some time to come, even if efforts to change attitudes will be successful.

**Figure 2.1**

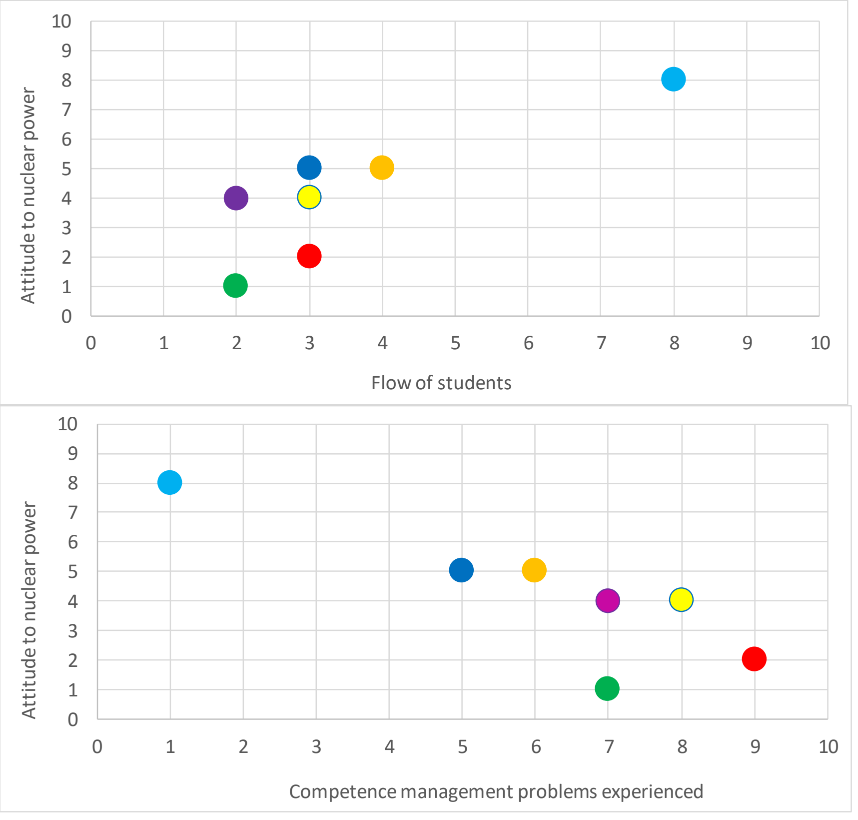


Figure 2.1: The upper figure shows the relationship between attitudes towards nuclear power (0 being a very negative attitude in society, 10 being a very positive attitude in society) and the student interest (0 being very few or no students applying to education relating to nuclear technology, 10 being very high competition for places on courses relating to nuclear technology). The lower diagram shows the attitude towards nuclear power versus experienced competence management problems (0 being very minor problems with finding competent staff, 10 being major problems recruiting competent staff (lower diagram)). Belgium (purple), Finland (light blue), France (blue), Spain (red), UK (orange), Germany (green) and Sweden (yellow with blue edge).

As a number of countries see the decommissioning of nuclear power as a near-future reality, are more personnel really needed in the sector? The answer from the countries surveyed is a clear yes, as dismantling and decommissioning of nuclear power plants is a major undertaking that will last for several decades and require both continued research and new competence to supplement the specialists currently working at nuclear technology plants. For Sweden, the process surrounding SKB's application to construct and operate a final repository for spent nuclear fuel requires continued research and development throughout the entire construction and operation period until the final closure of the repository. This means that the need of long-term competence management will remain also when SKB reaches an operational stage. It should also be noted that all countries in the study explicitly mentioned the need for continued research on decommissioning and waste management. However, such research is not prioritised in SKB's most recent RD&D programme.

The decommissioning and dismantling of nuclear facilities entail a comprehensive challenge, in which work must be planned in detail, in order for sequential decommissioning and waste management activities to take place in a safe manner. Plans for a final repository exist in many countries, however with varying degrees of maturity, with Finland having made the most progress. However, it is clear that activities to safely carry out dismantling and decommissioning activities associated with nuclear facilities will occupy the sector for many decades to come. Time for planning, constructing and operating an encapsulation plant and a final repository for spent nuclear fuel and high-level radioactive waste must also be added to this, with a time horizon in Sweden of 50–80 years. If this time horizon would be properly communicated to the students, this may well lead to an increase in interest in education in the relevant subjects.

## 2.3 National Coordination on Nuclear Waste

By national coordination we refer to the degree to which there is a long-term strategy in a country for research on and development/decommissioning of nuclear power and nuclear waste management. This can be expressed, for example, in specific national research programmes and through the level of cooperation between different operators in the country, use of national infrastructures, research centres, etc.

In this survey, we note that some countries have very strong national research institutes or centres, which are directly affiliated with the government or specific ministries. In some cases, these research centres are also involved in education. These institutes or national centres have several very important obligations. They provide continuity in research as they receive funds under special terms from national programmes, and they ensure that specialised education and training programmes are available that ensure the safe operation of nuclear power reactors as well as high-quality and efficient decommissioning of nuclear facilities. Furthermore, they serve as a bridge between research and the needs of the industry for new technology.

In Finland there are clear strategies and robust structures in place, which have a positive impact on the country's ability to ensure competence management, such as:

1. Reviews of nuclear technology competence through measures such as establishing formal committees comprising ministerial, authority, university, and business representatives, which among other things form a basis for the development of national nuclear technology research strategies.
2. Long-term national research programmes within the sector dating back three decades.
3. The technical support functions provided to STUK (the Radiation and Nuclear Safety Authority) by the research centre VTT. VTT undertakes, executes and coordinates much of the research requested by industry and the authorities. VTT has recently established a Centre for Nuclear Safety with the objective of establishing itself within R&D as an operator on the international stage, thereby supporting authorities and businesses in Finland.

In France, there are two strong national operators when it comes to education and research: IRSN and CEA. IRSN is a state supported expert institution for nuclear technology and radiation safety, with almost 1,800 experts and researchers. CEA is, by Swedish standards, a vast state research organisation with over 16,000 employees, running a number of research facilities and a large number of research programmes, as well as bringing together competence from the entire country within a number of technical sectors, including those linked to nuclear power, nuclear waste, and radiation safety for humans and nature. In addition to this, CEA administers a number of specialist training programmes within the nuclear technology sector, via INSTN, an educational institute.

In the UK, the organisation of research and education related to nuclear power and waste management is far more complex, with many different actors whose different roles and responsibilities are difficult to briefly summarise. These actors are responsible for research strategies, research programmes, requirement analyses, assessments, etc. Furthermore, there is also a state-owned nuclear research laboratory (NNL), which brings together national specialist competence and carries out research within the sector. They also collaborate closely with both the government and a number of universities, which through mutual agreements can access advanced equipment and a number of nuclear facilities. The range of relevant academic educations at undergraduate and graduate level is described as broad, with the universities leading the research forwards. The UK's Department for Business, Energy and Industrial Strategy (BEIS), launched an ambitious innovation programme in nuclear technology a few years ago. The primary objective is for nuclear technology innovations to meet climate challenges, and research is aimed at safe operation and development of nuclear power, as well as safe waste management. The programme is also aiming to compensate for reduced research resources from the public sector, which since many years have led to a reduction in the number of researchers in the sector.

Belgium has a national actor equivalent to the French CEA in the form of state research institute SCK CEN, which is responsible for a number of nuclear facilities, as well as organising a range of research programmes. Furthermore, SCK CEN offers training and education, sometimes in collaboration with BNEN, the Belgian Nuclear higher Education Network.

Spain also has a number of national research centres focused on the nuclear energy sector. CIEMAT operates under the Ministry of Science and Innovation and runs a number of research programmes to contribute to knowledge building in the nuclear technology sector and offers education and training as well as a 1-year master programme. ENRESA is to 80 % owned by CIEMAT, and runs research within the decommissioning, final repository and safety sectors. In addition to CIEMAT and ENRESA, there is also the technological platform CEIDEN, which brings together close to 100 private and public organisations in the nuclear technology sector in Spain. CEIDEN also aims to serve as a united nuclear technology voice for Spain, and organises national R&D programs and participation in international programmes. In addition to this, another platform, PEPRI, has a specialist focus on radiological protection.

In Germany, state support is divided between several different actors. The Helmholtz Organisation, one of Germany's largest research organisations, runs national research programmes on nuclear waste management and radiation protection. The German state provides basic support to e.g. the GRS institute, which operates within plant and reactor safety, and the research institute KIT, an actor in research and education within nuclear technology. Additionally, there is BGR, a federal institute for geosciences and natural resources, which provides the German government with independent expert support on issues related to geosciences in the form of the country's final repository plans. In parallel, BfE (the Federal Office for the Safety of Nuclear Waste Management) is responsible for a programme for long-term competence management, which will coordinate education and research, with focus on waste management and final repositories. With this programme, the German government is expected to take over responsibility for competence management for decommissioning of nuclear power, but primarily for nuclear waste management and final repositories throughout the entire country. The intention is that through these different programs, even after having decommissioned its commercial nuclear power plants, Germany will still be able to influence European strategies on nuclear power safety, ensuring it retains national ability to evaluate and assess nuclear technology scenarios. The programme is expected to be completed during the current government term, which will end in 2021.[4]

When it comes to national coordination, Sweden differs from the six other countries covered here, as it lacks both a long-term national strategy for research and development/decommissioning of nuclear power and nuclear waste management. Sweden has no national research centre or institute in neither nuclear technology, radiation pro-

[4] See: Oxfords PM under reports (The materials for the 2019 research into competence management) at: www.karnavfallsradet.se/en/publications (accessed 27 January 2020).

tection or safety. Nor is there any organised cooperation or division of responsibilities between universities/institutions of higher education and other operators working on these issues. This means that universities and institutes of technology are the primary guarantors in sustaining Sweden's long-term competence requirements in decommissioning, final repositories and radiation safety. This is particularly worrying, as SSM's recent report on national competence in Sweden show that research groups within these areas have subcritical funding and staffing. Currently, the ongoing research within nuclear technology, radiation protection and radiation safety at universities depend on the external funding from a range of research councils including Euratom. As the funding of research projects usually cannot be granted for more than 2–5 years, the conditions to ensure long-term competence development cannot be met. Furthermore, there is no coordination of activities or education between the different universities and institutes of technology in terms of long-term national competence requirements.

## 2.4 International cooperation

Regarding the countries' international involvement, we have made two observations which concern; a country's international involvement through representatives of authorities and ministries at research policy level (i.e. by using political means to influence the direction, scope and content of research) and the national participation in international research programs financed primarily by Euratom. This is discussed in more detail in the text below.

Swedish research groups have two primary sources of funding: direct government funding to the universities or institutes of technology and external grants, applied for in open competition, from Swedish and international research funding bodies. Research calls are often broad in their descriptions, which leads to different research sectors competing with each other. Here, the Swedish system differs regarding research concerning nuclear technology from those in most other countries in this study. In the majority of these countries, research institutes obtain targeted research grants directly from the level of ministries in order to carry out research in sectors of particular national interest, such as nuclear technology and nuclear waste management, see above. The situation in Sweden may result in grants available to researchers in the nuclear field at Swedish universities and institutes of technology can become more limited, compared to other countries. Figure 2.2 shows the link between national funding of programmes to carry out research in nuclear technology and nuclear waste management, and a) international involvement at authority level or b) the degree of national steering. Each country's rating on the scale is a subjective assessment made by the Council based on information obtained from the data collection work. We note that Sweden and Spain stand out as the countries with the least support from national programmes and the lowest involvement at authority level. This means that researchers at Swedish universities and institutes of technology are more dependant on external funding than those in the other countries, with the possible exception of Spain. We also observe that the international cooperation at authority level largely correlates with the degree of national steering of operations.

**Figure 2.2**

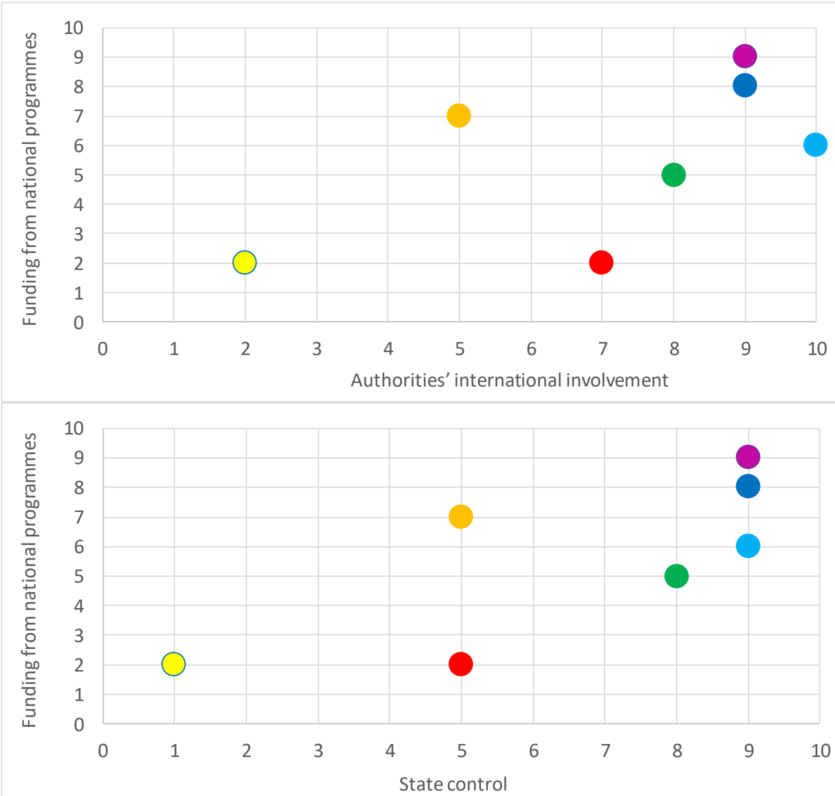


Figure 2.2: The upper figure shows the relationship between funding from national programmes (0 being no funding from national programmes, 10 being a high level of support from national programmes) and the authorities' international involvement (0 being authorities not involved in international collaboration, 10 being authorities dedicating large amounts of resources to involvement and influencing international collaboration). The lower diagram shows the relationship between funding from national programmes and the degree of national steering of the nuclear technology sector (0 being no state control, 10 being very high level of state control) (lower diagram). Belgium (purple), Finland (light blue), France (blue), Spain (red), UK (orange), Germany (green) and Sweden (yellow with blue edge).

### 2.4.1 International participation at authority and ministry level

Several of the countries included in the study (Finland, France, Belgium and Germany) have invested national resources to take an active leading position in the European Council and Euratom as well as a raft of other committees and expert groups through active participation. The representatives involved in this collaboration need to be well-versed in both issues at European level and their own country's competence and research needs, to allow them to both monitor and operate actively in these contexts. This kind of engagement facilitates not just active information accrual, but above all makes it possible to directly influence the research areas considered important within the EU and provides an opportunity to influence the call texts to benefit the national interests. For example, in many cases, comprehensive and multi-year preparatory work is required, including review processes, in order to get research priorities of national interest into the framework of the research programmes announced by Euratom.

In recent framework programs announcements of very large projects has become more frequent. This means that the research funding is granted to a large consortium, where the coordinator is an authority or large research institute, as significant financial resources are required in order to administrate projects that include many research institutions and universities. Individual universities with small research groups and without significant research administration resources are therefore at risk of being excluded from partaking or competing when they submit individual applications. This Euratom policy leads to reduced funding options for researchers in countries that are not investing resources in the formation of research policy and priorities at the European level, compared to countries that are more actively involved (see Figure 2.2). Figure 2.2 shows that international involvement at authority level, as well as the degree of state steering and co-financing has a major impact on ensuring that research within European collaboration can be funded.

The UK has been engaged in the European nuclear research policy, albeit to a significantly lesser extent than France, Belgium, Finland, Germany and Spain. Furthermore, it is also unclear how international research involving the UK will be developed in the future, as the outcome of the Brexit process is currently unpredictable.

From an authority perspective, Spain has been active at European level, but there have been major problems with respect to national research funding, which may have influenced the opportunities for researchers to access co-funding to participate in EU projects.

Sweden differs significantly from the other countries in the study when it comes to involvement at ministry and authority level, through very limited participation in the committees and expert groups that prepare and decide on the Euratom programme. This is noteworthy when it comes to Sweden's significant nuclear power involvement and very advanced repository plans. Like Finland, Sweden should be able to have leading positions in Europe on issues concerning waste management and final repositories. In Sweden there is a great deal of knowledge and experience in the sector, and during the interview, Finland's respondent highlighted that a closer collaboration between Sweden and Finland at the European level on these issues would be desirable.

### 2.4.2 Cooperation in international research projects

Regarding involvement in European research projects, there are differences between the countries, primarily regarding national research funders' resources and funding. Finland serves as an example of a country with strong state and industrial involvement and support. In several cases individual universities are involved in research projects, whilst in other cases the national authority STUK or technical support organisation VTT fulfil this role.

In France and Belgium, the large national research organisations CEA and SCK CEN, respectively, often support work on European cooperation projects, and on many occasions take a leading role. This means that France, Belgium and also Germany, with their national research institutions, are highly successful in terms of receiving funding from Euratom. The national programmes provide a long-term perspective, facilitate co-funding, and ensure that research institutes have the administrative capacity required to coordinate the projects. The UK also has a relatively high participation level in European projects, with individual universities as partners. In Sweden and Spain, and to a certain extent the UK too, research groups at individual universities and with limited guaranteed resources (often only the teaching and research positions the faculties can offer) are the ones expected to provide the long-term national competence required.

Both Sweden and Spain have research groups for which participation in Euratom projects is a necessity for their survival, as funding from national resources is insufficient. In these instances, however, participation often requires co-funding from the countries participating, which constitutes an additional difficulty.

In summary, the level of participation in European research projects funded by Euratom varies between the seven countries.

Authorities and national research institutes and universities in France, Germany and Belgium gain significant funding from Euratom relative to the proportion that goes to their universities. However, for Sweden and Finland, it is the universities who receive the majority of the funding from Euratom (in Finland also STUK to some extent and the research institute VTT). The Swedish Radiation Safety Authority (SSM) has a very limited research activity in-house and does not compete for research resources at the European level.

## 2.5 Competence management strategies

In the text above, the Swedish National Council for Nuclear Waste has attempted to provide an overview of the situation in Sweden and in six other European countries regarding their strategies for long-term national competence management. Below, the Council summarises the strategies each country highlights to tackle and reduce their problems to guarantee long term competence in the areas of nuclear technology, nuclear safety and radiation protection,

- Finland: Since 2010 a number of formal committees have monitored and investigated nuclear technology competence in the country. There is a clear national nuclear technology research strategy and continuous multi-year research programmes in line with the strategy.
- France: Several state-financed organisations have multi-year research programmes to ensure national competence. The country has also recently launched a new master's programme on decommissioning, where it is believed competence must be strengthened and more students educated. Annual conferences are organised to facilitate exchanges of experience in the sector, in order to spread newly acquired knowledge and experience.
- Belgium: In recent years, state funding of research within nuclear energy has doubled. The Belgian authorities have set up an internal system to ensure competence management, as well as developing a report on strategic research requirements in the sector.

- UK: Different initiatives to survey the needs required within higher education and research have been taken. A short-term solution to the competence issue within the nuclear technology sector, as in other branches, has been to launch an apprenticeship programme, within which trainee and intern placements have been created. The largest research efforts within the nuclear technology sector in the last 30 years have been seen from the ministerial angle.
- Spain: Several different platforms have been set up to coordinate and run national and international research and development. Additionally, two research programmes focusing on supporting and promoting knowledge management and coordination of training and education programmes within the nuclear energy sector have been established. In Spain, research collaboration is close between the research institutes, the national regulatory authority, commercial operators and platforms.
- Germany: For several decades there have been a so-called 'alliance for competence within the nuclear technology sector', which brings together the leading research organisations in the country. The objective is to promote collaboration and identify research sectors that need support in order to maintain a national competence. The operators have introduced a system of parallel recruitment, whereby a new staff member is recruited five years prior to a person's expected retirement date. A national concept is under development in order to propose details for a national programme for competence management within the nuclear technology sector, for which the state has full responsibility.

## 2.6 Summary and conclusions

In all of the countries studied, with the exception of Finland, concern has been expressed regarding the ability to secure future required competence in the nuclear power and waste management sectors. This situation is primarily caused by negative societal attitudes towards nuclear power, which in turn leads to difficulties in attracting students to undertake the necessary education and training and in sourcing competent applicants for positions within these sectors. At the same time, many professionals are close to retirement and a shift from operating nuclear power plants to decommissioning them is taking place.

In Finland, an expansion of the country's nuclear power capacity is planned, whilst it is also the only country in the world building a final repository for spent nuclear fuel. In Finland, the nuclear sector is being further developed and major large-scale investments are expected in the future.

Belgium, Spain and Germany have opted to decommission nuclear power for electricity production, albeit not within the same time frame. These countries have very negative societal attitudes towards nuclear power and it is considered a great challenge to attract sufficient number of students to education and training programmes to manage the decommissioning and management of nuclear waste agreed upon. In Germany and Belgium, the state has taken overall responsibility for resolving these challenges, see above. In Spain, the responsibility lies with the operators, and there is no overarching national planning.

France and the UK are planning to close nuclear power plants as well as to build new ones. In France, the planning of a long-term final repository for nuclear waste is well on the way, whilst the UK has no concrete plans in place. In both countries, societal attitudes towards nuclear power are mixed, but primarily somewhat negative. The French state has taken overarching responsibility for research and training, whilst in the UK it is divided between the state and operators in a complex system. Both countries are experiencing difficulties attracting students for training and education in nuclear technology and management of nuclear and radioactive waste.

Unlike Sweden, all the other six countries in the study have invested in national coordination encompassing research institutes that bring together competence in the sector. Education related to operation of nuclear power plants and nuclear waste management exist to larger extents in these countries compared to Sweden, along with dedicated education and research programmes within these sectors. Furthermore, there is very strong involvement at ministry and national authority level in positioning the country at the European level, to ensure that issues of great national importance are included on the agendas of European collaboration projects. In addition to this, national research institutes have taken the responsibility to manage the administrative procedures associated with these projects. In principle, it is only Sweden that has no clear profile in these contexts. In Sweden, it is left to individual universities and research groups to involve themselves in different issues, whilst commercial operators are expected to ensure that their competence needs are met. If Sweden is to compete for a greater proportion of the available research and development funds within Euratom, national efforts must be increased to promote excellence at universities within nuclear technology and radiation protection. Furthermore, the international involvement at e.g. Euratom level, of ministries and authorities must be prioritized. National representatives must have the necessary tools and knowledge to push for issues of interest to Sweden and actively collaborate with industry, universities/institutes of technology and research groups to understand their needs and make the most of their competences.

A national program for educational investments and long-term funding of research within nuclear technology and radiation protection is a basic condition to ensure the competence needed in Sweden in the longer term. Currently, steering of university education through government directives is very limited, but the government can use such initiatives to a greater extent than currently to ensure long-term research competence and the range of educational programmes considered particularly vulnerable and necessary. A positive step would be to initiate a higher degree of cooperation and coordination between educational initiatives of universities and institutes of technology with such competence, and the operators. It would also be possible to extend the coordination further and establish national education programmes to better use the resources and specialist competences at different universities and technical institutes of technology.

Sweden must strengthen research and education regarding decommissioning and dismantling of nuclear facilities, final repositories for radioactive waste as well as on the effects of ionising radiation on people and environment. An advisory body operating under the responsible ministry with the task to analyse and foresee the needs in research, education, and training and education of professionals would be valuable. It should support the development of national strategies and to ensure competence management and safe management of radioactive waste.

Within the sectors of nuclear technology and radiation protection, research and education is ongoing at four Swedish universities or institutes of technology: Chalmers, KTH, Stockholm University and Uppsala University. In order to efficiently utilise resources and competences within education and research and to increase competitiveness when it comes to international research funding, the coordination between these universities and institutes of technology, and SSM must be significantly improved, with a clear division of responsibilities for each organisation. To supplement this, the conditions required and the consequences of establishing particular institutes or centres of expertise within nuclear technology and radiation protection should be investigated. In several of the countries in this study, institutes or centres of excellence have been established in order to ensure long-term competence within strategically important areas. Strategic research areas in Sweden have previously been identified by the government at the recommendation of e.g. the Swedish Research Council, Fas, Formas, Vinnova and the Swedish Energy Agency, which has led to establishment of centres of excellence at universities and institutes of technology.

## 2.7 Recommendations

Regardless of the future role of nuclear power for electricity production in Sweden, the decommissioning of nuclear facilities and the safe management of nuclear-power-related-waste are operations that must remain functional for many decades to come. This means that research and education on the dismantling of nuclear facilities and the management of radioactive waste must be guaranteed for a long time ensuring access to a workforce with high competence and the best technology available.

In conclusion the Swedish National Council for Nuclear Waste wishes to propose the following recommendations based on the experiences of the countries included in this study.

- As a matter of urgency, an expert advisory group should be established to analyse the needs for research, education and training to ensure competence in the long term when it comes to implement decommissioning of nuclear power facilities and final nuclear waste repository projects in Sweden.

- This advisory group should investigate the kind of coordination and organisation required to ensure that Sweden is self-sufficient regarding competence and specialist knowledge in implementing the decommissioning and dismantling of nuclear power plants and safe management of nuclear waste. This task should also include an investigation of the conditions required and the consequences of establishing particular institutes or centres of excellence within nuclear technology and radiation protection.
- It is imperative that a national programme is established, for which the government is responsible, for long-term competence management within areas relevant to the decommissioning of nuclear power plants and safe management of nuclear waste.

## References

SSM. 2018. Grunden för en långsiktig kompetensförsörjning inom strålsäkerhetsområdet [The basis for long-term competence development within the radiation safety sector]. Date: 20 September 2018. Document No: SSM2017-134-23.

The materials for the 2019 study into competence management can be found in Swedish under "Material till undersökning om kompetensförsörjning i SOU 2020:9." See: https://www.karnavfallsradet.se/material-till-undersokning-om-kompetensforsorjning-i-sou-20209 (accessed at May 19th, 2020).

# 3 Stepwise licensing and beyond – process and reflections

The issue of a final repository for spent nuclear fuel is currently awaiting processing by the Government. (February 2020). Two forms of licensing will happen, one regarding permissibility under Swedish Environmental Code (1998:808) and one regarding licenses under the Swedish Act on Nuclear Activities (1984:3). Both acts apply in parallel, i.e. licenses must be granted under both regulatory frameworks in order for the process to be able to move forward.

If the government has granted permissibility under the Swedish Environmental Code, the matter will move on to the Land and Environment Court at Nacka District Court (Land and Environment Court), which will decide on licenses in accordance with the government's decision on permissibility. The Land and Environment Court will then decide on the likes of more specific conditions within the framework for the government's decision on permissibility.

Under the Act on Nuclear Activities, the government decides on the issue of licensing. The act states that the government may decide on the terms for the validity of the licensing. The terms can be established as stepwise licensing of a final repository. Establishing whether the licensing terms have been fulfilled by an operator shall be carried out by supervisory authorities.

Under the Act on Nuclear Activities, the supervisory authority is SSM.

Under the Swedish Environmental Code there are several supervisory authorities, including the Environmental Protection Agency, the Swedish Agency for Marine and Water Management, and County Administrative Board. On issues regarding ionising radiation, SSM is the relevant supervisory authority under the Swedish Environmental Code.

This chapter describes and discusses what the processes for constructing a final repository for spent nuclear fuel may look, focusing on the regulations within the framework for the Act on Nuclear Activities. The aim of this chapter is both to explain how the process to set up and operate a final repository for spent nuclear fuel may manifest, provided the government decides on permissibility under the Environmental Code and on licensing under the Act on Nuclear Activities, and to identify issues that require further discussion and clarification in relation to a continued process up until the final closure.

In the first section, the applicable regulations regarding nuclear facilities are described. The second section highlights the fact there are differences in terms of the regulations applied to the establishment and operation of other kinds of nuclear facilities, such as nuclear power plants, and what is required for the establishment and operation of a final repository for spent nuclear fuel.

In the following section an overview, based on current regulation, is given of the stepwise licensing and the following phases of the process, through to the final closure. When describing the different phases, the Council also gives its own perspectives. This is followed by a section on the options for making changes, if required. Finally, the Council provides some reflections.

There are a number of aspects requiring discussion and the Council wishes to emphasise the importance of clarifying all the constituent parts of stepwise licensing and the following phases in the process, through to the final closure. In this chapter, based on documentation issued by SSM and SKB, the following concepts will be used to describe and discuss the process for a final repository for spent nuclear fuel: stepwise licensing, standard operation, disassembly and dismantling, and final closure (see explanations in the box below). SSM's guidance documents and pronouncements deal primarily with the so-called stepwise licensing through to approval of standard operation.[1]

[1] SSM. 2018. Granskningsrapport 2018:06 *Uppförande och drift av slutförvarsanläggningen [Review report 2018:06 Establishment and operation of the final repository facility]*, p. 6 f; SSM. 2010. STYR2011-131 *Beredning av tillstånd och prövning av tillståndsvillkor gällande kärntekniska anläggningar och andra komplexa anläggningar där strålning används [Preparation of licensing and review of licensing conditions applicable to nuclear technology plants and other complex facilities where radiation is used]*, p. 22; See also Kärntekniklagutredningen [Inquiry into a New Nuclear Technology Act]. 2019. SOU 2019:16 *Ny kärnteknikklag – med förtydligat ansvar [A New Nuclear Technology Act – with clarified responsibilities]*, p. 194.

In its RD&D *Programme 2019* SKB indicates some of the key milestones and an overall timeline, including beyond the stepwise licensing through to sealing and decommissioning.[2] Based on SKB's timeline, the steps of the stepwise licensing will require the following amounts of time: establishing and entering operation approximately nine years and trial operation approximately three years. After this, SKB plans for standard operation to last approximately 30 years, which includes depositing the canisters in parallel with the ongoing expansion of the deposit area. Sealing and decommissioning is set to take approximately 10 years. (Final closure comes after this). One conclusion is that SKB plans for the stepwise licensing through to standard operation to only take just over a decade of the total 70-year process through to final sealing.[3]

**Overview of the phases under the Act on Nuclear Activities that will follow if the government grants permissibility/licensing**

*Stepwise licensing:* here, in accordance with SSM's regulations, means that safety reports, operational limits and conditions, etc. must be approved by SSM prior to construction, trial operation and normal operation.

*Standard operation:* in this phase means that SSM carries out ongoing supervision. Recurring full evaluations must be carried out at least once every 10 years.

*Disassembly and dismantling:* Prior to this phase, SSM must examine and approve reworked safety analysis reports.

*Final closure:* Prior to this phase SSM must examine and approve renewed safety analysis reports.

Throughout all phases (through the whole project), SSM carries out supervision and there are requirements for SKB to review technical and organisational changes.

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[2] SKB. 2019. *RD&D Programme 2019.* For timeframes, see p. 57, 59. You can also read more about SKB's descriptions of licensing and design work, establishment and entry into service in Section 3.4 'Genomförandeplan för använt kärnbränsle' ['Implementation plan for spent nuclear fuel'], p. 62 ff. See also SKB.2011. *MKB.* 10.1.2 'Verksamhetsbeskrivning' ['Description of operations'].

[3] The figure of 70 years comes from 'toppdokumentet' ['the top document'] in SKB's application under the Act on Nuclear Activities: www.skb.se/wp-content/uploads/2015/05/flik_01a.pdf (accessed 27 January 2020).

## 3.1 Relevant regulatory frameworks for nuclear power plants

Within the nuclear technology sector, international guidance is provided by the IAEA on the licensing of plants with a stepwise process.[4] This also includes a guide on safety analysis reports for nuclear facilities[5] and a special guide for geological repositories.[6] However, this guide is very general in nature and gives little in the way of detailed guidance for a final repository for spent nuclear fuel.[7] In Sweden, the Act on Nuclear Activities and the Radiation Protection Act (2018:396) contain the basic provisions on safety and radiation protection when it comes to nuclear facilities, which should be applied when licensing a final repository. These provisions are discussed in more detail in SSM's regulations.[8]

When establishing large nuclear facilities, primarily those with nuclear power reactors, so-called stepwise licensing has long been used by the responsible supervisory authorities in Sweden. Stepwise licensing has also been used during larger alterations to nuclear power reactors, for example when increasing the efficiency of a reactor and when establishing facilities for the final disposal and intermediate storage of low and intermediate level nuclear waste. In common with existing nuclear facilities is that stepwise licensing has been available during the construction of the facility. Reviews by authorities could be carried out using engineering methods in stages to inspect and check the construction on site. The plant construction period could take place within a decade.

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[4] IAEA. 2016. Governmental, Legal and Regulatory Framework for Safety; IAEA. 2011. Geological Disposal Facilities for Radioactive Waste for protecting people and the environment;IAEA. 2010. Licensing Process for Nuclear Installations Safety Standards; IAEA. 2004. Format and Content of the Safety Analysis Report for Nuclear Power Plants.

[5] Format and Content of the Safety Analysis Report for Nuclear Power Plants.

[6] *Geological Disposal Facilities for Radioactive Waste*.

[7] IAEA. 2011. *Geological Disposal Facilities for Radioactive Waste for protecting people and the environment. See, for example, Chapter 6 'Elements in a stepwise approach to the development of a geological disposal facility.'*

[8] SSMFS 2008:1The Swedish Radiation Safety Authority's Regulations concerning Safety in Nuclear Facilities apply to all types of nuclear technology plant.
Regarding long-term radiation safety for final repository, the key regulations can be found in: SSMFS 2008:21 The Swedish Radiation Safety Authority's regulations concerning safety in connection with the disposal of nuclear material and nuclear waste; SSMFS 2008:37 The Swedish Radiation Safety Authority's Regulations Concerning the Protection of Human Health and the Environment in Connection with the Final Management of Spent Nuclear Fuel and Nuclear Waste.

## 3.2 Conditions for the licensing process for a final repository for spent nuclear fuel

The conditions for using stepwise licensing for a geological repository for spent nuclear fuel are in some respects different to those for nuclear power plants in general. Some examples are that:

- construction and operation take place simultaneously
- safety within the barriers cannot be checked
- the final repository itself will not be decommissioned
- it must be safe for at least 100,000 years
- the project concerned is unusually long in duration, which entails major challenges in the implementation.

No final repositories for spent nuclear fuel have yet been established, so there are no established routines for safety checks in these contexts. As this project is different to the construction, operation, and decommissioning of a nuclear power plant, it is likely that it will require different regulations to those currently in existence. Concepts such as trial operation and standard operation used in connection with constructing other nuclear power plants may, for example, be more difficult to apply when it comes to a final repository for spent nuclear fuel.

In a final repository – as with other nuclear technology plants – safety must be maintained through a system of passive barriers. Each barrier is intended to, in one or multiple ways, contain, prevent or delay the spread of radioactive substances, either directly or indirectly by protecting other barriers in the barrier system – which is the principle behind a deep repository.[9]

The barriers to be used in the final repository are copper canisters (featuring cast iron inserts), surrounded by bentonite clay and bedrock. The plan is to place the canister and bentonite clay in the deposit holes in the deposit tunnels. After this, the tunnels will be sealed as the bedrock work proceeds.

For this reason, it may be difficult to establish whether the barriers are working well as part of a stepwise licensing process in the same

[9] SSMFS 2008:1, Chapter 2, Section 1 Barriers and defence in depth.

way as a supervisory authority would monitor and assess the construction of a safety system during the establishment of another kind of nuclear plant, such as a nuclear power plant. For this reason, the process that awaits, if the government gives its approval under the Environmental Code and the Act on Nuclear Activities, will be a unique one.

## 3.3 Stepwise licensing through to standard operation

### 3.3.1 Regulation of stepwise licensing

SSM has proposed[10] that the government set out terms for stepwise licensing in accordance with the authority's regulations. The authorities' regulations state that:

> A preliminary safety analysis report shall be drawn up before a facility may be constructed and, for an existing facility, before major refurbishing or rebuilding work or major modifications are carried out. The safety analysis report shall be updated before trial operation of the facility may commence so that the report reflects the construction of the facility. The safety analysis report shall be supplemented, taking the experiences of such trial operation into account, before the facility is subsequently taken into standard operation. The preliminary safety analysis report as well as the updated and supplemented safety analysis report in accordance with the second paragraph shall at all stages have been reviewed for safety in accordance with Section 3 and reviewed and approved by the Swedish Radiation Safety Authority. The safety analysis report shall be kept up to date thereafter.[11]

The government's licensing is based on a preparatory preliminary safety review. After this, SKB will carry out a new safety review prior to the trial operation, and a completed safety analysis report prior to normal operation, which will take into account experiences from the trial operation. The safety analysis reports[12] must be tested and

[10] SSM.2018 Yttrande över ansökningar om tillstånd till anläggningar för slutligt omhändertagande av använt kärnbränsle [Pronouncement on licensing for facilities for the final management of spent nuclear fuel]. p. 3.
[11] SSMFS 2008:1, Chapter 4, Section 2.
[12] You can read more about the safety analysis reports in SSMFS 2008:1, Chapter 4 Section 2 Safety analysis report (SAR) and in Appendix 2 to these regulations; SSMFS 2008:21, Section 11 Safety analysis report and in Appendix 1 to these provisions.

approved by SSM before the operator may proceed to the next step.[13] There are also particular provisions on instructions for the operation of a facility, so-called Operational Limits and Conditions,[14] which will be updated and approved by SSM before a facility can be given a trial operation or standard operation started.

In stepwise licensing, as in the subsequent phases, there are requirements whereby technical and organisational changes at a facility must be reported, and there are also requirements for the authority to approve these changes (and if necessary review the changes).[15] If anything about the facility changes or is supplemented, in terms of technology or organisation, the safety analysis report and the operational limits and conditions shall be changed and adapted accordingly.

In its pronouncement to the government in 2018, SSM described the review of the preparatory preliminary safety analysis report as being based on reference design. The reasons for this include that not all location-specific information is available and that not all detailed design solutions have been determined. Only once a facility has been constructed can SSM determine whether the design and installation systems meet the requirements. And only once a trial run has been carried out can SSM assess whether operations meet the requirements.[16]

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[13] More information on stepwise licensing can be found in SSM. 2010. STYR2011-131 Beredning av tillstånd och prövning av tillståndsvillkor gällande kärntekniska anläggningar och andra komplexa anläggningar där strålning används [Preparation of licensing and review of licensing conditions applicable to nuclear technology plants and other complex facilities where radiation is used]; SSM. 2018. Granskningsrapport 2018:6 Uppförande och drift av slutförvarsanläggningen [Review report 2018:06 Establishment and operation of the final repository facility], , Section 1.1 'On Stepwise Licensing'; SSM. 2019. Annex 1 'Prövningen enligt kärntekniklagen' ['Licensing under the Act on Nuclear Activities'] to Granskningsrapport – Utbyggnad och fortsatt drift av SFR [Review report – construction and continued operation of a final repository].

[14] Operational Limits and Conditions, see Chapter 5, Section 1 of SSMFS 2008:1.

[15] See Chapter 4, Section 5 of the Swedish Radiation Safety Authority's regulations concerning safety in connection with the disposal of nuclear material and nuclear waste (SSMFS) 2008:1.

[16] SSM. 2018. Granskningsrapport 2018:06 Uppförande och drift av slutförvarsanläggningen [Review report 2018:06 Establishment and operation of the final repository facility]. p. 6 ff.

### 3.3.2 The Council's perspectives on stepwise licensing

There are a number of question marks when it comes to how current regulation can be adapted to the specific circumstances that apply to the construction and operation of a final repository for spent nuclear fuel.

The Council believes stepwise licensing requires concretisation.[17] This could take place through the government, in the permissibility and licensing decisions, formulating the terms that would allow stepwise licensing with a high degree of flexibility, i.e. giving SSM sound opportunities to act based on new knowledge on safety barriers, for example. Furthermore, new regulations regarding operational limits and conditions must be developed and adapted to the conditions applicable in the establishment and operation of a final repository for spent nuclear fuel.

SKB responds to the Swedish National Council for Nuclear Waste's view that stepwise licensing must be concretised by highlighting that SSM's current regulations on stepwise licensing are applied today, that in the report SOU 2019:16 clearer legal regulation of stepwise licensing is proposed in accordance with the Act on Nuclear Activities, and that SKB itself proposes terms on trial runs and standard operation.[18] However, the Council considers that concretisation need not necessarily involve legislation, but at the least more comprehensive planning is required when it comes to the entire period through to final sealing: which phases are required and what they should entail. In its pronouncement, the Council proposed a comprehensive pilot phase.

In its pronouncement, SKB responds that a pilot phase would constitute an extraneous operation in the "long-accepted stepwise licensing under the Act on Nuclear Activities" and a requirement for a pilot phase would give rise to a number of uncertainties in terms of scope, content, implication and consequences. SKB states that, naturally, the company cannot provide an in-depth account of which

[17] The Swedish National Council for Nuclear Waste. 2019. Kärnavfallsrådets remissvar angående Svensk kärnbränslehantering AB:s kompletterande yttranden, dels i ärendet om tillåtlighetsprövning enligt 17 kap. miljöbalken, dels enligt Lagen (1984:3) om kärnteknisk verksamhet [The Swedish National Council for Nuclear Waste's comments regarding SKB's supplemented pronouncement, partially regarding permissibility assessment under Chapter 17 of the Environmental Code, partially under the Act on Nuclear Activities (1984:3)].

[18] SKB. 2019. Pronouncement regarding comments submitted on SKB's pronouncement under the Act on Nuclear Activities to the Ministry of the Environment April 2019.

operations would be included in a forthcoming trial run, but that it could start with SKB requesting approval to start a trial run.

The uncertainties surrounding the trial operation offer proof of the “accepted stepwise licensing under the Act on Nuclear Activities” being insufficient. Even if SKB cannot report in the finest of details which operations will be included in a trial run, it should consider what can actually be included. SKB is leaving matters very late if it intends to only provide more detailed information on what the trial operation will entail when it requests SSM’s approval to commence said trial run. Furthermore, new operations and phases may need to be introduced.

## 3.4 Standard operation

### 3.4.1 Regulation during standard operation

Throughout the entire process, up until final sealing, which includes so-called standard operation, SSM will carry out supervision[19] of the operations and provide details of any facility-specific terms if necessary. SSM may also demand measures such as pausing or stopping operations if doing so would be justified for reasons of radiation safety.[20] The supervision carried out by SSM will include, but not be limited to, inspections, monitoring of operations, and review of annual reporting. As part of the ongoing supervision, SSM may require the licensee to provide reports on particular issues.

The current Act on Nuclear Activities sets out requirements for full evaluations as specified in regulations.[21] At least once every ten years, the licensee shall carry out a collective analysis and full evaluation of the safety and radiation protection of the facility. This concerns both the way in which the facility meets the relevant safety requirements at the time of assessment, and whether there are

[19] For more information on supervision as per the Act on Nuclear Activities, please see Sections 16, 17 and 18. You can find out more about how SSM carries out its supervision of nuclear technology plants at:www.stralsakerhetsmyndigheten.se/omraden/karnkraft/vart-sakerhetsarbete/vi-bedriver-tillsyn-over-karntekniska-anlaggningar/ (accessed 27 January 2020). [English version: https://www.stralsakerhetsmyndigheten.se/en/areas/nuclear-power/Our-safety-and-security-work/exercising-supervision/].
[20] The Act on Nuclear Activities Section 15 (revocation of license) and 18 (option to impose on the licensee the orders and prohibitions that are necessary).
[21] The Act on Nuclear Activities, Sections 10 a, 10 b Full evaluations; SSMFS 2008:1, Chapter 4, Section 4 Periodic safety review (see also additional general advice regarding Chapter 4 Section 4).

conditions in place for operating the facility safely through to the next assessment, taking into consideration developments within science and technology. Analyses, assessments and the measures these lead to will be documented and reported to SSM, which shall decide on a more precise date for the assessment.

### 3.4.2 The Council's perspectives on standard operation

If a final repository for spent nuclear fuel starts normal operation, it is not yet considered completed and can be developed further in steps. Tunnelling, drilling of deposit holes, placement of the buffer and canisters, and refilling and sealing of the tunnels will happen simultaneously. Can standard operation truly be discussed under these preconditions, when the repository has not been completed, with construction and development ongoing simultaneously with operation? Construction and operation will take place simultaneously for several decades. What will ongoing supervision entail in such a situation. Will new requirements regarding ongoing supervision be imposed, and will it be possible to alter these requirements over time? In the view of the Council, these questions must be answered.

Regulation on full evaluations exists in current regulations, but these must be clarified and adapted to a final repository for spent nuclear fuel. These 'checkpoints' should be more frequent than once every ten years, as a great deal happens and there is a high degree of staff turnover during a period this long. In the Council's view, specific guidelines regarding the scope and review of recurring full evaluations for final repositories for spent nuclear fuel are required, not least concerning requirements for updating safety analysis reports. Even if the regulations are based on the full evaluations taking place to follow up on completed plants in operation, it is reasonable that the provisions also be applied during the construction of the final repository, given the very long construction period required in these contexts.[22]

[22] Please also see the Council's proposal that the assessments be sent for comment to ensure transparency and openness. International reviews should also be carried out: The Swedish National Council for Nuclear Waste. 2019. The Council's response regarding SKB's supplemented pronouncement.

## 3.5 Disassembly, dismantling and sealing

### 3.5.1 Regulation of disassembly, dismantling and sealing – requirements for updated safety analysis reports

After a safety analysis report prior to standard operation has been approved, there are two occasions under current regulations where SSM will review and approve safety analysis reports: prior to disassembly and dismantling of the structures that do not form part of the finished final repository and prior to the sealing of a final repository.

- SSM shall examine and approve a reworked safety analysis report prior to SKB/the operator being permitted to start disassembly and dismantling (SSMFS 2008:1 Chapter 9 Section 7).
- SSM shall examine and approve a renewed safety analysis report prior to the sealing of a final repository (SSMFS 2008:21 Section 11).

### 3.5.2 The Council's perspectives on disassembly, dismantling and sealing

After the final sealing of a final repository, nuclear material controls, physical protection and information preservation will be required, with many questions remaining on topics such as what will happen after sealing. What kind of regulation of 'the final repository area' will there be after sealing? It will most likely remain an area of national interest indefinitely, with specific restrictions for total defence, for example.[23] Will the state take over responsibility? What kind of surveillance of the repository and surrounding area will be required? How will information be retained for generations? In the view of the Council, these questions must be answered.

The Council is of the view that special permission should be required from the government for the final sealing of a geological final repository. Under the Act on Nuclear Activities, the government may then decide on terms to be fulfilled before the final

[23] See Chapter 3, Section 9 of the Swedish Environmental Code.

repository may be sealed. After this, the state shall assume responsibility for the sealed repository.[24] [25]

## 3.6 Opportunities for changes if required

The government makes decisions on licensing under the Act on Nuclear Activities and the Land and Environment Court decides on licensing under the Environmental Code.

*The Act on Nuclear Activities*

The government's decision is a so-called administrative ruling. The fundamental immutability of a positive decision is key in administrative law. A permit decision under the Act on Nuclear Activities cannot normally be revoked under the principle of res judicata for administrative decisions. However, the principle is not without its exceptions. One way to depart from this principle is to specify a number of conditions in the decision that must be fulfilled for the decision to be valid.

If the government grants a license for the final repository system (Clink encapsulation facility and final repository) under the Act on Nuclear Activities, from an administrative law perspective, it becomes a positive decision giving SKB the right to construct the final repository. A decision that is positive in nature for an individual party (SKB, in this case) may be altered to the detriment of that party only if it becomes apparent from the decision that:

– under certain conditions the decision may be revoked, or
– for imperative reasons of safety a decision must be altered immediately.

[24] See proposals in:Inquiry into a New Nuclear Technology Act.2019. SOU 2019:16 Ny kärntekniklag – med förtydligat ansvar [A New Nuclear Technology Act – with clarified responsibilities].
[25] The Swedish National Council for Nuclear Waste. 2019. Kärnavfallsrådets remissvar angående utredningen – Ny kärntekniklag med förtydligat ansvar [The Council's comments regarding the investigation – a new nuclear technology act with clarified responsibilities] SOU 2019:16.See also 2.4 "Ansvaret för slutförvaring av använt kärnbränsle" ["Responsibility for final disposal of spent nuclear fuel"]The Swedish National Council for Nuclear Waste. 2018. SOU 2018:8 Nuclear Waste State-of-the-Art Report 2018. Decision-making in the face of uncertainty.

An error involving the party having provided inaccurate or misleading information may also lead to the decision being revoked.

In SKB's application[26] [27] the company claims that the government gives a condition for licensing as the facility for final disposal of nuclear material being built, owned and operated 'in general agreement with' what is stated in the application documents (the same wording as used in the licensing for all nuclear power plants in Sweden). This kind of wording in the final repository for spent nuclear fuel licensing decision gives the supervisory authority, SSM, the opportunity within its supervisory activities and within the framework of the license to influence the design of the final repository facility. Under Section 18 of the Act on Nuclear Activities, SSM may decide on the measures and inform the licensee of the orders and prohibitions required for the safety requirements to be fulfilled. At the same time, measures that ought to be taken according to the authority in order to prevent errors discovered in the facility also apply. This may also concern measures to prevent the likes of sabotage, and not least measures to prevent unlawful dealings with nuclear materials or nuclear waste.

However, the extent of these provisions for alterations can be discussed, in the case that, for example, new scientific findings occur, regarding new or greater risks than previously assessed, but that would be difficult to detect concretely for a long time to come. In such a situation, it is not a given that SSM can definitively demonstrate the need for changes and implement the relevant requirements. Compared to the licensing process, in this kind of hypothetical situation it is the authority and the public, rather than the operator, who have the burden of proof. This underlines the importance of how licensing terms are formulated in the initial testing process.

[26] Toppdokumentet [The top document]: www.skb.se/wp-content/uploads/2015/05/flik_01a.pdf (accessed 27 January 2020).

[27] "Anläggningen ska uppföras, innehas och drivas i huvudsaklig överensstämmelse med vad som anges i ansökningshandlingarna. KBS-3-metoden med vertikal deponering ska tillämpas." ["The facility is to be built, owned and operated in general agreement with what is stated in the application documents. The KSB-3 method with vertical deposit shall be applied.]See: SKB. 2019. Yttrande över inkomna remissvar på SKB:s yttrande enligt KTL till miljödepartementet april 2019 [Pronouncement regarding comments submitted on SKB's pronouncement under the Act on Nuclear Activities to the Ministry of the Environment April 2019].p. 10.

*The Swedish Environmental Code*

Whilst this chapter focuses on nuclear technology legislation, there is also cause to say something here about the Swedish Environmental Code, which features certain rules of binding force. According to the Environmental Code, it is the Land and Environment Court that shall make a decision on licensing, following a permissibility decision by the government, and thereby on the terms the court considers necessary for the license. For larger nuclear facilities, this takes place after the government has decided on licensing for the operations. Under the Environmental Code, the applicant shall propose to the Land and Environment Court the terms it considers necessary for the license. However, the government may decide when examining permissibility, whether particular terms are required to fulfil public interest. This offers an opportunity to try to manage particular challenges brought about by the particular timeframe of the issue.

## 3.7 Concluding reflections

A final repository for spent nuclear fuel is, without a doubt, a large, long-term project, meaning that it is difficult to calculate exactly how long it will take. Furthermore, it is also the kind of project that is unusual and rarely implemented, which further complicates project planning in terms of time and cost.[28] It is likely that the project will not proceed as planned for the duration of the minimum 70 years SKB estimates it will take. For this reason, it is important to be prepared for changes and for developments to not go as planned.

There is a great deal of regulation within nuclear technology today, but the provisions are primarily adapted to suit nuclear power plants, which serve a different purpose to a final repository. For this reason, clear regulation is required for the process, during and after final sealing, which is adapted specifically for a final repository for spent nuclear fuel.

[28] The 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 s. 115; The Swedish National Council for Nuclear Waste. 2014. SOU 2014:11 Nuclear Waste State-of-the-Art Report 2014. Research debate, alternatives and decision-making p. 108.

In this chapter, the Council has highlighted some perspectives on the different phases.[29] There are also a couple of proposals based on the Council's pronouncement (September 2019) on SKB's supplementations.[30]

*Transparency and consultation*

There are no references to a need for consultation in the long term in current regulations. The Council believes that consultation is necessary throughout the process, through to the final sealing, and that the structuring of this is key, to ensure it provides participation, openness and transparency. The Council has proposed that a broad spectrum group be formed. Communication between different groups with different perspectives is important.[31]

*Demonstration or pilot repositories*

The supervisory authority cannot monitor and assess the construction and operation of the safety systems in the same way as for a nuclear power plant, as the barriers and functionality of the final repository are difficult to assess. One possible way of monitoring the development of the final repository's barrier system could be to use some kind of demonstration or pilot repository.

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[30] For more information please see Kärnavfallsrådets remissvar angående Svensk kärnbränslehantering AB:s kompletterande yttranden [The Council's response regarding SKB's supplemented pronouncement].
[31] For more information please see Kärnavfallsrådets remissvar angående Svensk kärnbränslehantering AB:s kompletterande yttranden [The Council's response regarding SKB's supplemented pronouncement].

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# 4 Modern2020 – the state of the art in monitoring

## 4.1 Modern2020 – an international research project on monitoring

On several occasions the Council has written about the importance of a monitoring programme and supervision. The aim of this chapter is primarily to examine the current state of the art regarding technical developments based on the EU monitoring project The Development and Demonstration of Monitoring Strategies and Technologies for Geological Disposal (Modern2020), which includes participants from a number of European countries. The Council has long advocated for social sciences research, and Modern2020 also features a work package about participation and involvement from different stakeholders as a decisive factor in implementing final repositories.

Modern2020 was an international, multidisciplinary research project running from 2015 to 2019, building on work in its predecessor project, MoDeRn (previously described by the Council, see box below). Modern2020 was funded by the European Commission, via Euratom's Horizon 2020 research and innovation programme. Modern2020 brought together scientific experts from Belgium, the Czech Republic, Finland, France, Germany, Italy, Japan, the Netherlands, Spain, Sweden, Switzerland and the UK. The participants included representatives of organisations and companies involved in nuclear waste management, supervisory authorities, consultants, academics and local stakeholders, as well as experts from a range of scientific disciplines, such as technology, geology, nuclear physics and social sciences.

The primary thinking behind the Modern2020 project was that monitoring offered the potential to meet both technical and societal needs in terms of management and final depositing of spent nuclear fuel and high level waste. The project focused on research, development and demonstration of strategies and technologies for the monitoring of final repositories for spent nuclear fuel and high level waste. The aim was to create a common basis for monitoring activities in the EU. In 2019 a second and concluding international conference was held, in which the results of the project were presented and discussed.[1]

This chapter is divided into different sections. Following the introductory background section, a summary of the key results is presented regarding developments in recent years in technology and methods of monitoring. This primarily describes the results of work packages 3 and 4. A summary of what Modern2020 has produced can be found in Monitoring in Geological Disposal & Public Participation: A Stakeholder Guide. [2] This stakeholder guide is the result of work package 5, about public stakeholder engagement. The work package is different in nature to the other work packages, and is described in brief in the third section of this chapter. The fourth section examines Swedish participation in the project, and ends with a summary.

MoDeRn: Monitoring Development for Safe Repository Operation and Staged Closure

The research project MoDeRn, predecessor to Modern2020, and the issue of strategies and methods for monitoring have been described in the Council's previous state-of-the-art reports. In the 2015 report, the chapter "Monitoring programmes for sealed areas" provides a more detailed description of the project, including the various work packages. It also reviews the preliminary results of a range of field research efforts and case studies on different technologies. [3] In the chapter "Strategies for monitoring programmes in planned final repositories" from 2016, different strategies for the formation of monitoring programmes at final repositories are reviewed and discussed, with examples from Posiva

[1] www.modern2020.eu/final-conference/home.html (accessed 27 January 2020).
[2] Meyermans, A. et al. 2019. Monitoring in Geological Disposal and Public Participation – A Stakeholder Guide.
[3] The Swedish National Council for Nuclear Waste. 2015. Nuclear Waste State-of-the-Art Report 2015 Safeguards, record-keeping and financing for increased safety.

(Finland) and Nagra (Switzerland) looked at in more detail.[4] The Swedish National Council for Nuclear Waste has, on a number of occasions, discussed the need for monitoring.[5]

### 4.1.1 Background – monitoring and supervision

The classic definition of 'monitoring' refers not only to taking measurements, but also to a wider concept of observing and controlling development or quality for a period of time.

*What should be monitored*? A distinction is often made between 'far-field', which is common and relatively simple today (monitoring of the environment through taking biota samples in the area around a repository) and 'near-field', which is more complicated, in particular regarding monitoring technical barriers (monitoring of developments down in the repository itself). Sometimes, there is a degree of resistance to near-field monitoring, which is motivated by the idea that it can threaten the functionality of the repository, as monitoring sensors and cabling are considered a disruptive factor in the repository's passive safety system. In order to not disturb the repository, as in Finland, it is possible to build a demonstration repository next to the actual depository – Finland is currently the first in the world to start implementing this. Designing and operating a demonstration repository involves creating a concrete environment to present a facility in, which can increase the transparency of the entire development process.

*When should it be monitored?* Another distinction that can be made is between 'operational safety monitoring', which has to do with monitoring the safety of workers in the workplace and following up on how operations impact the direct environmental and 'postclosure safety monitoring,' which has a different objective. This kind of

[4] The Swedish National Council for Nuclear Waste. 2016. SOU 2016:16 Nuclear Waste State-of-the-Art Report 2016.Risks, uncertainties and future challenges.
[5] For example, see: The Swedish National Council for Nuclear Waste. 2014. Review of the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D Programme 2013. 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. 2012. Kärnavfallsrådets synpunkter på behov av kompletteringar av ansökan för tillstånd till anläggningar i ett sammanhängande system för slutförvaring av använt kärnbränsle och kärnavfall [The Swedish National Council for Nuclear Waste's perspectives on the need for additions to the application for licensing for facilities relating to a cohesive system for the final disposal of spent nuclear fuel and nuclear waste].

monitoring may involve installation of sensors in the designed barrier system to observe the different processes and parameters in the repository, to gain a greater and deeper understanding of the development of the repository after sealing. In the event the monitoring reveals any parameters not meeting the requirements, retrieving the canister can be considered. In certain countries (not, however, Sweden), there is legislation in place for this.

This chapter looks primarily at monitoring the barriers through until final closure, i.e. 'near-field monitoring'. This period can last more than a century.

Different bedrock in different countries leads to different repository concepts and thus different strategies and technologies for monitoring.

One reason different countries are planning different final repository concepts is each country's strategy is dependent on its own bedrock. Companies and organisations focused on management of nuclear waste that are developing geological final repository systems in claystone or salt formations are relying on their strong natural encapsulation capacity. However, gneiss and granite, of which the bedrock in countries such as Sweden and Finland consist, lack such capacity. In these cases, the rock has a delaying impact on any leakage reaching the biosphere. The technical barriers are, therefore, more important here, relatively speaking.

## 4.2 Monitoring programme and supervision (technology)

In order to ensure that a repository is working, monitoring is considered necessary. The functionality of a repository is monitored by taking measurements or otherwise regularly observing certain critical parameters. In order to do this, a monitoring programme entailing methods and strategies must be established. As per international recommendations and guidelines,[6] a monitoring programme must include measurements during the construction and operating periods. Some form of monitoring for a period following the final closure may also be desirable. This chapter features a brief review of the

[6] IAEA. 2014. Monitoring and Surveillance of Radioactive Waste Disposal Facilities; ICRP. 2013. Radiological Protection in Geological Disposal of Long-lived Solid Radioactive Waste.

technical possibilities for measuring key parameters, as established by the research projects carried out within the Modern2020 programme, and future development opportunities are also discussed.

In Sweden, in SSMFS 2008:21 Section 8, SSM states that:

> The impact on safety of measures adopted to facilitate the monitoring or retrieval of disposed nuclear material or nuclear waste from the repository, or to make access to the repository difficult, shall be analysed and reported to the Swedish Radiation Safety Authority.

SSM should, therefore, carry out an assessment of any negative impact on safety.

The technical barriers, intended to provide passive safety in the long term, must not be negatively impacted by sensors, cabling or any other equipment required for monitoring. It is also important that the monitoring system works and emits the correct signals. Incorrect measurements may lead to unnecessary measures as well as unacceptable risks, such as costs arising.

## Objective and strategy

The primary objective of a monitoring programme for a final repository is to ensure that the repository fulfils the requirements set in the safety analysis regarding the functioning of the technical barriers, and these requirements will also need to be met after the final closure. The strategy regarding what must be monitored varies, depending on how far along the chain from planning to decommissioning the final repository is. Both the IAEA and ICRP have released reports describing/recommending monitoring programmes for final repositories for spent nuclear fuel.[7]

If the licensing process involves stepwise decision making, a basis for decisions on continuation of the project will be needed at the various stages through to final closure. In order for a positive decision to be made, the licensee must be able to verify that the repository keeps in line with the intended developments after the local tunnel has been sealed, and in order to be able to do this, some form of measurement data on certain critical parameters is required. A posi-

[7] IAEA. 2014. (International Atomic Energy Agency); ICRP. 2013. (International Commission on Radiological Protection).

tive decision may include conditions regarding certain critical data that must be met.

In order to be able to assess the functionality of the repository, it is imperative that information on changes or disruptions to the chemical and physical environment around the technical barriers or surrounding geosphere is available. One key issue also examined further in previous state-of-the-art-reports is checking that the bentonite clay around the canisters is water saturated to the intended extent. This is vital in order for this technical barrier to work, as is the ideal condition presumed by the safety analysis being achieved.[8]

Along with the temperature in the repository and the chemical composition of the inflowing water, i.e. prevalence of various dissolved salts, this is a key parameter upon which knowledge should be accumulated prior to continued operation. Any movements in the bedrock and changes in the fracture pattern are essential information, as they can influence the inflow of water and cause stresses.

The choice of monitoring method and location in a final repository where monitoring are to be taken depends on the formation of the repository. In a repository in crystalline bedrock, unlike in claystone, there is a greater variation in the inflow of water between different tunnels and shafts. Presumably it is possible to have some knowledge of this in advance, and after observations have been carried out in connection with construction of the tunnels. In this kind of repository, when it comes to the bentonite's properties what is of greatest interest are the values measured in the positions where extreme values are predicted in temperature, temperature increase, and water inflow.[9] A representative value for pore pressure, for example, can be challenging to establish. However, with a repository in clay, as is the case in France and Switzerland, amongst others, where a great deal of the research and development within the Modern2020 project has been carried out, the conditions are more homogeneous, making it easier to judge these parameters based on the measurements.

Options when it comes to retrieving the canister are an important factor worth considering when setting up a monitoring programme. Particularly during the deposit phase (operation), but also following

[8] Ideal condition' is the Council's description of a condition where, above all, the bentonite serves as protection by being water saturated, see for example, The Swedish National Council for Nuclear Waste. 2015, p. 95 f.

[9] Haapalehto, S. et al. 2019. "Rock Mechanics Monitoring At Olkiluoto, Finland. Case Study: Monitoring Strategy of Repository Temperature Evolution."

the final closure. What options are available to rectify any shortcomings revealed by the monitoring? As the repository is not designed for the canister to be retrieved, retrieval could entail a greater risk than leaving it undisturbed. For understandable reasons, a monitoring programme must be time-limited, and in practice the technology should dictate this limit. Future technological developments could most likely push it forward.

## Technology

The projects run as a part of Modern2020 include those to explore and develop a variety of technical solutions that can be used for monitoring in the sealed tunnels, primarily before the final closure. The proposals for measurement methods developed within the framework of the project are, in general, specifically designed to work in the geological conditions prevalent in the relevant repository.

However, in many instances it should be possible to adapt the methods developed in Switzerland or France, for example, so that they can be used for a repository in Swedish bedrock. A number of tests have also been carried out in the bedrock in Finland.[10] The methods presented are considered interesting, and a further examination could establish whether or not they could be appropriately adapted.

Focus here has been on two specific challenges:

- Wireless transmission of the signal through technical and natural barriers. Standard technology using high-frequency signals does not have long enough wave lengths in this kind of environment.
- Energy supply to sensors and transmitters/receivers. These devices will need to be supplied with power for extended periods with no option to replace batteries.

Measurement sensors and cabling, or antennae for wireless transmission must not compromise the functionality of the barriers. Optical cables now used instead of traditional copper wiring are more durable and offer greater capacity, however, they cannot supply power to sensors and other equipment. A sensor placed directly in the copper

[10] Haapalehto, S. et al. 2019; Toumas, P. 2019. "Monitoring programme for the Olkiluoto repository, Finland."

canister could potentially contribute to corrosion. Cabling running through bentonite clay and rock can cause channels that affect the water courses in the area, and later on to channels transporting radioactive materials that have leaked out through the canister. There are operators who, for safety reasons, do not accept instruments, sensors or antennae being placed in bentonite clay.[11] They consider the risk of deterioration in functionality to be high enough to outweigh the benefits knowledge on the parameters to be measured could bring. One alternative could be to instead place the measurement instruments in one or several 'demonstration tunnels' in well-selected locations in relation to the planned repository, to take measurements there after sealing.

### Wireless transmission of data and energy supply

New technologies under development are often based on the wireless transmission of data, potentially combined with an optical cable. These technologies require some form of power supply, for both the sensor and for generating and transmitting the signal. This means that the monitoring period would be limited to the lifetime of the battery – currently approximately 10 years. However, measurements would need to be carried out for a significantly longer period than allowed by current battery technology, following the closure of the repository. It is still unclear what kind of lifetime can be expected of batteries in the future – with further-developed battery technology a lifetime of 25 years might be possible. It is considered possible, at least in theory, that batteries could be charged 'remotely', using inductive charging, transferring energy through the rock. In testing a pilot system, Strömmer[12] shows that approximately 1 ppm of the output can be transferred wirelessly through 10 m of rock, i.e. 100 W input gives approximately 0.1 mW at a depth of 10 m, which is sufficient to charge a battery. Other ideas proposed include those based on using the heat development of the canister as an energy source, with a thermoelectric generator.[13] Another option to consider could

[11] Luterkort, D. and Andersson, J. 2019."SKB Monitoring strategy."
[12] Strömmer, E. 2019. "Electric Power Sourcing of Wireless Repository Monitoring Sensors."
[13] Strömmer, E. 2019; Strömmer, E. and Bohner, E. 2019. "Wireless energy transfer with data transfer add-on through low-conductivity host rocks"; Schröder, T.J. et al. 2019. "Thermal Energy Harvesting From High-Level Waste."

be nuclear batteries, as used in satellites and beacons, amongst others. This kind of battery based on the radioactive substance americium-241 has the potential to serve as a current source sufficient for hundreds of years. Regardless of the method, however, there is a range of safety aspects to be considered.

In Tournemire, in the south of France, there is a facility where several European operators have constructed a facility/laboratory in which to test new technologies for signal transmission in the field, 'Long-Term Rock Buffer Monitoring Experiment'.[14] A few dozen standard commercial sensors have been used to measure the various parameters. So far, these have not been tested in the bentonite buffer. What's more, some new or recently developed sensors have been tested that can measure total pressure, pore pressure, temperature, and relative humidity. Equipment produced by different manufacturers for the transmission of signals has also been tested, including both wireless and fibre optic options. With a 'multiroute-multihopping' system and radio waves at a frequency of 8–9 kHz, when using wireless transmission they have managed to reach a depth of 275 m in both clay and rock.[15]

Wireless transfer of data through bentonite clay and basement rock up to the surface requires strategically positioned antennae. In connection with the forthcoming final repository in Onkalo, and in Espoo at the VTT technical research centre in Finland, successful testing of wireless data transfer through 4–23 m of granite and bentonite clay has been carried out.[16] To allow the signals to be conveyed as best as possible through these barriers, a wide frequency range is used, from 4 kHz to 22 MHz; radio waves with lower frequencies are conveyed better in this environment.

[14] Dick, P. et al. 2019. "The Long Term Rock Buffer Monitoring (LTRBM) in situ test, assessing under realistic conditions the performances of monitoring devices developed in Modern2020."
[15] Dick, P. et al. 2019; Eto J.et al. 2019 "Development of a wireless relay system for monitoring of geological disposal using low-frequency electromagnetic waves"; Schröder, T.J. et al. 2019. "Demonstration of a two-staged, wireless transmission chain out of the LTRBM borehole to the surface of the Tournemire plateau"; Schröder, T.J. and Rosca-Bocancea, E. 2019. "Current state of the art of wireless data transmission systems for repository monitoring."
[16] Schröder, T.J. and Rosca-Bocancea, E. 2019.

## Geophysical methods

Geophysical measurements can be one way to avoid use of both sensors and cabling through sensitive areas. The technology presented from Switzerland by Maurer[17] can be used for purposes such as surveying fracture zones in the rock before making the deposit, but it is also useful for ensuring that the canister does not move after sealing. The technology is based on studies of how seismic waves spread through and are reflected in the bedrock.

Maurer also presented other potential technical solutions for measuring the location, moisture level and temperature around the canister. Geophysical methods can be used, at least in theory, for providing an opportunity to characterize the bentonite from the surface, regarding moisture levels, water composition and temperature.[18] These are tomographic technologies that are based on ground-penetrating radars and measurements of the ground's electrical properties. Using these methods (along with induced polarisation), it would be possible to measure the temperature and water content of the bentonite clay from the surface. By starting from different locations on the surface, tomographic technologies can be used with great accuracy to determine, and thereby also control the conditions surrounding the canister. The method has been tested in the field in claystone in Switzerland,[19] however there is a great deal of development work left to be done and it is not yet clear whether this technology will work for a repository in crystalline bedrock.

## Conclusions on technology

A key conclusion of the Modern2020 project is that monitoring is a complex concept. Many fundamental questions regarding both the objective and purposes of monitoring a final repository remain unanswered. What should be monitored? Why should we carry out monitoring? Can it be monitored? For how long should we carry out monitoring? Who is responsible for carrying out the monitoring?

[17] Maurer, H. et al. 2019. "Geophysical Monitoring of High-Level Radioactive Waste Repositories."
[18] De Carvarvalho, B. et al. 2019. "Non-intrusive Geo-electrical ERT Monitoring of High-Level Radioactive Waste Experiments in Tournemire URL."
[19] Maurer, H. et al. 2019. "Geophysical Monitoring of High-Level Radioactive Waste Repositories."

How should we communicate the monitoring data? How can knowledge produced by monitoring equipment be used in the management of the repository?

Research has been underway in Europe for several years on different methods for monitoring critical parameters, such as the water saturation and temperature of the bentonite. Viable technologies have been presented for this, based primarily on field research in countries such as France and Switzerland (in claystone).[20] These use wireless transfer of data, or transfer via a combination of wireless technology and optical fibres. The research has been focused on monitoring during the operating phase. A challenge that remains to be overcome is finding a method that would also work for monitoring for a short period following final closure. In addition to transmission of signals across longer distances underground, a stable electricity supply is required for perhaps 50 years. Sensors and other equipment will also be required to remain functional for this period. Research is underway in Europe on the development of a range of geophysical methods to monitor the qualities of the bentonite. Unlike taking measurements with sensors, these methods do not require any instruments or cabling to be placed into the bentonite. There is much still to be done before conclusions can safely be drawn that this is a feasible technology for use in an actual repository. However, thus far there is reason to doubt the usability of the geophysical methods in a repository in the crystalline bedrock instead of clay. Difficulties with monitoring a bedrock repository are also an issue that requires greater attention, particularly regarding how to interpret the results against a background of major variations in the flow of water between different parts of a repository – for example, could a very low water flow mean that the bentonite is not water saturated to the degree expected. For this reason, it is important that such a tunnel is found, and measurements are carried out in it. This also applies to demonstration repositories: several are needed given the variations in water flow, if the measurement results given are to form a legitimate decision-making basis for ongoing stepwise deposits and sealing.

[20] Dick, P. et al. 2019; Müller, H.R. et al. 2019. "Lessons learned after more than 7 years of monitoring the Full-Scale Emplacement (FE) Experiment at the Mont Terri URL."

## 4.3 A work package on involvement of different stakeholders

### Background and reports

In the report from the closing conference of Modern2020 it is stated that:

> Most repository programs have come to acknowledge the indispensable role of stakeholder engagement. Looking back to earlier years in geologic disposal efforts, there existed an uneven partnership between social and technical issues. The vital and complex role of stakeholders has now assumed an enduring partnership in the process of acceptance and licensing of repositories in most national disposal programs worldwide. [21]

The importance of contributing and participating applies not least when it comes to monitoring. According to Modern2020's predecessor, MoDeRn, it transpired that different stakeholders, primarily local ones, expected that monitoring could provide a continual source of information on the functionality of the repository.[22] One work package for societal issues (Work Package 5) was integrated into the successor project, Modern2020, with the aim of actively engaging local public stakeholders in both the strategy and research work of the Modern2020 project.

The work package has produced three reports (as well as the proceedings from the closing conference). *Repository monitoring in the context of repository governance* sets out the theoretical background, methods and results of the work package. In the report *What role for repository monitoring in the governance of geological disposal for nuclear waste?* Sweden, Finland, Belgium and France are compared to show that the vision of the monitoring can vary between countries for different reasons. This can be down to factors such as the concept planned, which, in turn, is dependant on the kind of bedrock the country has. This is also dependant on the country's own individual policy and the applicable legislation. Certain countries have enacted legal requirements for monitoring and retrievability, such as France and Switzerland.

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[21] Modern2020 Final Conference Proceedings, p. 11.

[22] Bergmans, A. et al. 2014. Monitoring and the Risk Governance of Repository Development and Staged Closure: Exploratory Engagement Activity in Three European Countries, p. 60. See also: Bergmans, A. et al. 2012. Monitoring the Safe Disposal of Radioactive Waste: a Combined Technical and Socio-Political Activity.

In the guide *Monitoring in Geological Disposal and Public Participation – A Stakeholder Guide* monitoring within a geological final repository is introduced as a socio-technical challenge, with the aim of the guide being to provide the reader with usable insights and tools for discussion of waste management, geological disposal, and monitoring. The guide also provides a broad description of final repository issues from different perspectives, looking at questions of ethics, amongst others.[23] The guide also explores issues of reflection on why, when, where and how participation should take place for monitoring. The point is then made that if data collection is initiated, new issues arise, such as:

- Who is responsible for maintaining and managing the monitoring data?
- Should the information be made available to all interested parties?
- Who decides what monitoring values are considered irregular and/or potentially problematic and which measures should be taken on the basis of this information?
- Who is responsible for the monitoring process?
- Should local stakeholders be involved in these decisions, and if yes, how?

## Some conclusions on participation

The work package arrived at the conclusion that how the public can be motivated to participate is not yet clear, and nor is how this can be done well (either for specific EU research projects or more generally in the final repository programmes of different countries).

Even though many of the stakeholders participating felt that the technical aspects ought to be left to the experts, at the same time they provided reasons for citizen involvement in research and development being valuable.

One reason is that local stakeholders will be better informed and thus better equipped to get involved with the process. Stakeholders

[23] Amongst others, there is a reference to C.R. Bråkenhielm's article (2015) on four ethical principles to reflect on in the management of high-level nuclear waste and spent nuclear fuel, see: Meyermans, A. et al. 2019. Monitoring in Geological Disposal and Public Participation – A Stakeholder Guide, p. 18 f.

who are involved can also distribute information further in their community. Another conclusion was that there needs to be something to negotiate on if meaningful participation is to take place – discussions must happen on what is open for negotiations and what is not, and the reasons for this.

The results of the work package could not provide answers on how participation can take place constructively, but instead serve more as a basis for further discussion.

## 4.4 Swedish participation in Modern2020

In Sweden, the Department of Sociology and Work Science at the University of Gothenburg was involved in both MoDeRn and work package 5 of Modern2020. The Municipality of Östhammar also partook in both projects, and in its statement on 3 December 2019 its representatives wrote that an assessment should take place as to whether: "... there is a reason to consider making part of the final repository a pilot facility."[24]

SKB partook participated partially in the predecessor project MoDeRn, and has increased its level of engagement in Modern2020, through means such as the underground laboratory in Äspö being used as a resource for the project. In SKB's "Monitoring Strategy"[25] SKB states that the company are currently developing an overarching monitoring programme for the final repository for spent nuclear fuel. The need for this was identified at an earlier stage during SKB's application process. Work on the Modern2020 project and meetings with the Finnish Posiva have, amongst other things, contributed even to discussions beginning on the monitoring of barriers related to safety post-sealing. The intention is that the programme form part of 'the application' to begin construction of the repository (if permissibility/a license is granted) by the government.

The Council has, multiple times since the statement on the RD&D Programme 2010, stated that SKB must develop a monitoring programme to facilitate verification of developments in the buffer, deposit hole and deposit tunnels over time following the sealing of the tunnels.

[24] The Municipality of Östhammar. 2019. Yttrande över Svensk Kärnbränslehantering AB:s komplettering i regeringsprövningen enligt miljöbalken [Pronouncement on SKB's supplementation to the government examination under the environmental code]p. 3 f.
[25] Luterkort, D. and Andersson, J. 2019, p. 87.

Previously, SKB considered that quality control and steering of the production process were what formed the basis for assessing:

> … whether the technical barriers fulfil the requirements (design requirements) imposed, based on factors such as safety requirements. However, SKB does not intend to monitor the initial development in the technical barriers for the deposited canisters. This kind of monitoring is considered to provide only limited further information of value when assessing the functionality of the barriers.[26]

The Council welcomes the new initiatives SKB has taken regarding monitoring prior to closure, in regard to long-term safety. This is also in line with the perspectives of the Land and Environment Court at Nacka District Court and SSM in their pronouncements to the government in January 2018. In their pronouncement, the Land and Environment Court writes that in the event of potential licensing, a more in-depth discussion is needed on issues relating to checking on radiation safety both before and after closure of the final repository. This may cover, for example, radiological emissions monitoring, monitoring of water saturation of the buffer, and potential oxygen intrusion in tunnels.[27] In its pronouncement, SSM writes:

> Furthermore, SKB's programme must include measurement and monitoring actions that form part of a more comprehensive and long-term monitoring programme, to confirm the performance of the final repository prior to and after sealing. SSM emphasises the importance of careful monitoring and documentation of the properties of the barrier system after construction, operation and decommissioning/sealing phases, to ensure the initial conditions when the repository is first sealed and to facilitate transfer of knowledge on the repository to future generations.[28]

Interest in monitoring can also be found in the USA, for example. In the USA, the Nuclear Regulatory Commission has set requirements regarding the retrievability of spent nuclear fuel and high level waste, as well as requirements for monitoring to ensure that natural and man-made barriers work as intended. Further information is available in the report *Repositories: Performance Moni-*

[26] SKB. 2013. Bilaga K:2 Ämnesvisa svar på Kompletteringsönskemålen [Appendix K:2 Responses by subject to the request for supplementation]. (Version 2 April 2013), p. 57.
[27] The Land and Environment Court at Nacka District Court 2018. Yttrande 2018-01-23 [Pronouncement 23 January 2018], p. 20, 554 ff.
[28] SSM. 2018. Uppförande och drift av slutförvarsanläggningen [Establishment and operation of the final repository facility], p. 70 f.

*toring and Retrievability of Emplaced High-Level Radioactive Waste and Spent Nuclear Fuel* May 2018, authored by the NWTRB, the Council's counterpart.[29]

## 4.5 Summary

*Technology*

- Programmes and strategies for monitoring critical parameters in the sealed spaces during operation, primarily moisture levels and temperature, should/must be established.
- Currently, there is no safe and functional method with which to monitor the sealed tunnels in bedrock repositories, but research results indicate that one may be developed in the future.
- Technology for the wireless transfer of measurement data has been tested successfully in sealed spaces in claystone and granite. For monitoring post-closure, the method must be developed further, because, for instance, the signal will need to be transmitted far further underground.
- Seismic methods have been tested in repositories in claystone. Development of the method is not yet finished, but it could entail the possibility of transfer after final closure. However, currently there is doubt as to whether these methods would work in a granite repository.
- Inhomogeneities in the water flow in a bedrock repository make it difficult to draw up a strategy with random sample testing, as extreme values are of interest here.
- The water must be monitored in the bentonite to ensure that it works as a barrier, for this reason it is important to identify and monitor tunnels with extremely low water flows.
- The monitoring must not compromise the functionality of the technical barriers.

[29] See: www.nwtrb.gov/our-work/reports/geologic-repositories-performance-monitoring-and-retrievability-of-emplaced-high-level-radioactive-waste-and-spent-nuclear-fuel (accessed 27 January 2020).

- There are many challenges still remaining, including power supply for the sensors and wireless transmitters for a sufficient period of time.

*Participation*

- The contribution of and interaction with all concerned stakeholders is a key factor in the implementation of a final repository for spent nuclear fuel/high level waste being successful.
- There are also challenges in encouraging public involvement, as well as ensuring this involvement is well implemented (both in terms of specific EU research projects or more generally in the final repository programmes of different countries).
- The results of the work package cannot provide answers on how participation can take place constructively, but instead serve more as a basis for further discussion.

## Final remarks

Whilst there are many challenges, monitoring of the development of the barriers over time prior to final closure does not necessarily conflict with achieving passive safety afterwards.

In its 2015 state-of-the-art report the Council wrote that the motivation for establishing a monitoring programme in sealed areas can be divided into four headings: safety assessment, transparency, operations oversight and knowledge building. Monitoring can uncover serious issues in sealed tunnels and provide key new knowledge to take into consideration in the ongoing final repository process. For municipalities and regions, a monitoring programme provides increased transparency, which is key to citizens' trust in the deposit process. From an international perspective, the measurements will provide important new knowledge on final repository processes, as SKB's timeline makes it one of the first projects of its kind.[30] It will be interesting to be involved in the development work going forward,

[30] The Swedish National Council for Nuclear Waste. 2015.

and hopefully continue international collaboration to tackle these challenges.

> From Modern2020's Stakeholder Guide:
> This apparent contradiction between the goal of passive safety and the new possibility of active monitoring may not be so clear-cut or contradictory at all, however. After all, in the period before we 'walk away' from the repository and achieve passive safety, monitoring can provide valuable insights into the dynamics and processes going on in the repository. Here, monitoring is both a learning tool and an instrument for achieving the desired goal of passive safety.[31]

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# 5 Development in barriers – the state of art regarding the integrity of the copper canister

## 5.1 Introduction

A fundamental condition for the KBS-3 concept to work as a final repository method for spent nuclear fuel is that the copper canister and its cast iron insert can withstand the chemical and physical impact of their surroundings. Comprehensive research has been underway for many years on the chemical reactions that could impact upon the stability of the copper canister. According to the pronouncement of the Land and Environment Court at Nacka District Court, the following uncertainties remain unresolved regarding the protective capacity of the copper canister: /1/ i/ corrosion due to reactions in oxygen-free water, ii/ pitting due to reactions with sulfide, including the impact of the sauna effect on pitting, iii/ stress corrosion due to reactions with sulfide, including the impact of the sauna effect on stress corrosion, iv/ hydrogen embrittlement, and v/ the impact of irradiation on pitting, stress corrosion, and hydrogen embrittlement. Additionally, the Swedish Radiation Safety Authority (SSM) stated in its 2018 pronouncement that there was a need for development in the following areas: vi/ far too little ductility of the copper liner when under a load (creep ductility), during slow loading in the building of the surrounding buffer's swelling pressure, vii/ how the absorption of hydrogen in copper influences the deformation characteristics of the copper liner, viii/ pitting of the copper liner due to the occurrence of a passivating sulfide film during unsaturated conditions and rapid supply of sulfide, and ix/ stress corrosion of the copper liner as a result of the occurrence of a passivating sulfide film during unsaturated conditions and rapid supply of sulfide. /2/ The

Council believes that these are issues requiring further research efforts and/or analysis. Research on the inner part of the copper canister, the cast iron insert started some years ago. Impurities in the cast iron in the form of copper and hydrogen, for example, and ageing due to the impact of ionising radiation, have been shown to have a negative impact on the mechanical properties of the cast iron in the form of various embrittlement mechanisms. This would result in reduced mechanical integrity of the copper canister if the cast iron insert will crack. Further research is therefore considered necessary on the mechanical properties of the cast iron insert over time in an environment with high radiation intensity, even if these issues have not been considered by the Land and Environment Court.

In this chapter, a scientific summary of the current status of research is presented in terms of the chemical and mechanical stability of the copper liner and the mechanical impact on the cast iron insert from the hydrogen content and embrittlement mechanisms.

## 5.2 Localised corrosion of the copper as a result of the occurrence of a passivating sulfide film

The planned final repositories in Forsmark and Olkiluoto will contain hydrogen sulfide ions, $SH^-$. These will be formed in the ground water by sulfate-reducing bacteria in environments with low oxygen content, turning normally occurring sulfate ions, $SO_4^{2-}$, into hydrogen sulfide, $H_2S$, which transforms into hydrogen sulphide ions, $SH^-$, due to the pH value of the ground water, and by dissolution of sulfide minerals, e.g. pyrite, $4\ FeS_2 + 3\ H_2O \rightarrow 4\ Fe^{2+} + 6\ SH^- + S_2O_3^{2-}$ /3, 4/. $H_2S$ and $SH^-$ ions are potentially harmful to copper canisters, as they can serve as oxidants of metallic copper. /4–6/ Knowledge on the characteristics of the copper(I)sulfide film expected to form on the copper canister for spent nuclear fuel is essential to determine whether localised corrosion in the form of pitting and cracking due to stress corrosion are potential degradation mechanisms. For localised corrosion to occur a protective, passivating film of sulfide compounds, primarily copper(I)sulfide must form, and for this reason, the characteristics of these sulfide films are key factors within a wide concentration range of $SH^-$. Chloride ions, $Cl^-$, can cause corrosion in a similar way as hydrogen sulfide and $SH^-$ ions.

The copper canisters will be exposed to a number of corrosion processes. /3, 4/ As the exposure conditions will initially be oxidizing due to the presence of oxygen gas, $O_2$, which will remain at the sealing of the repository and will form through radiolysis of the ground water, there is a potential risk for localized corrosion in the form of pitting and cracking due to stress corrosion; radiolysis causes the water to split into pure oxygen and hydrogen gas under influence of high-energy ionising radiation. The scope of the general corrosion resulting from oxygen gas and radiolytic corrosion is currently expected to be minimal, 80–90 µm. /3/ The conditions required for pitting to occur is that the copper surface is passive, and the conditions must be such that the anode and cathode in the electrochemical corrosion reaction are physically separated in order for this kind of corrosion to occur. /5, 6/ Whether pitting occurs or not depends on the balance between the factors promoting passivation and the factors leading to the film breakdown and occurrence of general corrosion.

Copper(I) sulfide, $Cu_2S$, is more stable in aqueous solutions containing hydrogen sulfide and $SH^-$ than copper oxides, based on thermodynamic data. For this reason, the transformation of the existing copper oxide film, primarily copper(I)oxide, $Cu_2O$, on the surface of the copper canister to $Cu_2S$ in aqueous solutions containing sulfides takes place:

$$Cu_2O\ (s) + SH^-\ (aq) \rightarrow Cu_2S\ (s) + OH^-\ (aq) \quad (1)$$

At oxygen-free conditions, the greatest threat to the long-term durability of the copper canister is, therefore, corrosion with sulfide compounds. Corrosion studies in solutions containing water and $SH^-$ have shown that sulfide corrosion is a two-step reaction in which the adsorption on the copper is the first step to form chemisorbed $Cu(SH)_{ads}$ /7–10/:

$$Cu\ (s) + SH^-\ (aq) \rightarrow Cu(SH)_{ads}\ (s) + e^- \quad (2)$$

This chemisorbed $Cu(SH)_{ads}$ then reacts with metallic copper and $SH^-$, leading to deposition of $Cu_2S$ on the copper surface:

$$Cu\ (s) + Cu(SH)_{ads}\ (s) + SH^-\ (aq) \rightarrow Cu_2S\ (s) + H_2S\ (aq) + e^- \quad (3)$$

Hydrogen evolution under oxygen-free conditions is the equivalent cathodic reaction:

$$2\ SH^- + 2\ e^- \rightarrow H_2 + 2\ S^{2-} \quad (4)$$

which leads to the formation of hydrogen gas on the conductive $Cu_2S$ film in aqueous solution. This reaction can also take place on the copper surface at the pores, when porous films are present. This cathodic reaction leads to hydrogen uptake in the copper metal when sulfide corrosion takes place. /11/

The growth of $Cu_2S$ film occurs in two distinct layers, with an initial growing cellular layer on the copper surface, which only reaches a limited thickness, whilst most of the film growth occurs as a much thicker, more compact, but still cellular outer deposit layer. The film growth takes place at the film/electrolyte interface. During static conditions, a parabolic film growth rate can be observed, primarily controlled by $Cu^+$ transportation in the film. The high porosity facilitates the transportation of $Cu^+$ ions at the film/electrolyte interface, leading to the formation of the outer sulfide layer, which indicates that an accumulation of this deposit controls the overall growth rate of the film at high $HS^-$ concentrations. At lower $SH^-$ concentrations, a linear growth rate can be observed, leading to the formation of a thin and porous $Cu_2S$ film with a fine grain structure, the growth of which is mainly controlled by the $SH^-$ diffusion in the solution. At low $SH^-$ concentrations, a thin, porous, non-protective single-layer film is formed, but when the $SH^-$ concentration rises to $5\ 10^{-4}$ M and at high $SH^-$ flows, a double-layer film is formed. /7–10, 12/

The unrestricted supply of $HS^-$ at higher electrode potentials leads to increased film growth in the form of a thicker outer deposited sulfide layer. The reaction between copper and $SH^-$ is very rapid on the copper surface and the sulfide film formation can lead to depletion of $SH^-$ on the copper surface. A number of electrochemical measurements have indicated that no passivating sulfide layer is formed on the copper surface. /7–10/ In situations with high $SH^-$ concentrations and high $SH^-$ flows, the rate of film growth is controlled by the characteristics of the outer sulfide layer. When a water-saturated bentonite buffer is on the surface of a copper canister in a final repository, these conditions are impossible to achieve, and it is unlikely that any passivation of the copper canister will occur, meaning that there is no longer a risk of pitting corrosion. The separation of the sulfide layer on the copper surface from the pure metal confirms that the topography of the corroded copper surface is rough, but it shows no pitting. /12/ The potentiodynamic polarisation curves for metallic copper in oxygen-free solutions containing sulfides and chlorides indicate, however, that copper can be passive in a broad potential range, showing breakdown of passivity in the high corrosion potential range (not typical for oxygen-free repository conditions after the first phase when oxygen gas is present) and pitting. /5, 6/

The reason for these different results for copper passivity in oxygen-free aqueous solutions containing sulfides and chlorides, as found in different kinds of experiment must be established in order for a final assessment of pitting due to sulfide corrosion to be carried out. For this reason, the Council believes it is important to investigate whether the surface of the copper canister is active or passive in a final repository environment. If active behaviour can be confirmed, the possibility of pitting can be ruled out.

## 5.3 The impact of ionising radiation on localised corrosion and hydrogen embrittlement

The maximum radiation level at the surface of the copper canister is 1 Gy/h. /3, 13/ The radiation is dominated by the radioactive decay of $^{137}Cs$, which has a half-life time of approximately 30 years, which means that the radiation level will reduce significantly within a few hundred years. This radiation is expected to induce radiolysis of the water, resulting in the formation of oxidising radicals, in addition to hydrogen and oxygen gas, which will increase the redox potential in the surrounding, in turn influencing the corrosion processes. Studies of the behaviour of copper in intense radiation situations (but with a corresponding overall dose as expected in the repository) have been carried out. /14, 15/ Corrosion reactions of irradiated samples show a special kind of corrosion product and corrosion nodules, with little penetration, but no real pitting. This is the case even when the deposit of the local corrosion product is hundreds or even thousands of micrometres wide /15/. Radiation at high dose rates (>300 Gy/h), but with total doses similar to those expected in a repository, demonstrates the hydrogen uptake in copper under these conditions. /16/ Higher levels of hydrogen absorption, i.e. at levels over 1 weight-ppm, can influence the mechanical and creep properties of copper. /17/

## 5.4 The impact of hydrogen uptake in copper on the deformation characteristics of the copper liner

The maximum permitted hydrogen content of copper in the KBS-3 concept is 0.6 weight-ppm /13/. A recently completed study investigated the effects of oxide particles in an FSW weld (welded in air) on the hydrogen impact and occurrence of deformation in the copper weld. It showed that oxide particles can absorb a considerable amount of hydrogen, but the effect of this hydrogen (<4 weight-ppm) on the macroscopic deformation behaviour of copper was minimal. /18/

The role of hydrogen gas in sulfide-induced intergranular cracking due to stress corrosion in the copper can be key factor, as the hydrogen is formed in the cathodic corrosion reaction (reaction 4) and hydrogen uptake can take place in the copper. /11, 19/ The hydrogen content in the copper increased from 0.5 to 1.2 weight-ppm during the short-term testing – two weeks. /11/ This indicates that the mechanism for intergranular surface cracking due to stress corrosion in copper under reducing oxygen-free sulfide conditions can be linked to hydrogen uptake and the local impact of hydrogen on the copper. Cracking on grain boundaries is similar to that observed in hydrogen-induced creep of Cu-OFP (OF refers to 'oxygen-free' and P to the phosphorous content). /17/ Microscopic pores on the grain boundaries were observed in a simulation study on hydrogen impact on copper, showing that hydrogen stabilises divacancies and promotes the accumulation of vacancies in micropores. /20/ Impurities and alloying elements such as O, P, S and Ag also contribute to the accumulation of vacancies in micropores. /20/

The Council considers hydrogen-induced vacancy injection in cracking due to stress corrosion under oxygen-free conditions and creep require further studies. Vacancy injection can be linked to sulfide-induced copper corrosion in the same way as with cracking due to stress corrosion of copper in nitrite solutions in oxic conditions. /21/

## 5.5 The creep ductility of copper when subject to slow loading

Creep ductility (plasticity under mechanical loads) of copper is a key mechanical property. It was originally thought that pure, oxygen-free Cu-OF copper (no phosphorous alloying) would be used for the canisters. Early creep tests with oxygen-free high-conduction copper (OFHC), however, resulted in brittle intergranular cracking with a creep ductility of less than 1 % at temperatures above 175°C. /22/ This was significantly lower ductility than required for the canister, as the maximum creep strain locally can reach 20–30 % in critical parts of the copper canister. /13/ For this reason, intensive research was launched to find new copper materials with better creep ductility properties. The final choice was oxygen-free copper with phosphorous alloying (Cu-OFP, 30–100 weight-ppm phosphorous (P)), which shows clearly improved creep properties compared to OFHC-copper. The impact of the phosphorous alloying on the creep properties of copper has been studied comprehensively /23–25/, but the mechanical understanding of phosphorous' positive effect on the creep properties of copper is not yet complete. The mechanical studies have concentrated on factors such as dislocations and grain boundaries, grain-boundary sliding, micropores, phosphorous-vacancy interaction and stacking-fault energy. /26/

The view of the Council is that a broader mechanical understanding of the positive effects of the phosphorous alloying on creep properties of copper is necessary in order to demonstrate that the long-term material properties are not altered and to develop a validated model of the properties of the copper alloy under mechanical loads, showing how the copper canister's mechanical integrity can be maintained when subjected to different loads for long periods of time.

## 5.6 The mechanical characteristics of nodular cast iron

The canister must be able to withstand heavy loads occurring as a result of earthquakes or future ice ages. A 50 mm shear displacement along a fracture in the bedrock around the deposit hole could cause a 1–2.5 % local plastic strain on the canister's cast iron insert /13/

and if the insert fractures, the copper canister can break. The likelihood of major earthquakes that could cause this kind of event in the proximity of the repository is low, but there are uncertainties due to the very long timeframe of at least 100,000 years. In general, there are greater uncertainties regarding embrittlement of the cast iron insert than there are regarding the copper liner. This applies to mechanical properties, microstructure and chemical composition of the nodular cast iron. Variations occur when the inserts are cast, which affect the quality of the inserts in the form of toughness and brittleness. The latest research has shown that different hydrogen content in the cast iron can substantially alter its mechanical properties. /27/ The primary so-called metallurgical hydrogen content of the cast iron, which is fairly evenly distributed in the material, comes from the manufacturing. Different manufacturing processes and even different production batches can give varying hydrogen content in the cast iron. After the fuel is dried, according to current requirements, a maximum of 600 g of water in the canister after sealing is allowed. Water can cause anaerobic (oxygen-free) corrosion of iron and the formation of hydrogen gas, which can be absorbed by the insert's cast iron. This can result in that the hydrogen content of the cast iron may increase and its mechanical properties can be reduced. Furthermore, the ionising radiation from the spent nuclear fuel can split the water (radiolysis) into hydrogen and oxygen gas. The permitted hydrogen content level in cast iron and impact of the hydrogen content on the mechanical properties must be investigated further, in the Council's view.

Uncertainties concerning the properties of the cast iron insert in a final repository, in addition to creep, include three types of embrittlement mechanisms: radiation-induced embrittlement, hydrogen embrittlement, and blue brittleness, which are described in detail in the 2018 State-of-the-Art Report, p. 83–94. /28/ These phenomena can make the cast iron insert brittle, and if it mechanically fails, it is possible that the copper canister will also break, which can result in radioactive materials leaking out. The Council believes that knowledge of the combined effects of these embrittlement mechanisms and their impact on the integrity of the cast iron insert, along with its creep properties, are important. /27, 28/

## 5.7 Summary

There is still research to be done primarily on the cast iron insert in copper canisters for spent nuclear fuel, as well as on details regarding the corrosion of copper in the presence of water containing hydrogen sulfide and chloride ions. The present knowledge on primarily the mechanical properties of the cast iron insert is insufficient as this research started recently, but it has intensified in recent years. Hopefully, ongoing research and development work will provide answers to the remaining questions. These issues should be prioritised in forthcoming RD&D programmes, but there should also be clear requirements in a continued stepwise licensing from SSM. In conclusion, it is worth emphasising that the copper canister is a part of a larger system of technical and natural barriers, the combined protective ability of which is fundamental to the KBS-3 concept. The copper canisters are key in this system, but as SSM highlights in its regulations:

> The barrier system [shall] contain several barriers so that the necessary safety levels, in so far as possible, are maintained even if a shortcoming is to occur in one barrier. /29/

Naturally, this does not reduce the need for ongoing research and increased understanding to optimise the protective capacity of the canister.

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# 6 Nuclear waste and the public

## 6.1 Introduction and background

This chapter contributes to knowledge on public attitudes to, and knowledge on, Swedish nuclear waste. The objective was to expand the basis for assessment of the public's informational needs and how these needs can be satisfied. After an introductory background, in the first section the results of the Council's most recent survey are summarised. A comprehensive report on the study can be found on the Council's website.[1] The second section presents an in-depth so-called cluster analysis, and the third, concluding section, the relevance of the results for the Council's future work is examined.

Sweden has been characterised for many years by its political unity on Sweden disposing of Swedish-produced nuclear waste within Sweden's borders. Additionally, since 2011, a licensing process has been underway to establish a final repository facility for spent nuclear fuel in Forsmark, in the Municipality of Östhammar. In November 2013 the Council launched a survey aimed at members of Swedish Parliament[2], which was followed with a further, similar survey in 2016.[3] Both surveys asked current members of parliament about how informed they were on the nuclear waste issue and in which areas information dissemination efforts might be needed.

In autumn 2018 the Council took the initiative to launch a national survey of public knowledge on the planned final repository for spent nuclear fuel, this time aimed at Swedish citizens. The results of this study are presented in this chapter.

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[1] See reports at: www.karnavfallsradet.se/en/publications (accessed 27 January 2020).

[2] Palm. 2014 Kunskapsläget hos Sveriges Riksdagsledamöter om kärnavfall och dess slutförvar [State of knowledge amongst members of Sweden's Parliament on nuclear waste and its disposal].

[3] Palm. 2017. Kunskapsläget hos Sveriges riksdagsledamöter år 2013 och 2016 om kärnavfall och dess slutförvar [State of knowledge amongst members of Sweden's Parliament in 2013 and 2016 on nuclear waste and its disposal].

The company Ingrid Friberg Samhällsinformation AB was tasked with carrying out telephone interviews with a representative sample of 1,000 citizens between the ages of 18 and 75. The questions focused on citizens' knowledge, needs for information, and trust in the institutions responsible for the nuclear waste issue. Responses were received from 67 % of those invited to participate. Non-responses were primarily as the potential participants "could not be reached".

## 6.2 Summary of the survey results

This section provides an overview of how the citizens responded to the survey. For a more comprehensive presentation of the results, see the report on the website of the Council.[4]

An introductory question concerned whether the respondent knew that a final repository for spent nuclear fuel was being planned in Sweden. 55 % of the total sample responded yes and 45 % that they did not know this. We asked whether the citizens knew which municipality a final repository was intended for. In SKB's application, Östhammar is suggested as a location for the final repository (where the Forsmark nuclear power plant and final repository for low level waste, SFR are located). To this, 27% responded either Östhammar or Forsmark, whilst 61 % responded that they did not know. A subsequent question concerned the method proposed by SKB for final disposal. Here, 44 % responded copper canister.

We asked how well the respondents felt that the following statement matched their views: "I feel I have sufficient knowledge on final disposal of spent nuclear fuel." They could chose their answer from a five-point scale, from "Completely disagree" (=1) to "Completely agree" (=5). 49 % disagreed completely and only 4 % agreed completely. The mean was 1.8. Therefore – based on the respondents' own self-assessment – knowledge on the topic is relatively poor. On the topic of sources of knowledge on nuclear waste, it was revealed that 79 % of the citizens got their information from newspapers, TV and radio; 13 % from social media; and 12 % from friends, acquaintances and colleagues. 47 % wanted more information, whilst 53 % did not want more information.

[4] See reports at: www.karnavfallsradet.se/en/publications (accessed 27 January 2020).

We asked the respondents whether they believed that Sweden, as a country, could manage and dispose of the waste safely. 58 % responded yes, 18 % responded no, and 25 % were unsure or did not know. One question concerned whether citizens consider a final repository for nuclear waste an important issue.

They could answer on a scale of 1 to 5, where 1 meant "not important at all" and 5 meant "very important". The majority felt that it was an important issue, with the mean falling at 4.4.

Three questions concerned how much the respondents trusted in 1) politicians', 2) authorities', and 3) researchers' ways of dealing with issues concerning the disposal of spent nuclear fuel. Respondents had the most confidence in researchers and experts, followed by authorities, with politicians coming in last. On a five-point scale, between "Little confidence" (=1) and "Lots of confidence" (=5), politicians received a mean score of 2.3, authorities 2.9 and researchers/experts 3.5.

As part of one question, a list of threats were read out, where the respondents were asked to decide whether they felt great concern (10) about the threat, or no concern at all (1). Three clear 'storm clouds' arose, i.e. concern about the climate, overuse of antibiotics, and uneven division of the world's resources, leading to poverty and famine. Concern about radioactive spent nuclear fuel came last. When asked whether they felt that Sweden was generally on the right path or not, 43 % responded yes, 29 % no, and 28 % were uncertain.

We concluded the study with the question: "If a referendum were proposed on Sweden's future use of nuclear power, how do you think you would vote?" 48 % were pro decommissioning taking place immediately or as soon as possible. 26 % wanted to invest in new nuclear power plants.

## 6.3 An in-depth cluster analysis

The survey itself comprised a combinations of questions to assess values, knowledge questions, and questions on more general attitudes, such as trust, mistrust and view of the future. We commissioned an in-depth analysis of whether there were any particular patterns in how citizens respond to different questions. The purpose of such a so-called cluster analysis is (1) to study whether there are population segments ('clusters') with substantially different attitudes to topical nuclear waste issues, and (2) to describe how each of these segments is differentiated when it comes to attitudes to nuclear waste, attitudes more generally, and socio-demographic aspects (such as age, gender, education).

The Council has enlisted the help of the company Ingrid Friberg Samhällsinformation AB to carry out a cluster analysis of this research survey. The input data for the cluster analysis were the responses to 9 of the 19 questions (alongside the sociodemographic questions, see the attached questionnaire in the Appendix). The main result is that the total sample (670 people) was divided into three clusters, each with a particular response profile, which we will return to shortly. The definitive cluster solution is very stable, i.e. the likelihood of a person in repeated cluster runs being placed in the same cluster is 96 % on average. (For most cluster analyses, the stability value is between 70 and 90 %).

Below is a description of the different clusters, with an indication of the percentage they represent of all responses within brackets.

### 6.3.1 Cluster 1 (K1, 46 %): "I feel somewhat concerned, but I have great confidence that things will sort themselves out"

K1 is the largest cluster. Those who belong to this cluster are concerned about a great deal, but the focus is more on climate change, air pollution, uneven distribution of the earth's resources, and overuse of antibiotics than the nuclear waste issue. The nuclear waste issue is considered important, and at the same time there is a high degree of confidence in society's handling of the nuclear waste issues. Confidence is particularly high in authorities and researchers/experts, but politicians' decisions on the final repository also inspire a degree of confidence.

K1 has a general demographic profile, i.e. there are no specific deviations in terms of division by age, gender, education and place of residence.

### 6.3.2 Cluster 2 (K2, 28 %) "I'm not at all concerned, I have confidence that things will sort themselves out"

By and large, K2 are not particularly concerned, and certainly not by the handling of the nuclear waste issue. On the contrary, they want to see greater investment in nuclear power. Confidence in society's ability to manage the nuclear waste issues is fairly high, however not as high as amongst K1. The nuclear waste issue is also considered more minor than in other clusters.

Cluster 2 contains a high proportion of men (66 %) and a somewhat higher proportion of people in the age-group 18–35.

### 6.3.3 Cluster 3 (K3, 26 %) "I'm very concerned, I have no confidence that things will sort themselves out"

Those who fall into K3 are the most concerned of all respondents about how things are going, and are worried not least about the nuclear waste issue and nuclear power. However, their experienced knowledge and confidence in society's management of the nuclear waste issues are very low. Only researchers/experts inspire some trust.

Cluster 3 contains a high proportion of women (62 %) and a somewhat higher proportion of people in the age-group 56–75.

### 6.3.4 Comparison of the clusters

The difference between the three clusters can be clarified with the help of a so-called four-field table, see table 6.1. Vertically, you can distinguish between concern and calm (or indifference); horizontally between confidence or a lack of confidence in our ability, i.e. what we (individually or collectively) have the potential to influence and change and what we can't do anything about.

**Table 6.1**

| | Confidence in our ability to influence | Lack of confidence in our ability to influence |
|---|---|---|
| Concern | Cluster 1 | Cluster 3 |
| Calm, indifferent | Cluster 2 | |

One box is empty, i.e. the combination of calm and lack of confidence in our ability to influence. This square corresponds most closely with the life philosophy represented by classic stoicism, i.e. calm or indifference when faced with both pleasure and pain – and not least the kind of suffering that we cannot influence.

### *Basic attitude*

Concern or calm, confidence or lack of confidence can be described as examples of different life experiences or basic attitudes. Basic attitude is a key concept in current world view research and is explained as follows by world view researcher Anders Jeffner:

> Two people in the same actual life situation can perceive their own lives and existences in very different ways. One might see the light in life, whilst the other in the same actual situation may have a dark outlook. This life experience, which is therefore partially independent of the actual outer circumstances can be very difficult to establish and describe in further detail[5]

If this life experience is relatively stable, i.e. the same in similar situations for a longer period, it is down to basic attitude. When this kind of basic attitude is combined with a certain image of reality and certain basic values, we can begin to talk about world views. These links will not be studied further in this study.

### *Comparison of the three clusters and responses to different questions*

To further investigate the different basic attitudes expressed on the nuclear waste issue and other environmental issues, a further study was carried out. The three clusters were compared with the responses to each of the 21 questions. It was revealed that the clusters respondents belonged to were indicated by how the interviewees responded to both knowledge and attitude questions. For example, there was a striking distance in responses to the questions if the respondents knew where the final repository is intended to be located.

Is there reason to believe that those who belonged to the third cluster – “I am very concerned, I have no confidence that things will

[5] Jeffner. 1976. Livsåskådningsforskning [World view research], p. 14.

sort themselves out" – also have a somewhat lower level of knowledge on the nuclear waste issue than those who belonged to the other two clusters? An affirmative answer is strengthened by an answer to another question, where the respondents were asked whether their knowledge on the long term management of spent nuclear fuel was sufficient; those who belonged to the third cluster were less inclined to respond that they had sufficient knowledge than those in the other clusters (11 % in cluster 3, compared to 31 % in cluster 2 and 28 % in cluster 1). This could suggest that if those who were worried and mistrustful had a higher level of knowledge, their views would also change and they would become less worried and mistrustful. But this is not a certainty – at least not generally speaking. A basic attitude is clearly often dependent on our knowledge, with a higher level of knowledge leading to less concern. Many people who refuse measles vaccinations due to concerns about side effects would perhaps be less concerned if they had better knowledge. But concern and mistrust are not just based on our knowledge, they are also based on our values. One person, A, has a bright outlook on life as they value a good income far more highly than another person, B, who also has a good income does. But perhaps B does not assign the same importance to their good income, but instead places higher value on children and family than A. B has neither children nor family, and for this reason has a darker outlook on life. Similarly, a person who is worried and mistrustful regarding the management of spent nuclear fuel can be completely uninfluenced by new knowledge, as they believe the nuclear waste issue to be more important than many other people do, and for this reason they feel greater concern than those who do not feel that this issue is as important. Naturally, it cannot be ruled out that there are people who become more concerned the more knowledge they have on the nuclear waste issue.

*The relationship between general basic attitudes and specific attitudes*

Within attitude research, the relationship between specific and general values is a much-discussed issue. General values on, for example, human dignity and human rights have a poor link with specific attitudes on immigrant issues or attitudes towards ethnic groups. It could also be expected that this is the case that on the topic of the link between a basic attitude linked to more general issues and attitudes concerning more specific issues relating to the environment and nuclear waste. On the basis of our limited study, there does not, in fact, appear to be any such difference. Those who form part of K3 feel a far higher level of concern regarding radiation from spent nuclear fuel than those who belong to the other clusters do. Those who form part of K3 also feel general concern regarding the overall development of society.

Against this background, it could be hypothesised that concern regarding spent nuclear fuel is influenced by a more general pessimism regarding the development of society. It is possible that this pessimism in certain people is rooted deeper in their personality and cannot be dislodged by new knowledge or values. It is also possible that this pessimism is incorporated into the personality from an early stage in life and is as the result of certain social and psychological circumstances. However, further research is required to prove or disprove this hypothesis.

*Generational, age and gender differences*

Generational and gender differences are other factors that can be interesting to consider. There is a difference in the way the youngest respondents, between the ages of 18 and 25, responded. The youngest generation, 18–25 years, are the least worried and are indifferent to a higher degree than average to societal development and environmental issues – "things will sort themselves out". Of those who form part of the older generations, there is a somewhat higher percentage who are both worried and pessimistic. The explanation for this may be that these groups were more affected by the nuclear waste issue when it peaked previously in the 1970s and 1980s. Since then, other environmental issues have come to the fore. However, it is still somewhat surprising that environmental involvement has no visible impact on basic attitudes of the youngest respondents. Those who have left upper secondary education do not appear concerned or mistrusting to any higher degree than average – quite the opposite, in fact. The study was carried out at the turn of 2018 and 2019, and there may have been changes to younger people's attitudes since then, due to the increased media focus on Greta Thunberg, for example.

There are no differences when it comes to education. Place of residence does not appear to play any decisive role, unlike gender, where the differences were surprisingly substantial. According to this study, men are not particularly worried and believe that things will sort themselves out; women are more mistrustful and pessimistic about the future.

## 6.4 Summary

In summary, the study shows that the nuclear waste issue is the tip of a social and psychological iceberg of attitudes and visions of the future. This strengthens the often-presented reflection that the issue is not just one of science and technology, it also has links with a whole range of knowledge, values and basic attitudes. Succinctly put, there is much more to investigate at this interface of technology, science, social sciences and humanities.

The Council, with its multidisciplinary composition, is a particularly well-suited forum for stimulating such studies.

### 6.4.1 Relevance for the future work of the Swedish National Council for Nuclear Waste

Citizens' participation in conversations and decisions on the final repository issue, not least regarding a final repository for spent nuclear fuel, is key for a number of reasons. One reason is democratic – that citizen participation strengthens democracy and increases the legitimacy of the decision. It is important that those affected by a decision are involved in the discussions regarding what the right decision would be. The public can also provide the knowledge and experience decision makers lack.

The Council believes that the nuclear waste issue must be grounded in widescale participation, which would also bring legitimacy to the issue. For this reason, it is important to investigate what knowledge citizens have/need and how they view the nuclear waste issue, which this questionnaire study has contributed to. It is vital that citizens are involved and participate in the decision-making process under way, and feel that they can be involved in a conversation on the future storage of nuclear waste. This study has, amongst other elements, contributed to investigating whether citizens feel they have sufficient knowledge on the nuclear waste issue. This does not appear to be the case,

– particularly amongst those who feel concerned and a lack of confidence. This is important knowledge for the Council's continued work on creating dialogue and a meeting platform for different stakeholders on nuclear waste.

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Palm, J. 2017. Kunskapsläget hos Sveriges riksdagsledamöter år 2013 och 2016 om kärnavfall och dess slutförvar [State of knowledge amongst members of Sweden's Parliament in 2013 and 2016 on nuclear waste and its disposal]. The Swedish National Council for Nuclear Waste.

The reports by Palm, J. above can be found under Reports at: www.karnavfallsradet.se/en/publications (accessed 27 January 2020).

# Appendix

## Questionnaire

*Introduction (oral)*

Hello, my name is NN and I'm calling from Samhällsinformation AB in Stockholm.

We are currently carrying out a study commissioned by the Swedish National Council for Nuclear Waste. This study forms part of a larger research study on public knowledge and attitudes on issues surrounding the processing of nuclear waste and the amount of trust people have in the parties making the decisions.

(All participation is voluntary and all responses are processed with the strictest confidentiality). The questions will only take a short while.

A number of years ago, discussions on the management of nuclear and where the repositories should be located were perhaps a little louder than they are today, but the issue is just as relevant now as it was then.

*Question 1*: Are you aware that a final repository for spent nuclear from nuclear power plants is being planned in Sweden?

1. Yes
2. No □ GO TO QUESTION 3

*Question 2*: Do you know where the final repository is intended to be built?

1. Yes, in Östhammar,
2. Forsmark
3. Yes, other municipality
4. NO/DO NOT KNOW

TO ALL:
Question 3: Do you know who makes the final decision on final repositories for spent nuclear fuel?
READ OUT. SELECT ALL ANSWERS THAT APPLY

1. SKB (The Swedish Nuclear Fuel and Waste Management Company)
2. The municipality in which the facility is going to be built
3. The EU
4. The Swedish Radiation Safety Authority (SSM)
5. The Land and Environment Court
6. Parliament
7. The government
8. NO/DO NOT KNOW

*Question 4*: What solution for the final disposal of spent nuclear fuel does SKB recommend that the company that applied to build the final repository use?
READ OUT Is it ...

1. A deep hole drilled 3 km down into the ground
2. Copper canisters placed 500 metres down in the bedrock
3. A self-draining rock cavern
4. Transmutation, i.e. the nuclear waste being converted so that the radioactive material is eliminated
5. DO NOT KNOW

*Question 5:* How much do you agree with the following statements?
"I think that

I have sufficient knowledge on final storage of spent nuclear fuel."

1. Completely agree
2. Partially agree
3. Partially disagree
4. Completely disagree
5. DO NOT KNOW

*Question 6*: Regardless of how much information you possess on final repositories for spent nuclear fuel, where does your knowledge on the topic come from?

Does it come from ... READ OUT. SELECT ALL ANSWERS THAT APPLY

1. Friends, acquaintances and colleagues
2. Social media, Wikipedia or similar
3. Information from authorities or municipalities (brochures/printed material)
4. Information from authorities or municipalities via the internet
5. Newspapers, TV, radio
6. Information from other organisations
7. Other informational material
8. Work/school/education
9. ______________

*Question 7*: Would you like to have more information on final repositories for spent nuclear fuel?

1. Yes
2. No □ GO TO QUESTION 9

*Question 8*: What area would you like more information on?
OPEN TO ALL.

*Question 9*: Regardless of how familiar you are with the management of spent nuclear fuel, do you think that we here in Sweden can safely manage and dispose of the waste or not?

1. Yes
2. No
3. Not sure/don't know

Question 10: Do you think that this is an important issue or not?

Please answer on a scale of 1 to 5, where 1 means "not important at all" and 5 means "very important". Scale of 1 to 5, plus DO NOT KNOW.

*Question 11:* To what extent do you agree with the following statements?

"I trust politicians' decisions on where and how the final repository for spent nuclear fuel should be built."

1. Completely agree
2. Partially agree
3. Partially disagree
4. Completely disagree
5. DO NOT KNOW

*Question 12:* "I trust the reviews carried out by the authorities, concerning where and how the final repository for spent nuclear should be built."

1. Completely agree
2. Partially agree
3. Partially disagree
4. Completely disagree
5. DO NOT KNOW

*Question 13*: “I trust researchers’ and experts’ investigations of where and how the final repository for spent nuclear fuel should be built.”

1. Completely agree
2. Partially agree
3. Partially disagree
4. Completely disagree
5. DO NOT KNOW

*Question 14:* I’d now like to read out some threats that individuals might experience both in the near and far future. Please answer on a scale of 1–10, where 10 means that you are very concerned about the threat and 1 means that you are not concerned at all.

MAKE SURE YOU DO NOT LIST THE OPTIONS IN THE SAME ORDER EVERY TIME!

- Climate change due to overconsumption of the earth’s resources.
- War and conflict around the world.
- Violence and gang-related shootings, both in Sweden and the rest of the world.
- Uneven division of the world’s resources, leading to poverty and famine.
- Overuse of antibiotics, leading to resistant bacteria becoming established.
- Air pollution due to burning coal and emissions from industries and flights.
- Radioactive spent nuclear fuel from nuclear power plants.

*Question 15*: Is there anything else you feel particularly worried about?

OPEN QUESTION

*Question 16*:Generally speaking, do you feel that Sweden is more or less on the right path or not?

1. Yes
2. No
3. DON'T KNOW/HAVE DOUBTS

*Question 17*: If a referendum were proposed on Sweden's future use of nuclear power, how do you think you would vote?
READ OUT!

1. Decommission nuclear power plants as soon as possible.
2. Decommission nuclear power plants as soon as current reactor start to get old.
3. Continue using the nuclear power plants we currently have.
4. Invest in new nuclear power plants.
5. DO NOT KNOW

*And finally, some background questions.*

*Question 18*: How old are you?

1. 18–25
2. 26–35
3. 36–45
4. 46–55
5. 56–65
6. 66–75

*Question 19*: What is the highest level of education you have completed?
READ OUT

1. Comprehensive school or equivalent
2. Upper secondary school or equivalent
3. University/university of applied sciences
4. No reply

*Question 20:* What kind of area do you live in?
READ OUT

1. Big city area (Stockholm, Gothenburg, Malmö)
2. Large urban settlement, 90,000 or more residents
3. Small urban settlement, 10,000–90,000 residents
4. Area with fewer than 10,000 residents

*THANK AND END CONVERSATION!*

*RECORD GENDER:*

1. Man
2. Woman

ASSIGNE SEQUENTIAL NUMBER:______

# 7 Remembering a final repository

One of the problems investigated and discussed is if, and if so, what future generations should know about a potential final repository for spent nuclear fuel, how it should be designed, its geographical location, the risks associated with the encapsulated material, and other related issues, such as whether the final repository may be relevant to future needs for resources. This means that the issue of conveying information and creating memories for the future is of greater practical concern when it comes to designing a final repository for spent nuclear fuel. The Land and Environment Court at Nacka District Court also highlighted the importance of these issues in its pronouncement to the government in 2018.[1] "We must not forget to remember." On several occasions the Swedish national council for nuclear waste has highlighted issues regarding information and knowledge preservation, most recently in its statement to the government regarding SKB's supplements (September 2019).[2]

There are few guidelines and regulations in Sweden about the type of information to be passed on to future generations regarding the location, content and design of a final repository, as well as where this information should be stored, or archived. The documents that do exist primarily concern 'information preservation' and the preservation of 'knowledge'. However, the development work we describe here broadens the perspective on the issue of how

[1] The Land and Environment Court at Nacka District Court 2018. Pronouncement 23 January 2018.
[2] The Swedish National Council for Nuclear Waste. 2019. Kärnavfallsrådets remissvar angående Svensk kärnbränslehantering AB:s kompletterande yttranden [The Council's response regarding SKB's supplemented pronouncement]. See also:The Swedish National Council for Nuclear Waste. 2018. SOU 2018:8 Nuclear Waste State-of-the-Art Report 2018 – Decision-making in the face of uncertainty; Swedish National Council for Nuclear Waste. 2015. SOU 2015:11 Nuclear Waste State-of-the-Art ReportSafeguards, record-keeping and financing for increased safety.

society remembers and forgets. In other words, which processes influence institutional and collective memory. Concerning the period following the sealing, the report on a new act on nuclear activity proposes that the state assume responsibility for a final repository prior to sealing, and that the state designate the authority responsible for monitoring the obligations.[3] As part of this responsibility, it is proposed that the authority maintain the documentation required under Article 17 of the nuclear waste convention.[4]

**Swedish legislation on information preservation and final repositories**

SSM makes some references to preservation of information in its regulations. In the regulation SSMFS 2008:38 On archiving in relation to nuclear facilities there are general guidelines on the selection of documents and how long certain documents should be stored in archives for, making reference to the regulations of the Swedish National Archives. In the regulation 2008:37 it is stated that:

*Preservation of knowledge about the repository could reduce the risk of future impact on humans. A strategy for preservation of information should be produced so that measures can be undertaken before sealing of the repository.*[5]

The Swedish National Archives are responsible for national archiving under certain laws, regulations and directives, and also receive official archive records from other authorities and organisations to preserve them in the longer term. The National Archives' regulations primarily concern correct handling of documents in paper and electronic formats, as well as construction and maintenance of archives to safeguard the useful life of documents.[6] In terms of preserving digital media, the National

[3] Inquiry into a New Nuclear Technology Act. 2019. SOU 2019:16 Ny kärntekniklag – med förtydligat ansvar [A New Nuclear Technology Act – with clarified responsibilities], p. 268.
[4] IAEA. 1997. Joint convention on the safety of spent fuel management and on the safety of radioactive waste management.
[5] SSMFS 2008:37 The Swedish Radiation Safety Authority's Regulations Concerning the Protection of Human Health and the Environment in Connection with the Final Management of Spent Nuclear Fuel and Nuclear Waste.
[6] SFS 2019:445, SFS 2019:782, SFS 2009:1593.

> Archives do not currently have a time limit for how long such media should be stored. A strategy involving communication between generations is considered the primary solution. This 'migration strategy' involves managing data carriers over time, both due to their having aged physically and in terms of converting the format over time based on new technology. The documents preserved are now considered an information package comprising both data and metadata.[7]

The aim of this chapter is to explore the development work carried out on information preservation for the future and the opportunities for creating common memories relating to a final repository for spent nuclear fuel. The objective here is to demonstrate the broad and multi-faceted nature that is required in this complex work. This starts with a short description of institutional memory as a field of research. This is followed by a summary of the OECD's[8] development work on information preservation through generations. Some outcomes of an international workshop in Stockholm in spring 2019 are then given. Finally, some conclusions and comments are provided on key issues for the continued process in Sweden to establish a final repository for spent nuclear fuel.

## 7.1 'Remembering' is something we do

We tend to think of memory as an individual psychological and experience-based capacity, i.e. something our brains can objectively register from our own observations and experiences. However, multidisciplinary research shows that both individual and institutional 'memory' should be seen more as "something we do than something we have".[9] This means that memories are built in different ways and the process of remembering something takes place through the complex cognitive, social and cultural processes we humans form

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[7] As per ISO 14721: 2012.

[8] The Organisation for Economic Co-operation and Development (OECD): www.oecd.org/ (accessed 27 January 2020).

[9] Terry, J. 2013. "When the sea of living memory has receded: Cultural memory and literary narratives of the Middle Passage.'

part of. 'Memory' is an individual concept that includes a range of different human capacities.[10]

Collective memories are those shared by a group of people, regardless of whether each group member themselves has experienced the origin of the memory. They key processes for the formation of collective memories include descriptions of historic events and the circumstances observed and retold. However, collective memory is not an exact rendering and reproduction of historical events and circumstances. Instead, it should be considered representations of the past coloured by the present.

The collective memory can be seen as contexts in which individual and personal memories are created and articulated.[11] The individual memory is tangible, i.e. based on something the individual experienced.[12] However, collective memory contributes to expanding the individual memory with information that goes beyond one's own experience of the world.[13]

Research on memory also works at creating formalised tools, memory practices and memory institutions, in order to create memories for the future. Memory practices can, for example, involve the ancient art of storytelling, encompassing modern techniques for recording and transferring information. Societal formal and cultural memory creation institutions have developed through time: runestones, monuments, libraries, archives, museums, environmental monitoring programmes, national parks, etc. We also 'remember' through cultural practices, such as songs, festive rituals (e.g. at Christmas), art, etc.[14]

## 7.2 Information preservation efforts within the OECD

Next, we will provide a short summary of the OECD's development work on memory and information preservation in relation to final repositories for spent nuclear fuel. Within the OECD framework

[10] Olick et al. 2014. "Response to our critics."
[11] Linde. 2000. "The acquisition of a speaker by a story: how history becomes memory and identity." identity."; Linde. 1997. "Narrative: experience, memory, folklore."
[12] Gavriely-Nuri. 2014. "Collective memory as a metaphor: The case of speeches by Israeli prime ministers 2001–2009."
[13] Wilson. 2005 in Gavriely-Nuri. 2014.
[14] Hilding-Rydevik et al. 2018. "Baselines and the Shifting Baseline Syndrome – Exploring Frames of Reference in Nature Conservation."

there is the Nuclear Energy Agency (NEA), with its subgroup the Radioactive Waste Management Committee (RWMC). Under the RWMC, so far three groups have worked on issues relating to final repositories and information preservation for future generations. During 2019 these three groups have merged into a fourth group, which will commence its work in 2020. Below are short descriptions of the four groups.

*Preservation of Records, Knowledge and Memory across Generations (RK&M)*

The Group RK&M has been working since 2011 on issues regarding very long-term preservation of information and knowledge on final repositories for spent nuclear fuel and nuclear waste.[15],[16] Four reports were produced in 2018 and 2019. These concern two different document types for preserving information – a bibliography and a final report.[17] A catalogue of efforts in 12 different countries is planned for completion in spring 2020.

*Radioactive Waste Repository Metadata Management (RepMet)*

Since 2014 the RepMet Group has involved organisations from 12 different countries, including Sweden and SKB, in work on creating better understanding as needed for the identification, management, administration and application of metadata. Saving information in a way that ensures it is accessible for longer timeframes is often challenging. In this context, also saving metadata, which shows how the information was originally created, is even more challenging. At the same time, this metadata is decisive in making the information accessible, valuable and usable by future generations. Metadata is important as it will help future generations find, understand and use the information. This is particularly relevant for longer timeframes, as the quality of the information tends to slowly erode as knowledge on measurement methods, calculations, terms, etc. evaporates.

[15] www.oecd-nea.org/rwm/rkm/ (accessed 27 January 2020).
[16] More information is available in The Swedish National Council for Nuclear Waste. 2018; 2015.
[17] RK&M. 2019. Preservation of Records, Knowledge and Memory (RK&M) Across Generations. Final Report of the RK&M Initiative.

The work has resulted in five documents to support different national programmes for the long-term management of spent nuclear fuel and radioactive waste, as well as for international harmonisation in the sector:

- An overview report on the use of metadata in terms of applications and implementation, with recommendations. [18]
- Three so-called libraries or data models for how relevant objects can be described in a structured way, along with the relationships between them. Within the framework for these libraries, key aspects of data and metadata within different scientific and technical disciplines are discussed, relating to the whole lifecycle for the storage of spent nuclear fuel and nuclear waste. The first library concerns data and metadata on the location of the repository, whilst the second deals with data and metadata on the encapsulations of the nuclear fuel and nuclear waste and the third looks at the design of the repository. [19]
- The fifth document has to do with different tools, methods, standards and instructions used to shape the libraries. One of the several recommendations is that within organisations tasked with managing spent nuclear fuel and radioactive waste, a culture is created where metadata is considered highly important, for example by developing metadata policies. The management of the metadata must be carried out appropriately right from when the information starts to be created. If mistakes are made here, the risk is that the problems will become greater than if the metadata had not been processed at all.

*Expert Group on Waste Inventorying and Reporting Methodology (EGIRM)*

The EGIRM group was initiated by the OECD/NEA, IAEA and the European Commission, and since 2014 it has developed methods to ensure that records and inventories for radioactive waste are standardised in order to achieve good comparability between countries

[18] OECD/NEA. 2018. Metadata for Radioactive Waste Management.
[19] Camphouse et al. 2017. "Metadata in Geological Disposal of Radioactive Waste:The RepMet Libraries."

as well as to simplify work on extracting knowledge on the global situation in the sector. The work has resulted in two different documents: National Inventories and Management Strategies for Spent Nuclear Fuel and Radioactive Waste: Methodology for Common Presentation of Data[20] and National Inventories and Management Strategies for Spent Nuclear Fuel and Radioactive Waste: Extended Methodology for the Common Presentation of Data.[21]

### *Information, Data and Knowledge Management (IDKM)*

The IDKM group was formed in March 2019 to bring together the work of the three groups mentioned above.[22] the IDKM will supply the global demand for new tools for effective and practical management of information, data and knowledge in the short and longer terms. The time horizons should be viewed in relation to the lifespan of a final repository and the radioactive waste. The background is often the high costs that come with reliable information and knowledge management within the nuclear power sector, due to the complexity of such management work. Simultaneously, when it comes to managing the waste of nuclear power, not least spent nuclear fuel, different national programmes tend to run for decades, which means that ensuring access to the relevant data, information and knowledge is vital, even if it was created decades ago. The issue here, quite simply, is ensuring the accessibility of data, information and knowledge in a time when competence management within the nuclear power sector is faltering on many fronts throughout the world.[23]

IDKM will lead and coordinate the tasks within data, information and knowledge management, which will be drawn up and collected in a document entitled the IDKM Roadmap, as well as maintaining and altering this plan as new requirements arise, along with new opportunities to satisfy these requirements. The group will also serve as a neutral forum for the exchange of experiences, shared needs, and challenges between supervisory bodies, licensees and other stakeholders. For this, the group will form a platform that monitors

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[20] OECD/NEA. 2016. National Inventories and Management Strategies for Spent Nuclear Fuel and Radioactive Waste: Methodology for Common Presentation of Data.
[21] OECD/NEA. 2017. National Inventories and Management Strategies for Spent Nuclear Fuel and Radioactive Waste: Extended Methodology for the Common Presentation of Data.
[22] See: www.oecd-nea.org/rwm/workshops/2019/idkm/ (accessed 27 January 2020).
[23] For further information on competence management, see Chapter 2 of this report.

trends and tendencies within data, information, and knowledge management, to assist the members in applying these to their management of nuclear waste and spent nuclear fuel.

There will be four expert groups within the IDKM, each with their own area:

- documentation on safety analysis
- transfer of knowledge between generations
- archiving
- preservation of memories.

In the safety analysis area, the work will be divided up into three so-called macro-activities concerning documentation and information management before and during construction, after sealing, and documentation and information management for the whole system for the management of spent nuclear fuel and radioactive waste. In the working area for transfer of knowledge between generations, the work is divided up into work concerning strategies and work concerning support systems. In the working area for archiving, the work is divided up into work concerning document archiving and work concerning digital archiving. In the working area for preservation of memories, the work is divided up into platforms for information and discussion, implementation and particular studies and overviews.

The four working areas will each be led by their own expert group comprising specialists who meet several times a year, depending on need and their working plan. The work of the expert groups will be coordinated by the IDKM Working Party, which meets in plenum once a year and has initially been appointed for a three-year term. The members of the Working Party will be a variety of specialists, scientists, engineers, and social scientists with knowledge on information management over very long timeframes. The work began in mid-January 2020.

## 7.3 Guidance and practical objectives – a two-day international workshop

### 7.3.1 Principles of guidance

Another effort in discussion of information and memory creation for the future was a two-day international, multidisciplinary workshop held in Stockholm in May 2019, by the name of 'Information and memory for future decision making – radioactive waste and beyond', organised by the Swedish National Council for Nuclear Waste along with the Swedish National Archives, SSM, and Linneaus University.[24]

One objective of the workshop was to examine the issue of information preservation and memory in a greater context than just the nuclear waste sector, by enlisting expertise from different sectors requiring information preservation. The broad discussions held in the workshops led to the development of three principles [25] on preserving information, creating knowledge, and memories for the future of a final repository for spent nuclear fuel, amongst other facilities. The aim of the principles and practical objectives described below is to provide a basis for future work on Records, Knowledge and Memory (RK&M) for future generations and their wellbeing.

*Principle number one* states that we must provide future generations with the opportunity to understand and manage the waste/legacy previous generations have left behind:

1. Enabling future members of society to make knowledgeable decisions to suit their needs is part of responsible, ethically sound management of environmental and other impacts of the legacies we leave behind.

The issue of why it is important to preserve information and create memories was highlighted at the workshop, and is linked primarily to principle 1 above. Three fundamental reasons were highlighted: a) legal reasons, b) pragmatic and political reasons, and c) ethical

[24] The documents from the workshop can be consulted at: www.karnavfallsradet.se/en/workshop-information-and-memory-for-future-decision-making-radioactive-waste-and-beyond (accessed 27 January 2020).
[25] Information and Memory for Future Decision-Making – Radioactive Waste and Beyond. Proceedings of the Stockholm workshop 21–23 May 2019.

reasons. The first, legal reasons are linked to factors such as international conventions, for example the Aarhus Convention.[26] This stipulates, for example, the public's right to environmental information, but not specifically how it can be preserved and made available or whether there may be legal grounds for refusing access to such information. This must be clarified.

In terms of the second set of reasons – pragmatic and political reasons – the existence of information preservation and memory creation measures influences the legitimacy and trustworthiness of a final repository and its operators.

When it comes to the third reason, there are many factors to be taken into consideration in this context. This may have to do with creating justice between generations on topic such as access to information. Also mentioned at the workshop was UNESCO's 2007 Declaration on the Responsibilities of the Present Generations Towards Future Generations[27], which states that: The present generations have the responsibility of ensuring that the needs and interests of present and future generations are fully safeguarded. The Aarhus Convention also makes reference to the importance of public participation and access to information on the location, physical and technical characteristics, and estimates of expected by-products and emissions, but, as previously mentioned, it does not state how this can be ensured.

Another reason that was proposed is minimising the risk of a negative impact on future generations. Amongst other factors, they should be given the opportunity to repair or increase the safety of a final repository. Ensuring future generations, the opportunity to make their own decisions is perhaps the most important reason for efforts regarding information preservation and memories.

One issue that was also highlighted was the ambivalence in the message to future generations regarding a final repository – on the one hand stating that the repository is safe and under control, and on the other hand emphasising that carefulness must absolutely be exercised.

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[26] Aarhus Convention (1998): UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (see Gov. Bill 2004/05:65).
[27] http://portal.unesco.org/en/ev.php- URL_ID=13178&URL_DO=DO_TOPIC&URL_SECTION=201.html.

*Principles number two and three read:*

2. The relevant institutions ought to plan for continuing oversight. This is also in line with a prudent approach for protecting health and safety.
3. Any strategy for the preservation of Records, Knowledge and Memory (RK&M) should integrate the possibility of a future disruption of the foreseen methods of transmission. The intention should be to regain oversight, in case oversight was lost.

Two different attitudes to the future are discussed in relation to the preservation of information and that are linked to principles 2 and 3 – a rolling present and a rolling stewardship. A rolling present involves us seeing the future as a continuation of the present. However, research and societal experiences show clearly that major leaps and changes will take place in society over timeframes as long as these we are discussing for a potential future final repository. We must assume that societies of the future will be very different to the present ones. This means that we must consciously conduct ongoing change and that creating a secure transformation of information and societal memories will be pivotal.

A rolling stewardship will mean that the repository must be designed in such a way that monitoring, retrieving, repairing and repackaging of the waste can take place if and when it is considered necessary. This also means that an operator must be designated as responsible for information management, assessment of needs, and implementing measures.

### 7.3.2 Practical objectives

Beyond the principles above, the participants also generally agreed on a number of practical objectives for memory and information preservation. These are described below, along with other relevant factors.

The first practical issue has to do with responsibility:

*Who?* Different kinds of operators must decide and communicate their roles in the preservation actions and take relevant and coordinated measures. Legislation can identify roles and objectives, whilst regulations can guide the practical application.

When work on the preservation of information should be started is the next practical issue:

*When?* Measures for the preservation of information, knowledge and memories should be prepared at the same time as strategies for the management of waste (not least spent nuclear fuel) are planned, designed, implemented and funded. During the long period it will take to construct, operate and seal a final repository for the likes of spent nuclear fuel, for example, in Sweden, there is the opportunity to develop inclusive and usable strategies. During the operating phase, institutional operators can make the preparations and establishment of an archive easier, as well as in time facilitate preparations for the transfer of responsibilities to future operators. It must also be determined in advance who has responsibility during and after final sealing of a repository.

Research on societal memories, development work within the OECD, along with the expected technical development, and societal changes clearly demonstrate that the following conclusion is key:

*How?* There is no single technique or process that can exclusively take care of preserving information and knowledge and creating memories for long timeframes. All possible methods for preservation and creation must be investigated, and a number of potentially usable pathways selected.

The issue of how the work on memory and information preservation will actually be carried out is, consequently, complex, and a number of proposals were put forward during the seminar. The different components in the system for preserving information and memory must apply robust and simple techniques and use durable materials. Several methods and components that complement one another are required (as put forward, for example, in the RK&M project's proposal for a toolbox)[28] to create good conditions for information preservation and memory creation over long timeframes. Strategies must be multifaceted, involving the application of different tools and mechanisms – technical, administrative and cultural. Regular monitoring and updating of the system is important. We must facilitate future understanding of the documents. Information

[28] For example, see: RK&M. 2019. Preservation of Records, Knowledge and Memory (RK&M) Across Generations. Final Report of the RK&M Initiative, p. 63.

on the contexts in which waste and documentation are created must also be developed. Systems for the preservation of information, knowledge and memories must be flexible and adaptable over time.[29]

Cooperation between organisations within different sectors of society, both nationally and internationally, is required to make vital contributions to the development and implementation of the work. Multidisciplinary cooperation between knowledge sectors contributes to a broader knowledge base. National strategies may be more robust if they feature an international element. A collective methodology at international level may make the work easier.

At the workshop, emphasis was placed on the fact that continued work to define and implement a national-level legislative framework to support long-term information preservation also requires the participation of various operators. Work to formulate the regulations for the WIPP[30] in the USA could provide some valuable lessons. The regulations must ensure that the methods for information preservation are made multifaceted.

## 7.4 Cultural heritage and art

Another issue discussed is how the cultural heritage sector and research can contribute to work on creating memories on a final repository for spent nuclear fuel and whether future generations will even consider the documentation for a final repository as cultural heritage.[31] Society's cultural heritage work has to do with protecting and preserving a suitable selection of cultural heritage and cultural environments.

Nuclear waste can be considered a very special form of cultural heritage.[32] Some may view it as meaningless waste from the past, whilst others believe it to be something valuable and important. Perhaps nuclear waste does not constitute positive cultural heritage, but it is historical heritage nonetheless, in the same way as battlefields, concentration camps, or locations linked to World War II may be. The nuclear waste and its repositories are also tangible proof

[29] The Swedish National Council for Nuclear Waste. 2018, p. 59.
[30] The Swedish National Council for Nuclear Waste. 2018, p. 59.
[31] Holtorf. 2019. "Cultural heritage, nuclear waste and the future: what's in it for us?"; Palm and Jordan. 2019. "How to Make Information on Nuclear Waste Sustainable? A Case for the Participation of the UNESCO Memory of the World Programme."
[32] Holtorf. 2019.

of a historic 'atom culture' that – through the energy produced – created a distinct development of the global economy during the latter half of the 20th century. However, through the risks it has been linked with, it has contributed to the development of a global environmental movement.

The cultural heritage sector's approach can contribute to work on memory and information preservation regarding spent nuclear fuel by highlighting the societal complexity this work takes place amidst and must take into account. For example, in the Netherlands, close cooperation is taking place between the company that collects, processes and stores nuclear waste and the cultural heritage sector.[33] As part of the Swedish research project 'Minne över generationerna' ('Memory across generations'), financed by VINNOVA, the cultural heritage perspective is the basis for developing cultural processes and strategies that can contribute to achieving long-term memory of spent nuclear fuel and other hazardous waste.

The role of art in relation to final repositories has been discussed by the likes of Carpenter et al. and in the Modern2020 project.[34] The purpose of Modern2020 was to develop tools to create and implement cost-effective and efficient monitoring programmes adapted to the design of the final repositories and national needs.[35]

The French equivalent to the Swedish SKB is Andra, which is working on cultural heritage issues as part of a project where local residents from different backgrounds create a comic about a future in which the repository has been forgotten.[36] In the French planning for the management of radioactive material and waste, the importance of including social and human sciences is emphasised in the objective of creating more robust solutions, particularly in relation to information preservation and memory creation after the sealing of final repositories.[37] Andra is currently surveying the potential for launching multidisciplinary social sciences and humanities 'labora-

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[33] COVRA: www.covra.nl (accessed 27 January 2020). See also Holtorf.2019.
[34] Carpenter et al. 2019. "Nuclear Culture and Citizen Participation: Networked and distributed artworks."
[35] www.modern2020.eu/ (accessed 27 January 2020). For more on this, please see Chapter 4 of this report.
[36] See: www.andra.fr/une-bd-pour-parler-memoire (accessed 27 January 2020).
[37] Autorité de sûreté nucléaire. 2017. French national plan for the management of radioactive materials and waste for 2016–2018.

tories' to work on the issue of information transfer across generations and how very long-term perspectives can be dealt with.[38]

## 7.5 Conclusions

In summary, this chapter shows that the issue of information preservation and memory for the future is complex. This means that currently there are no simple technical, institutional or cultural solutions that can naturally be expected to endure throughout very extensive timeframes. For this reason, it is highly important that structured work is started now and in collaboration with operators in other disciplines and sectors, along with international efforts. Today's decision-makers are responsible for making this happen – for protecting the environment and human health today and in the future, and for creating the conditions for future generations to exercise freedom of action.

Memory research shows that memory and the lack of memory are fundamental processes, both individually and at societal level, shaping how we create meaning, identity and a perspective on the present.[39] Creating tools for future collective and societal memories of a final repository is, therefore, an issue requiring an array of research sectors to be stimulated to ensure multifaceted management. This applies to everything from the materials that can be used for information storage in a hundred thousand years to the more general analyses of how future generations might be imagined to consider the future, the future's futures or meta-futures. Regardless of how it is tackled, the key issue is how the opportunities to convey information technically, institutionally and culturally can be optimised as technology, institutions and culture change.

Furthermore, memory research shows the importance of creating memories about a final repository after it has been sealed, following the slogan 'We must not forget to remember'. Certainly, voices of warning are still calling out, pointing out that markers and insufficient knowledge on historical establishments such as gravesites and similar, as far as we know has never prevented humans from trying to access them, and that the best strategy would be to not have

[38] Autorité de sûreté nucléaire. 2017, Appendix 2. p. 217.
[39] Hilding-Rydevik et al. 2018. "Baselines and the Shifting Baseline Syndrome – exploring frames of reference in nature conservation."

official markers at the site or on maps and other representations. Naturally, this does not mean that the information must be destroyed or classified as confidential, even if the decision is made to not indicate the site of a final repository.

When choosing between the two incompatible strategies to, on the one hand use different means to restrict or complicate access to information on a sealed repository or, on the other hand, not just mark a final repository in a different way, but also actively spread different kinds of information on a final repository in a variety of contexts and ways, the latter approach gains stronger support, even if the former is in no way a relic of the past. The consequence is increased interest in how the conditions could be created for very long-term information and memory preservation and increased activity in the sector.

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# 8 Nuclear waste and good technology

The different chapters in this state-of-the-art report deal with a range of different questions on and around the issue of a final repository for spent nuclear fuel. They illustrate the multifaceted nature of the issue and the necessity of cooperation between several different research disciplines in exploring and deepening the issue. This also illustrates the difficulty of building an overview and finding a red thread amidst the mass of information. Is it possible to formulate some kind of synthesis, bringing together the different contributions into one whole? In this chapter we have tried to create one such synthesis and thus present a summary of the content of this report. By doing so, we also hope to position the issue in a broader societal perspective.

The starting point is the concept 'the good technology'. The chapter is divided into three parts. The *first* part looks at some of the hallmarks of a good technology, the *second* part at the way in which a final repository for spent nuclear fuel should be able to be (or become) an example of this kind of good technology, and the *third* part the societal conditions for such a technology.

Initially, we will briefly look at two overarching issues: (1) what is meant by 'technology'? and (2) from a general perspective is technology something positive or negative? Both of these issues have been explored in research – primarily in the history of technology and the philosophy of technology. The bibliography for this chapter includes literature suggestions for any readers who may be interested. Here, we will keep to brief answers.

## 8.1 Introduction

What is meant by 'technology'? As far back as we can trace human activity, we can also find tools, which humans used to create their living environment and to satisfy their needs, e.g. caves, stone axes and campfires. These differ from other physical objects as they are *functional constructions intended to fulfil particular human purposes*. Both old remains and modern designs such as cars, clocks and computers are only one part of what we refer to as technology in this text. We will be using the concept in a wider sense. It encompasses not just designed objects but also those who use them – technicians and engineers – and their organisational surroundings. In terms of ancient relics, these contexts have been lost to time, but they can be reconstructed, provided they date to the last few centuries, and sometimes even further back.

Is technology something positive or negative in general? History gives us examples of radically different responses to this question. The 19th century was a century of optimism for technology. The industrial use of different technical inventions – such as the steam engine – contributed to a strong faith in progress, higher living standards, improved communications, health and, ultimately to the enrichment of human life. Of course, this kind of optimism towards technology does still exist today. It encompasses not just the importance of technology for human welfare – the first moon landing 50 years ago is one example. How did this fascination come about? This is one answer:

> It was partially because it was a challenging and inspiring experience in an entirely new area. The astronauts gained experiences no human had ever had before: the peculiar weightlessness of space, the wonderful view out over our planet Earth, the striking beauty of the desolate moon. These people gave us new hope and a feel for humanity's ability to create and its dignity. With the launch of these huge rockets we experienced the power of humanity, its autonomy and supremacy; this represented an expansion of humanity's supremacy over nature.[1]

On the other hand, at the same time there are perhaps at least as many examples of technology-focused pessimism, i.e. the perception of technology as generally evil. The background to this is largely

[1] Barbour, I. 1970. *Science and Secularity*.

based on World War II-nuclear weapons, and the tangible harm of technological developments on our living environment.

Contemporary critics of technology are rarely extreme enough to describe technology as something evil. One possible exception to this was French sociologist and theologian Jacques Ellul (1921–1994). In the book *La technique, ou, l'enjeu du siècle*[2] he writes:

> Those who have devoted themselves to the technological world can be compared to housewives who do nothing but clean and polish, and in doing so make the home so uninviting that no one wants to be there. Just as she suffers from a kind of cleaning psychosis, modern technology appears to serve as a compulsive neurosis: once in full swing, it is reluctant to let the human out of its grasp to do anything else. She has to keep on going, being drawn ever deeper in. She loses all sense of proportionality and makes it her one sole interest at the expense of all else.[3]

Ellul believes not just that technology as such is evil (technological pessimism) – he also seems to believe that it is impossible to control (technological determinism). It is difficult to determine whether or not he is right, on a scientific basis. Thankfully, in this context we do not need to take a stance on such major questions. We can satisfy ourselves with working on the basis that (1) technology is not value-neutral, and (2) that technology is often difficult to control, but it is not impossible to control. Statement (1) is examined in the *first and second sections*. Technology is not value neutral. There is good, less good and purely evil technology. The main issue is what differentiates the good technology from the bad. In the *third* and concluding section, we deal with statement (2), i.e. the issue of whether and how technology can be controlled and governed.

## 8.2 What are the hallmarks of good technology?

Our basis is that the difference between good, less good and bad/evil technology largely depends on the consequences it entails. Against this background, the Council wishes to propose a number of different features that, in general, could be hallmarks of good technology. What we are looking for, therefore, are the hallmarks of technology that can, from a human standpoint, have positive consequences and impacts on what Alfred Nobel called in his will – 'the greatest benefit

[2] English translation 1964: *The Technological Society*.
[3] Ellul, J. 1964. *The Technological Society*.

to humankind.' We have identified seven such hallmarks. The list is not exhaustive – readers are invited to revise or add to it.

## Good technology relies on a scientific basis (1)

*Technology relying on a scientific basis refers to things developed using knowledge acquired with diligence, awareness of problems, use of well thought-out and intersubjectively provable methods and critical thinking.*

Good technology is based on a grounding in technological and scientific research. These sciences "[try] to explain why something has happened by showing that it can be subsumed under a natural law".[4] With the help of well-designed experiments and observations, different hypotheses are verified or falsified. Through these measures, conclusions can also be drawn on future progress. One difficulty with making such predictions is the uncertainties on the circumstances that will prevail in the future. Predictions based on results gained so far must always be combined with *critical thinking*, i.e. keeping an open mind in all research and development to the question 'but what if the opposite is true?'

One difficulty with this hallmark is that sometimes there is a lack of agreement between expert researchers on the scientific basis for a certain technology. Sometimes it is apparent that extrascientific factors play a decisive role. One such example is the climate issue. Economic interests can also play a role here. In other cases, scientific controversies are more difficult to analyse, and despite significant investments of time and energy can be very drawn out. One example of this is the controversies surrounding gene technology.

## Good technology requires competence (2)

*Competence has to do with technological proficiency gained through the relevant education, training and proven professional experience.*

The second hallmark is closely connected to the first and linked to the competence of the practitioner of the technology, i.e. the

[4] Swedish Research Council. 2017. Good Research Practice, p. 19. See: www.vr.se/download/18.2412c5311624176023d25b05/1555332112063/God-forskningssed_VR_2017.pdf (accessed 27 January 2020) [English version: https://www.vr.se/download/18.5639980c162791bbfe697882/1555334908942/Good-Research-Practice_VR_2017.pdf].

engineer, construction worker and administrator. Competence has been described as "the capacity to implement personality, problem-solving capacity, experiences, knowledge, skill and motivation in behaviour that is key for a particular working output."[5] Technological competence in the form of knowledge and skills is gained primarily at institutes of higher education and universities.

Individual motivation is, of course, key, but the quality of the education and its applicability to the technological operations within the industry are also important.

To a large extent, competence is an issue of the individual's personal responsibility, whilst *competence management* is more an issue for the individual company, sector, and national authorities. Good technology requires good competence management and has largely to do with attracting young people to technological operations that are important to society's key functions. This includes the energy and transportation sectors, as well as the armed forces.

### Good technology is consequence-aware and prepared for reconsideration (3)

*Awareness of consequences is based on studies in which scientific knowledge is used to assess the result of a certain technology compared to other solutions, as well as with regard to the social impact of the technology.*

This hallmark has been discussed to a greater extent and in the long-term perspective concerns the responsibility of technological researchers, engineers and innovators for the consequences of a certain technology. Such consequences range from direct economic and commercial ones to others that are relatively difficult to predict and social or existential in nature. One high-profile case was responsibility for nuclear weapon development at the end of World War II. To what extent did the researchers involved have personal responsibility for the consequences of the atom bombs dropped on Hiroshima and Nagasaki? Similar questions about responsibility and consequences can be asked of today's researchers. There is a growing consensus that both future and current engineers must be made aware of and educated on the social consequences of their technology. Engineering

[5] www.wise.se/den-svara-konsten-att-bedoma-kompetens-del-1/ (accessed 27 January 2020).

ethics has also constituted a key element of education at technical institutes of higher education and universities for several decades.

One technological sector with significant social consequences is telecommunications. This technology has revolutionised social lives, but at the same time it has restricted our sensory experiences. Talking to a good friend on the phone is one thing, but meeting them face to face is quite another. Seeing a puppy on a mobile phone screen and touching its soft fur and smelling its scent in reality are quite different.[6] Perhaps these are trivial examples, but the issue is that the breakthrough of social media has restricted our experiences of reality in a way that could not have been predicted 20–30 years ago.

Naturally, it is highly difficult to predict the consequences of technological innovations, but we should still try. This brings with it what can be termed preparation to reconsider, i.e. rethink and think soundly about something against the background of technical and social consequences. It is here that those with a direct influence on technological development have particular responsibility. This is also reflected in the ethical code adopted by the Swedish Association of Graduate Engineers. According to this code, engineers must "in their work, take personal responsibility for technology being used in a way that benefits people, the environment and society."[7] The scope of this individual responsibility compared to those with managerial responsibility for the technical systems entails difficult balances.

## Good technology is value-aware (4)

*Value awareness involves people paying attention to consequences being taken into consideration in respect to the values sought, but also in relation to the different values the technology impacts upon.*

Technology influences our everyday lives and can often awaken strong emotions. This is true of everything from train transportation to social media or surveillance cameras. How many dinner table conversations revolve around these kinds of topics? In many cases, it has to do with what is valuable and what is not. There is cause here to consider what we really are talking about. Is it an issue of what is valuable for its own sake, or what is valuable as means for something

[6] For more information see Hansson, S-O. 2002. *Teknik och etik [Technology and ethics]*.
[7] www.sverigesingenjorer.se/om-forbundet/sveriges-ingenjorer/hederskodex/ (accessed 27 January 2020).

else? Furthermore, there are all kinds of different values. Environmental values, cultural values, happiness, health and economic growth are just some examples. How can we balance these different values against one another: economic growth versus untouched nature, security versus efficiency, mass culture versus high culture, extending lifespans versus pain-free death?[8]

Another example is the issue of monitoring and how these kinds of activities should be weighed against personal integrity. It is vital that technicians and engineers participate in the discussion on such assessments.

Some consider that this issue can be left to legislation and politicians to resolve. However, law and morals are not the same thing.

> Morals influence legislation, but the law can be incorrect, insufficient, or open to various different interpretations. For this reason, engineers must be trained in ethical thinking in order to be able to reflect on their own actions and their consequences for people, society and the environment.[9]

This quote also brings into focus the issue of technical and natural sciences research and training in comparison to social sciences and humanities. Current statistics indicate that the humanities are becoming less and less popular and the number of new of students fell by 17 % from 2009–2010 to 2017–2018. One solution to the humanities crisis could be to afford humanities topics greater space in technical and natural sciences education. The history of technology and engineering ethics already form part of the education provided by technical schools of higher education.

## Good technology is aware of long-term objectives (5)

*Awareness of long-term objectives means regularly assessing whether and how the shorter-term goals contribute to the realisation of long-term objectives and acquiring a goal-oriented basic attitude.*

Both the public and politicians are often focused on the short-term solutions. This can apply to the likes of the new generation of technology for our telecommunications, Volvo's latest car model, or

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[8] Jeffner, A. 1986. "Ethical views on technological development", p. 31.

[9] Nihlén Fahlqvist, J. "Ingenjörer måste ta sitt moraliska ansvar" ["Engineers must take on their moral responsibility"]. *SvD* (2 November 2013).

the next metro network extension. It is clear that the immediate problems are often the most pressing. The threat of destructive climate changes is changing this. Long-term problems beyond the next quarterly report or the next election are forcing their way to the foreground.

Awareness of long-term objectives means acquiring a goal-oriented *basic attitude*. As citizens we are also responsible for adopting such an attitude, even if we are more inclined to focus on the means rather than the objective. This has to do with more than a change in basic attitude. What are we aiming for with the development of society and how are new technological systems contributing to long-term objectives? Do some technological systems make things more difficult rather than making them easier? And what can be done about this?

### Good technology provides transparency through open communication (6)

*Transparency means giving the operators concerned and the public in general easy access to information on the basis for and considerations behind important decisions on technological systems and who is responsible for said decisions.*

Society is becoming – for better or worse – ever more dependant on technology. At the same time, we are working to maintain and strengthen our democratic institutions. Many are apprehensive about dependency on technology and democratic aspirations are pulling in different directions. Political decisions are becoming ever more dependant on science and technology, which at the same time become more and more incomprehensible to the majority of the population who are not highly educated specialists. Was the old car with a combustion engine one of the last comprehensible technologies? Our new, electronically controlled cars are beyond the understanding of normal people. This is not just a generational issue. It is also an issue of the technological complexity actually having grown through a combination of factors, including IT and globalisation.

It is difficult to make technological dependency and democratic participation to advance in the same direction. Political responsibility requires technology and science to be understandable and comprehensible to people in general. To do this, engineers and technicians would need to be trained in making their technical knowledge accessible. This also requires a certain view on humans, i.e. faith in their rationality. In our age, this faith has been undermined by a mistrust in the truth and universal values. If this is true, we will need to regain something of the faith in reason that was characteristic of the age of enlightenment, and specialists will also have to work to meet the public in the middle. One Swedish company working in the technology sector sells an excellent little book by the title *Så funkar det? Hemma och runtomkring*. ['How does it work? Inside and beyond the home'].[10] In the same vein, SKB has strived to explain to the wider public how a final repository system could work.[11] The goal is to communicate and promote understanding– and that doesn't need to be impossible.

Measures to ensure transparency require the operation of technological systems to be monitored continually. Technological systems that are becoming ever complicated are linked to such monitoring systems. One example is the air traffic management system, without which air traffic would be impossible. In certain cases, information from these monitoring systems is also communicated out to a wider audience. Public discussion on climate changes is guided by such information from satellites and control stations across the globe. Public faith in such systems naturally requires that the systems are reliable.

### Good technology requires a comprehensive orientation of the surrounding world (7)

*Comprehensive orientation of the surrounding world involve technicians, engineers and managers to acquire knowledge of the social and cultural contexts within which new technology is implemented and developed.*

Technology and science are always part of a broader cultural and social context. For this reason, all the more frequently we are hearing

[10] Wärnblad. M., 2015. *Så funkar det? Hemma och runtomkring* ['*How does it work? Inside and beyond the home*'].

[11] Amongst others, see the 'toppdokumenten' ['top document'] in SKB's applications under the Environmental Code and Act on Nuclear Activities: www.skb.se/projekt-for-framtiden/karnbransleforvaret/vara-ansokningar/ansokningshandlingarna/ (accessed 2 February 2020). You can also find out more about the safety analysis in the summary in: SKB. 2011. *SR-Site Redovisning av säkerhet efter förslutning av slutförvaret för använt kärnbränsle* [SR-Site review of safety following the sealing of the final repository for spent nuclear fuel]. Huvudrapport från projekt SR-Site [Main report from the SR-Site project]. Part I, p. 15 f.

talk about socio-technical issues. This concept draws attention not just to the social consequences of the technology, but also to the ways in which a cultural and social context influences the development of technology. Good technology requires such comprehensive knowledge. In a recent report from the international project Modern2020, the following examples of the interplay between society and monitoring are given:

> It's clear that plans to develop monitoring technologies for geological disposal sites vary significantly from country to country: some countries are planning to implement extensive monitoring, but others are not. Why is this? A single focus on 'the technical' cannot answer this question – we need to look at 'the social' as well. In fact, when developing monitoring technologies, existing plans for waste management, the needs of local residents, legislation, and so on all have to be taken into account, which explains the variation between countries.
>
> In other words, Socio-Technical Theory can help make it clear why different countries have different ambitions and make different choices when it comes to the future monitoring of nuclear waste repositories.[12]

A comprehensive orientation also involves knowledge on how the public perceive different technological systems and particularly those systems that provoke global concern. This includes gene technology and nuclear technology, as well as uses of technology that influence climate change (positively or negatively).

## 8.3 The final repository and good technology

The previous chapters of this state-of-the-art report deal with different topics which appear unrelated to each other and to the issue of a final repository for spent nuclear fuel for which SKB submitted an application to build and operate a repository for spent nuclear fuel. But upon closer reflection, each chapter contributes to the issue of the final repository and in what way it is – or is not – an example of good technology. In this section we attempt to clarify this issue. In other words, the intention is to show *how the different in different chapters of this book relates to the hallmarks of good technology*. One chapter can bring to the fore several different hallmarks, but for

[12] Meyermans, A. et al. 2019. *Monitoring in Geological Disposal and Public Participation – A Stakeholder Guide*, p. 9.

reasons of space we will limit ourselves to how one of the aforementioned hallmarks of good technology is dealt with in a particular way in each of the previous chapters of this state-of-the-art report.

a) Long-term safety and the scientific basis

The final repository project builds on scientific research that has been carried out since the mid-1970s. Different nuclear fuel safety methods have been developed by SKB and resulted in the so-called KBS-3 concept in the mid-1980s. The aim was to fulfil the requirements of the so-called Stipulation Act (Villkorslagen), which required the owners of nuclear power facilities to show how a safe disposal, of spent nuclear fuel is possible. SKB has been responsible for research since 1986, with ongoing reviews taking place in the form of scientific publications and reports and the RD&D Programme every three years.

This shows that the KBS-3 concept has a scientific basis, thus demonstrating a key hallmark of good technology. However, this has not prevented scientific criticism aimed at different parts of the concept. In recent years the topic attracting the most attention is the protective capacity of the copper canister.[13] In its pronouncement on SKB's supplementations to its application, the Council put forward the view that there are still unanswered questions that could impact upon long-term safety.[14] These perspectives are developed further in chapter 5. In the view of the Council, these unanswered questions merit particular attention by SKB's ongoing research efforts and by SSM´s ongoing supervision during the ongoing stepwise licensing process. However, the Council has emphazised that there are no guarantees that continued research will provide strong and clear-cut proof of the protective capacity of the canister.

Good technology relies on a scientific basis, but the scientific basis is not always unambiguous. The nuclear waste issue is marked by scientific controversies, and examples of these were covered in the Council's state-of-the-art report from 2014.[15]

[13] This protective capacity is also discussed in Chapter 5.
[14] The Swedish National Council for Nuclear Waste. 2019. *Kärnavfallsrådets remissvar angående Svensk kärnbränslehantering AB:s kompletterande yttranden [The Council's response regarding SKB's supplemented pronouncement*].
[15] The Swedish National Council for Nuclear Waste. 2014. SOU 2014 *Nuclear Waste State-of-the-Art Report 2014 Research debate, alternatives and decision-making*. p. 15–32.

b) Monitoring and the importance of transparency through open communication

In several of its state-of-the-art reports and pronouncements, the Council has examined the issue of monitoring and monitoring programmes for a final repository for spent nuclear fuel.[16] This is largely focused on the experiences gained through the international research project Modern2020 (2015–2020) and its predecessor MoDeRn2020 (2010–2015). The issue brings into focus unanswered technical questions, due to the fact that such measures could have an impact on the safety and protective capacity of the repository, amongst other issues.[17] We will not repeat the technological conclusions here,[18] but instead we will draw a link between the issue of potential monitoring measures and the issue of the aforementioned hallmark of good technology, i.e. transparency through open communication.

Modern2020 involved a societal work package that directly concerns the issue of transparency. This work led to the report *Monitoring in geological disposal & public participation: a stakeholder guide*.[19] The report covers not just transparency through monitoring but also broader issues of public involvement in the issue of management of nuclear waste. *Why is it important? What should be included? How should communications be arranged? When should local stakeholders be involved?*

The report is a key contribution to ongoing discussion on a final repository for spent nuclear fuel, and it also highlights other issues, such as if and how much information on the design and properties of the final repository should be communicated to future generations (see below).

c) Long-term competence management and the need for value awareness

[16] For example, see the Swedish National Council for Nuclear Waste 2016. SOU 2016:16 *Nuclear Waste State-of-the-Art Report 2016. Risks, uncertainties and future challenges*.; the Swedish National Council for Nuclear Waste. 2015. *Nuclear Waste State-of-the-Art Report 2015 Safeguards, record-keeping and financing for increased safety*; the Swedish National Council for Nuclear Waste. 2014. *Review of the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D Programme 2013*.

[17] Cf. SSM's regulations SSMFS 2008: 21, Section 8.

[18] Further information about Modern2020 can be found in Chapter 4.

[19] Meyermans, A. et al. 2019. *Monitoring in Geological Disposal and Public Participation – A Stakeholder Guide*.

Competence is another one of the hallmarks of good technology and has been described as "the capacity to implement personality, problem-solving capacity, experiences, knowledge, skill and motivation in behaviour that is key for a particular working output." Competence is not just an issue of individual ability, it is also a broader problematic on companies', authorities' and politicians' capacity to staff our technological systems with skilled and experienced staff. experienced staff.

The issue of competence management has become a key issue for the Council in recent years. In Chapter 2 of this state-of-the-art report the results of an international study are presented, looking at six different countries compared to the situation in Sweden. It covers topics such as their preparedness for short- and long-term competence needs and the preconditions for maintaining competence management in each country. The study led to three key recommendations. This includes the importance of establishing a national programme for long-term competence management "within areas relevant to the decommissioning of nuclear power plants and safe management of nuclear waste."

Another issue must also be examined here. This has to do with value awareness as a hallmark of good technology. This kind of value awareness also forms part of the competence of well-trained technicians and engineers. Initially, the issue is examined in specialist literature.[20] Here, the elements emphasised include building ethical competence as an important factor in the education provided by institutes of higher education and universities. But the issue also brings to light the need for internal education of construction workers and other staff who will be responsible for parts of the final repository project within SKB. Radiation safety requires particular procedures beyond those required for other non-nuclear construction activities.

d) Stepwise licensing, consequence awareness and preparedness for reconsideration

The issue of the future process once the government has approved SKB's application has been an issue of great importance in recent years. There is much discussion of a stepwise licensing process, and the issue was the topic of a special seminar held by the Council on

[20] For example, see Hansson., S-O. 2002, p. 75–100.

12 November 2019. One of the prior chapters in this report (3) is dedicated to this issue. Technology is constantly developing and necessitates the continuing reconsideration of prior solutions. For this reason, the IAEA has designated stepwise licensing a basic requirement of nuclear technology facilities.

Stepwise licensing is linked in particular to one of the aforementioned hallmarks – consequence awareness and preparedness for reconsideration. SKB's application and supplements and the reviews carried out by SSM and other stakeholders entail a fundamental analysis of the construction of a final repository, with particular attention into the technological and in some respects also social consequences, which – for example concern the local consequences of the nuclear waste project and the infrastructure conditions for successful implementation. At the same time, preparation for the unexpected events is required. For this reason, safety reviews must be repeated at different times. This has happened prior to construction and according to SSM's regulations must happen again before any trial operation and again before standard operation of the facility. After this, recurring full reviews will be carried out. Safety reviews must also take place during disassembly of the construction site and, finally, in connection to the sealing of the repository.

These reviews primarily cover the technological systems, but they also look at finances, the organisation of work, and the safety culture. These reviews should also cover the social consequences of the project and how the project will impact upon – and be impacted by – the surrounding society. Safety issues cannot be determined from this broader context.

The stepwise licensing process also requires preparedness for reconsideration. It may turn out that earlier solutions are no longer sufficient and rethinking is required. Be prepared! The old scouting motto is also applicable to the stepwise licensing process.

e) Public opinion and the significance of orientation to the surrounding environment

One of the chapters of this state-of-the-art report deals with the current state of knowledge in society and values relating to the nuclear waste issue. Nuclear waste no longer brings about the same sense of worry it did 20–30 years ago – nowadays it is the climate threat that takes centre stage. The majority of those asked still considered it an important issue. The mean on a ten-point scale was 5.7 – compared to the climate threat, which had a mean of 7.7. In summary, the nuclear waste issue has been shown to be the tip of the iceberg in attitudes and perceptions of the future.

The Council commissioned this study for purposes including satisfying the need for a comprehensive orientation of the surrounding world. Previous studies have been carried out by both SKB and SSM with the same objective. Knowledge on the values linked with the nuclear waste issue is also important for a variety of reasons; it is key in facilitating communication between technicians and the general public, and it can also form the basis for fulfilling the need for further knowledge. Research shows, for example, that those interviewed felt that they had a poor level of knowledge on the disposal of spent nuclear fuel. Yet almost 60 % believed that a country like Sweden could manage and store nuclear waste safely in the long term. The question could be posed as to what this opinion is based on, if the majority do not feel that they have sufficient knowledge. Perhaps the answer is simply that Swedish experts and authorities inspire a high level of trust.

f) Remembering the final repository and the long-term goals

One of the issues accompanying competence management and stepwise licensing that has arisen in recent years is the issue of knowledge and information preservation. This has to do with the issue of whether and how we should communicate knowledge to future generations on the final repository's location, design and risks associated with the encapsulated spent nuclear fuel. One of the previous chapters in this report sheds light on international work underway on these issues and the combination of technological, scientific and humanities-based research required to attempt to resolve these issues. This concerns memory research and communications media.

One important hallmark of good technology is awareness of long-term goals. The climate issues bring these goals to the fore, as does the final repository issue. Naturally, the long-term goal of the repository is to protect current and future generations from the harmful nuclear waste. How does documentation of the final repository's design and contents contribute to this objective? And what kind of documentation is important? This is not an issue that can be resolved by sending a collection of RD&D reports to the future.

Instead, the issue more closely resembles that of conveying information via the space probes Pioneer 10 and 11 to any interested intelligent civilisation in a remote part of our galaxy. The probes included content such as an image of the human body. Documentation of the content of the final repository places even higher requirements on our communication capacity, and it is easy to lose yourself in the tangle of the problem. For this reason, it is particularly important to preserve knowledge on the long-term goals of the repository, its location and its contents.

## 8.4 Societal control and steering of technology

"Så kommer tekniken att omforma samhället" ["This is how technology will reshape society"] was a headline in the 8 December 2019 edition of Swedish national newspaper Dagens Nyheter (DN). The article examined new 5G technology and the telecom company Ericsson's efforts in this area. Chief Technology Officer Erik Ekudden of Ericsson commented:

> We need to satisfy a completely new set of consumer demands, such as capacity to play advanced VR games – and that's without even mentioning corporate customers. There, the demands have to do with an entirely new infrastructure built on machines being connected directly to the internet ...[21]

"This is how technology will reshape society." Can society reshape technology – and how? After all, the traffic between technology and society is not one-directional. Technology is a powerful factor in the development of society, but culture and politics are more than just puppets in the hands of technology. And this applies to us as individuals too. We are not slaves to our mobile phones – check the on-screen clock, turn off the phone after 8 pm, or buy a mobile phone hotel for the family. Similarly, we can use political means to control larger technological systems. Humans are the ones who invent technology – we must also have the power to steer and control it.

In the introduction to this chapter we brought to the fore the issue of how controllable and steerable technology is. There is a great

[21] "Så kommer tekniken att omforma samhället" ["This is how technology will reshape society"] was a headline in the 8 December 2019 edition of Swedish national newspaper Dagens Nyheter (DN).

deal of research available in this area, and we will only look at a few overarching issues briefly. First, we will describe the difficulties with controlling the development of technology, after which we look at potential measures for managing difficult-to-control technology, before finally exploring the issue of how a century-long project such as the building, operation, and sealing of a final repository for spent nuclear fuel can be controlled and steered towards the hallmarks of good technology.

## Collingridge's dilemma

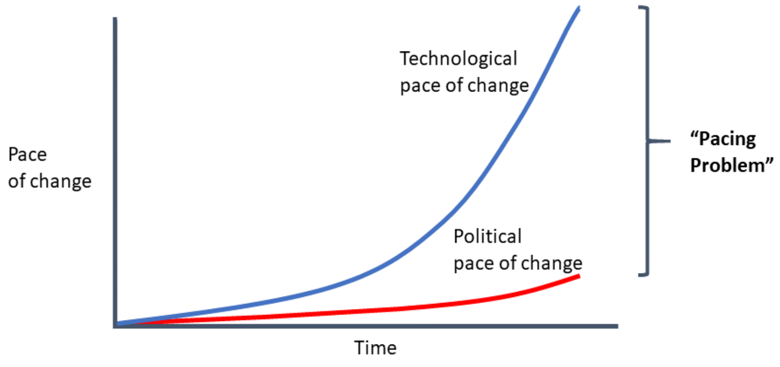
Modern research on the development of modern technology discusses topics such as 'Collingridge's dilemma'. This dates back to a book by English technology researcher David Collingridge under the title *The Social Control of Technology* (1984). The dilemma arises between two different processes. One has to do with the development of technology. The breakthrough of a technology cannot be predicted before it has become well-developed and generally applied. The second has to do with power. Potential for controlling a technology is limited once the technology has become an ingrained part of societal life. Drones and artificial intelligence (AI) are examples of technologies that are already well-rooted in broader societal development. Collingridge summarised this dilemma elegantly:

> When change is easy, the need for it cannot be foreseen; when the need for change is apparent, change has become expensive, difficult and time consuming.

Adam Thierer describes the dilemma as a 'pacing problem'.[22] Technology develops exponentially in great leaps, whilst policy and legislation develop in smaller steps. He illustrated this with the figure below.

[22] See https://techliberation.com/2018/08/16/the-pacing-problem-the-collingridge-dilemma-

**Figure 8.1 Pacing Problem**




*Source*: Figure based on Thierer et al 2019.

A much-cited example of technological development is that of information technology. According to the original version of what is known as Moore's Law, the number of transistors a chip can accommodate has doubled every 18 months since the early 1970s. The technological driving force is strengthened by social demand. The public demands new tools in their everyday lives and expects that they will be provided at regular intervals. At the same time, policy and legislation are lagging behind and demonstrating a growing incapacity to control development.

The conclusion from these observations are often pessimistic. Policy cannot keep pace with technology and problems are arising all the time in new areas. Electric scooters laying scatterd in our cities are one example that very clearly illustrates one of the otherwise positive consequences of new and more effective lithium ion technology combined with IT developments.

## What should be done – and what can be done?

The 'pacing problem' poses significant challenges for politicians. And there is no lack of extreme solutions. If one has the basic attitude that technology frees humanity, naturally one will seek out as little political control and regulation by authorities as possible. The path towards a promising future leads via resources and innovation. On the other hand, for those who see the technology as a threat, well-developed regulatory frameworks and far-reaching legislation are imperative. The so-called precautionary principle is a cornerstone of this perspective. New innovations must be held back or prohibited until their producers can demonstrate that they will not cause harm. In many areas, we see these two worldviews in confrontation with one another.

If a middle path is sought between these two worldviews, a modification of the precautionary principle can be a key solution. We sometimes hear mention instead of 'anticipatory control' or 'upstream steering'. Political decisions or authority regulations must be issued at as early a stage as possible. One researcher – John Frank Weaver – writes, for example, that in terms of AI, we must regulate 'early and often', otherwise the negative consequences for humans in general will be significant.[23]

Another possibility is choosing between 'hard law' and 'soft law'. The difference usually arises in international rule of law, but it could also be relevant in national legislation. Hard law is binding legislation with clear sanctions. This corresponds to, for example, SSM's regulations, whilst soft law has to do with recommendations linked to the regulations. 'Soft law theory' also comprises other elements, as Adam Thierer et al. describe in a recently published article.[24] One clear element is cooperation between the parties affected by a new technology ('multistakeholder processes') to ensure continual assessment and influence over the technological development. Autonomous industrial self-regulation (internal or between different companies) is another element of the theory.

## A final repository for spent nuclear fuel – a century of challenges

The Council has emphasised how the combination of the long establishment period, complex safety analyses and future uncertainties mean that the KBS-3 project entails unique challenges. As the Council stated in its 2017 state-of-the-art report, "The repository will be built

[23] https://slate.com/technology/2014/09/we-need-to-pass-artificial-intelligence-laws-early-and-often.html (accessed 27 January 2020).
[24] https://ctlj.colorado.edu/wp-content/uploads/2019/03/3-Thierer_3.18.19.pdf (accessed 27 January 2020).

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."[25] This was clarified in a contribution by Clas-Otto Wene – a former member of the Council. He wrote, amongst other elements, the following:

> 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.[26]

In its pronouncement on SKB's supplements (submitted 13 September 2019), the Council emphasised a number of issues, including – that provided SKB's application receives a positive decision – the ongoing process will be designed so that the above requirements are satisfied. Against the background of the previous chapter, it is particularly important that the so-called pacing problem is taken into account. The forthcoming decision-making process must keep up with technological developments. As previously mentioned, the soft law theory emphasises the importance of cooperation between all parties concerned to ensure continual assessment of technological developments. Such collaboration could be planned in dialogue with international experience and current legal and technical-scientific research. The Council believes that this experience and research can play a key role in contributing to the final repository project being able to manage future challenges for a century to come.

Several of the chapters in this report examine the issue of stepwise licensing and how a future process after a potential positive government decisions with certain conditions might look. An important part of the response is that the process must ensure stakeholders, including residents of the municipality concerned and the public in general, comprehensive transparency. Another important part is that the process maintains openness towards technological and scientific developments. Finally, it is also vital that the supervisory authority, SSM, continues to provide resources for monitoring SKB's future safety analysis reports and ensures that the conditions decided by

[25] The Swedish National Council for Nuclear Waste. 2017. SOU 2017:8 *Nuclear Waste State-of-the-Art Report 2017. Nuclear waste – an ever-changing issue*, p. 11.
[26] The Swedish National Council for Nuclear Waste. 2017, p. 125–126.

the government are fulfilled. Policy and authorities can and must steer large-scale technology – not vice versa.

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# PART 2

# The nuclear waste field

# 9 The work of the Swedish National Council for Nuclear Waste and the nuclear waste field

## 9.1 The work of the Swedish National Council for Nuclear Waste in 2018 and 2019

### 9.1.1 Amended directive

The Council's work is regulated and steered by instructions set out in a directive. During 2018 a supplementary directive on the Council was passed, altering its work to a degree. Previously the Council published and reviewed the previous year's work and issued a report on its independent assessment of the state of the art in the nuclear waste field every year. The supplementary directive states that the Council will now do this every other year. A further change is that the task of the Swedish National Council for Nuclear Waste shall be time limited to last until the 31 December 2022. After this, the task may be extended by a maximum of five years at a time.[1]

[1] Kärnavfallsrådets direktiv 2018:18 [Directive on the Swedish National Council for Nuclear Waste 2018:18].

### 9.1.2 Publications and communications

*State-of-the-Art Report 2018*

In February 2018 the Council published a report by the title SOU 2018:8 Decision-making in the face of uncertainty.[2] The report deals with the fact the government must reach a decision on a final repository for spent nuclear fuel, and this decision will be made in the face of uncertainty. In itself, this is not an unusual situation for the Government, and decisions are made in different areas under such circumstances all the time, however, this project is unusual due to its level of complexity. Based on its multidisciplinary approach, the Council provided some examples of different areas that feature uncertainties and discussed the management of and approaches to uncertainties in decision making, both in general and when making a decision on a final repository for spent nuclear fuel in particular.

*Documents circulated for comment and communications*

In accordance with the directive, the Swedish National Council for Nuclear Waste shall investigate and shed light on the management and final disposal of spent nuclear fuel and nuclear waste, and the closure and dismantling of nuclear power plants. The Council will also advise the Government on these issues.

During 2018 and 2019, the Council responded to a number of documents circulated for comment:

– Kärnavfallsrådets synpunkter på Strålsäkerhetsmyndighetens: Remissversion i regeringsuppdraget om långsiktig kompetensförsörjning [The views of the Swedish National Council for Nuclear Waste on the Swedish Radiation Safety Authority's document circulated for comment in the government task on long-term competence management] (August 2018)[3]

[2] www.karnavfallsradet.se/sou-20188-kunskapslaget-pa-karnavfallsomradet-2018-beslut-under-osakerhet (accessed 27 January 2020).

[3] The Council's communication can be accessed at: www.karnavfallsradet.se/karnavfallsradets-synpunkter-pa- stralsakerhetsmyndighetens-remissversion-i-regeringsuppdraget-om (accessed 27 January 2020).

– Kärnavfallsrådets synpunkter på förslag till föreskrifter om kostnadsberäkningar, ansökningar och redovisning vid finansiering av kärntekniska restprodukter [The views of the Swedish National Council for Nuclear Waste on proposals for regulations on cost calculations, applications and accounting for funding of residual products from nuclear technology] (June 2019).[4]
– Remissvar angående Svensk kärnbränslehantering AB:s kompletterande yttranden till regeringen [Response to document circulated for comment regarding SKB's supplementary pronouncement to the government] (September 2019).[5]
– Skrivelse om Remissyttrande översyn kärntekniklagen [Communication on statement of opinion regarding review of the Act on Nuclear Activities] (September 2019).[6]

Furthermore, in its communication[7] the Council proposes to the government on 22 January 2019 that the Act on Financing of Management of Residual Products from Nuclear Activities be amended so that non-governmental organisation (NGO) can once again receive funding from the Nuclear Waste Fund. The Council believes that the input and knowledge of NGOs more than adequately fulfils the requirements for the financial support provided during the licensing of a final repository for spent nuclear fuel. If NGOs can receive funding from the Nuclear Waste Fund, they will also be able to plan their work with a longer-term perspective.[8]

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[4] The Council's communication can be accessed at: www.karnavfallsradet.se/karnavfallsradets-synpunkter-pa-forslag-till-foreskrifter-om-kostnadsberakningar-ansokningar-och (accessed 27 January 2020).

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### 9.1.3 Seminars and meetings

In accordance with the directive, the Council shall investigate and shed light on important issues in the nuclear waste field, for example by holding hearings and seminars, in order to make well-founded recommendations to the Government.

The Council has had several meetings with the Ministry of the Environment and SSM. The Council also meets with other stakeholders, such as NGOs and municipalities on a regular basis. The Council has also met with SKB, which has, amongst other things, presented how work on its RD&D 2019 programme is progressing.

*Presentations of the state-of-the-art report 2018*

The Council presented the state-of-the-art report 2018 on decision-making in the face of uncertainty to both the then Minister for the Environment Karolina Skog and to the Defence Committee. Additionally, the Council held an open seminar on the report on 21 March 2018.[9]

*Round-table discussion on participation – with environmental organisations and with municipalities*

In late 2018 the Council held a round-table discussion with representatives of environmental organisations active in the nuclear waste sector. The focus was on participation in a stepwise licensing process as per the Act on Nuclear Activities (1984:3). Transparency and participation are a key part of stepwise licensing and through until the final closure – if the government agrees to permissibility and licensing of a final repository for spent nuclear fuel. During spring 2019, the Council followed up with a round-table discussion with representatives of the municipalities of Oskarshamn and Östhammar.

[9] www.karnavfallsradet.se/seminarium-om-karnavfallsradets-kunskapslagesrapport-2018-beslut-under-osakerhet-sou-20188 (accessed 27 January 2020).

*Almedalen 2018 a final repository for spent nuclear fuel – decision-making in the face of uncertainty?*

A seminar held at Swedish political forum week Almedalen in 2018 explored the lingering uncertainties the Council has found in the final repository process and how these could be reduced.

On the same day, the Council also held a joint seminar with SSM, under the title: Vad händer med slutförvaret för använt kärnbränsle? [What's happening with the final repository spent nuclear fuel?] The objectives for both seminars included reaching politicians and a broader target group.[10]

*Almedalen 2019 What do young people think about nuclear waste – and what do they want to know?*

The Council organised a panel discussion with the aim of examining the perspectives of the younger generation and thereby increasing and strengthening their involvement in the nuclear waste issue. It is important that the younger generations are aware that nuclear waste does exist and that it must be dealt with. The members of the Council were questioned by young researchers. Key points of the conversation were the responsibility of the current generation, choice of method and location for final storage, and transmission of information on the final repository to future generations.[11]

*Workshop: Information and memory for future decision making – radioactive waste and beyond*

In May 2019 a workshop was held on information and memory preservation. The workshop was arranged in collaboration between the Council, Linneaus University, the Swedish National Archives, and

[10] www.karnavfallsradet.se/karnavfallsradets-seminarier-i-almedalen-3-juli (accessed 27 January 2020).

[11] www.karnavfallsradet.se/karnavfallsradets-panelsamtal-i-almedalen-2-juli-2019 (accessed 27 January 2020) [English version: https://www.karnavfallsradet.se/sites/default/files/documents/report_2019_1.pdf].

SSM. Proceedings, presentations, etc. from the workshop can be found on the Council's website.[12]

*Seminar on stepwise licensing and a century of challenges*

In November 2019 the Swedish National Council for Nuclear Waste held a seminar on stepwise licensing and a century of challenges. The aim of the seminar was to discuss and shed light on issues regarding what is currently regulated and what needs to be developed, as well as the challenges present regarding the process associated with a final repository for spent nuclear fuel. [13] You can read more about stepwise licensing and the process through to final sealing in Chapter 3 of this report.

### 9.1.4 Global perspective

As per the directive, the Swedish National Council for Nuclear Waste keeps track of other countries' programmes for final disposal in terms of the management of nuclear waste and spent nuclear fuel. The Council should also monitor and, where necessary, participate in the work of international organisations on the nuclear waste issue.

*International working groups and conferences*

The Council monitors and participates in a number of working groups/projects within OECD/NEA *(OECD Nuclear Energy Agency):*

*Advisory Bodies to Governments* (ABG) is a collaborative project between OECD/NEA, the Council, and its equivalent advisory organisations in the USA, UK, Switzerland, France and Germany. During summer 2018 the Council hosted a meeting in Stockholm, as part of which the participants also visited the final repository for low and intermediate level waste, SFR, in Forsmark. In summer 2019

[12]www.karnavfallsradet.se/en/workshop-information-and-memory-for-future-decision- (accessed 27 January 2020). For more information on the workshop, please see Chapter 7 of this report.

[13] www.karnavfallsradet.se/seminarium-om-en-stegvis-provning-och-ett-sekel-av-utmaningar (accessed 27 January 2020).

the Council participated in an ABG meeting in Braunschweig, Germany. In connection with the meeting, a study visit was arranged to an older final repository for low and intermediate level waste in Morsleben.

*The Forum on Stakeholder Confidence* (FSC) also operates under the OECD/NEA. The Council participated in the FSC meetings in Paris in autumn 2018 and autumn 2019. The other member countries include Germany, the USA, Canada, Russia, Italy, Japan, Switzerland, Spain, the UK, Belgium and Hungary. One point of discussion at both meetings was the difficulty of getting young people to engage in issues regarding the management of nuclear waste.[14]

One group operating under the OECD/NEA is *Information, Data and Knowledge Management* (IDKM) and this group held a meeting in Paris in 2019 in which the Council participated. The group's focus lies on topics such as long-term information management.[15]

In December 2019 the Council attended the OECD/NEA conference The nuclear and social science nexus: challenges and opportunities for speaking across the disciplinary divide in Paris.

The meeting ran for two days and attracted approximately 100 participants from the various OECD/NEA member countries. The meeting gathered social scientists and humanities researchers represented just as well as engineers and natural scientists. One key conclusion was that the management of nuclear waste and spent nuclear fuel are largely dependent on people's ideas of these kind of materials and that there may also be consequences for their management. For example, chemical waste such as mercury and dioxins, which must be protected from nature and culture for very long time frames, commands only a thousandth of the costs that come with nuclear waste, despite the fact chemical poisons, much like nuclear ones, cause harm in a way unperceivable to the human mind. The reason for this is that ideas people have of these different waste types are strikingly different, therefore requiring different kinds of safety measures. On this basis, current social sciences ideas on nuclear energy technology were discussed, with one of the objectives being to formulate practical recommendations.[16]

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[14] www.oecd-nea.org/rwm/fsc/ (accessed 27 January 2020).
[15] www.oecd-nea.org/rwm/workshops/2019/idkm/ (accessed 27 January 2020). For more on this, please see Chapter 7 of this report.
[16] www.oecd-nea.org/download/nssnexus/ (accessed 27 January 2020).

The Council has also participated in other international conferences, with some examples given below.

Representatives of the Council participated in the closing conference for *Modern2020.*[17]

In November 2019 the Council attended *the 7th International Workshop on Long-term Prediction of Corrosion Damage in Nuclear Waste Systems* (LTC 2019).[18]

### *Council study visits*

Some of the Council's lessons learnt from study visits and meetings in different countries were published in the report Overview of eight countries – status April 2019.[19] The information in this text is based largely on the countries' reports submitted to the seventh review meeting of the Joint Convention [20], held in spring 2018. The report includes links to different websites featuring the latest information. The countries described in the report are Sweden, Finland, Spain, France, the UK, Switzerland, Germany, and the Czech Republic.

### *Germany*

In October 2018 the Council undertook a study visit to Berlin to meet its equivalent ESK (Entsorgungskommission).[21] The Council also met with the supervisory authority BfE (Bundesamtes für kerntechnische Entsorgungssicherheit)[22] and BGE (Bundesgesellschaft für Endlagerung)[23] which are responsible for implementing the site

[17] The Development and Demonstration of Monitoring Strategies and Technologies for Geological Disposal: www.modern2020.eu/ (accessed 27 January 2020). Please also see Chapter 4 of this report.
[18] www.cefracor.org/fr/manifestations/7th-international-workshop-long-term-prediction-corrosion-damage-nuclear-waste (accessed 27 January 2020). Please also see Chapter 5 of this report.
[19] www.karnavfallsradet.se/rapport-20191-oversikt-av-atta-lander-status-april-2019 (accessed 27 January 2020) [English version: https://www.karnavfallsradet.se/sites/default/files/documents/report_2019_1.pdf].
[20] www.iaea.org/topics/nuclear-safety-conventions/joint-convention-safety-spent-fuel-management-and-safety-radioactive-waste (accessed 27 January 2020).
[21] www.entsorgungskommission.de/ (accessed 27 January 2020).
[22] www.bfe.bund.de/EN/ (accessed 27 January 2020). BfE has recently changed its name to BASE – Bundesamt für die Sicherheit der nuklearen Entsorgung.
[23] www.bge.de/en/ (accessed 27 January 2020).

selection process for spent nuclear fuel, high level waste and partially also intermediate level waste. BGE is also responsible for designing, constructing and operating planned and existing final repositories.

*Finland*

During October 2019 the Council undertook a study visit to Finland to meet with STUK (Säteilyturvakeskus/the Radiation and Nuclear Safety Authority)[24] and Posiva Oy[25] and to visit the final repository for spent nuclear fuel Posiva is currently building at Olkiluoto.

### 9.1.5 Study visits on decommissioning and dismantling

In accordance with the directive, the Swedish National Council for Nuclear Waste shall investigate and shed light on the management and final repositories for spent nuclear fuel and nuclear waste, and the decommissioning and dismantling of nuclear power plants.

During March 2018 the Council, along with representatives of the Ministry of the Environment, visited Ågesta Nuclear Plant outside Stockholm. Shortly after the visit, Vattenfall was granted permission by the Land and Environment Court at Nacka District Court to disassemble and decommission the Ågesta Nuclear Plant. In March 2019 the Council visited Greifswald, Germany and met with EWN (*Entsorgungswerk für Nuklearanlagen*), who shared information about their decommissioning project.[26] In Greifswald the Council also visited the Max Planck Institut to find out more about fusion research and technological developments of the fusion reactor Wendelstein 7-X.[27]

[24] www.stuk.fi/web/sv (accessed 27 January 2020).
[25] www.posiva.fi/en (accessed 27 January 2020).
[26] www.ewn-gmbh.de/unternehmen/?L=0&L=1 (accessed 27 January 2020).
[27] www.ipp.mpg.de/w7x (accessed 27 January 2020).

## 9.2 The nuclear waste field in Sweden in 2018–2019

*The licensing process for a final repository for spent nuclear fuel*

In March 2011 SKB submitted its applications for the final disposal of spent nuclear fuel to the Land and Environment Court and SSM. During autumn 2017, the Land and Environment Court held its main hearing in accordance with the Environmental Code (1998:808). In January 2018, the Land and Environment Court and SSM submitted their pronouncements to the Government. SSM supported SKB's application, whilst the Land and Environment Court stated that SKB needed to further revise the basis for the protective capacity of the copper canister. In its pronouncement, the court also criticised the lack of clarity on who is responsible for the facility after sealing.

In 2018 the Ministry of the Environment requested that SKB provide supplementation regarding issues such as the shortcomings criticised by the Land and Environment Court. On 4 April 2019 SKB supplemented its application and the supplementations were circulated for comment.

During December 2019 SKB received the responses to the documents circulated for comment.[28]

The municipalities concerned, Oskarshamn and Östhammar, have the right of veto under the Environmental Code. The government cannot grant permission for operations before the municipal council of the Municipality of Östhammar supports the application. The municipal council of Oskarshamn has already supported the application for the facilities planned in its municipality.[29]

During 2017 the government launched an investigation to carry out a review of the Act on Nuclear Activities. The task included proposing a regulation on ultimate responsibility after the sealing of a final repository. The Inquiry into a New Nuclear Technology Act submitted its report to the government in 2019.[30] The inquiry's suggestions include repealing the current Act on Nuclear Activities and replacing it with a new nuclear technology act with a new struc-

[28] Further information at: regeringen.se/remisser/ (accessed 27 January 2020).
[29] Municipality of Oskarshamn, Record No KS 2018/000521-1.
[30] Inquiry into a New Nuclear Technology Act. 2019. SOU 2019:16. Ny kärntekniklag – med förtydligat ansvar [A New Nuclear Technology Act – with clarified responsibilities].

ture. The inquiry also proposed provisions clarifying that the state is responsible for a geological final repository after sealing.

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

At the end of 2014 SKB submitted applications for the construction of SFR to the Land and Environment Court and to SSM. The supplementary information phase of the application took place from 2014 to 2017, when the applications were published/announced by both the Land and Environment Court and SSM.

SSM supported SKB's application for construction in June 2019. During autumn 2019, the Land and Environment Court held its main hearing and in November it also supported the application for the construction of SFR.

The government previously decided that permissibility for the planned enlargement would be licensed under Chapter 17 Section 3 of the Environmental Code, which entailed, among other elements, that the application would need to be supported by the municipal council of Östhammar before the government could grant permissibility.[31]

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Kärnavfallsrådets direktiv [Directive on the Swedish National Council for Nuclear Waste] 2018:18. Committee terms of reference. Supplementary terms of reference for the Swedish National Council for Nuclear Waste (M 1992:A).

[31] The Land and Environment Court at Nacka District Court, section 3. M7062-14, document appendix 47.

Inquiry into a New Nuclear Technology Act. 2019. SOU 2019:16. Ny kärntekniklag – med förtydligat ansvar [A New Nuclear Technology Act – with clarified responsibilities]. Stockholm: Norstedts Juridik.

The Land and Environment Court at Nacka District Court, Section 3. M7062-14, document appendix 47.

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www.karnavfallsradet.se/karnavfallsradets-synpunkter-pa-forslag-till-foreskrifter-om-kostnadsberakningar-ansokningar-och

www.karnavfallsradet.se/sites/default/files/documents/karnavfallsradets_yttrande_over_skb_s_kompletteringar_20190913.pdf.

www.karnavfallsradet.se/karnavfallsradets-remissvar-angaende-utredningen-ny-karntekniklag-med-fortydligat-ansvar-sou-201916.

www.karnavfallsradet.se/skrivelse-fran-karnavfallsradet-till-statsradet-for-miljo-och-energidepartementet-om-ideella

www.karnavfallsradet.se/seminarium-om-karnavfallsradets-kunskapslagesrapport-2018-beslut-under-osakerhet-sou-20188.

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www.stuk.fi/web/sv www.posiva.fi/en.

www.ewn-gmbh.de/unternehmen/?L=0&L=1 www.ipp.mpg.de/w7x. For more information, please see: regeringen.se/remisser/

# 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 instructtions 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)

# Committee terms of reference 2018:18

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

Decision at Government meeting of 01 March 2018

### Amendment of task and timeframe

The Swedish National Council for Nuclear Waste was established by a decision at a Government meeting on 27 May 1992 (dir. 1992:72) replaced by the supplementary terms of reference (2009:31).

From the beginning of 2018, the Swedish National Council for Nuclear Waste shall review the work of the previous years and submit a report on its independent assessment of the state of the art in the nuclear waste field every other year, instead of every year.

The task of the Swedish National Council for Nuclear Waste shall be time limited until the 31 December 2022. After this, the task may be extended by a maximum of five years at a time.

These terms of reference replace the terms of reference from 08 April 2009.

### Task

The Swedish National Council for Nuclear Waste shall investigate and shed light on matters relating to management of nuclear waste and decommissioning and dismantling of nuclear facilities. The Council shall 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 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 other year, starting in 2018, the Council shall submit a report on its independent assessment of the state of the art in the nuclear waste field over the last two years.

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.

The task of the Swedish National Council for Nuclear Waste shall continue until the 31 December 2022. After this, the task may be extended by a maximum of five years at a time.

## Organization

The Swedish National Council for Nuclear Waste shall consist of a chairperson and not more than ten other members (one of whom also acts as deputy chairperson). 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. Chairperson, members, experts, consultants, secretary and other assistants shall be appointed for a defined term.

(Ministry of the Environment and Energy)