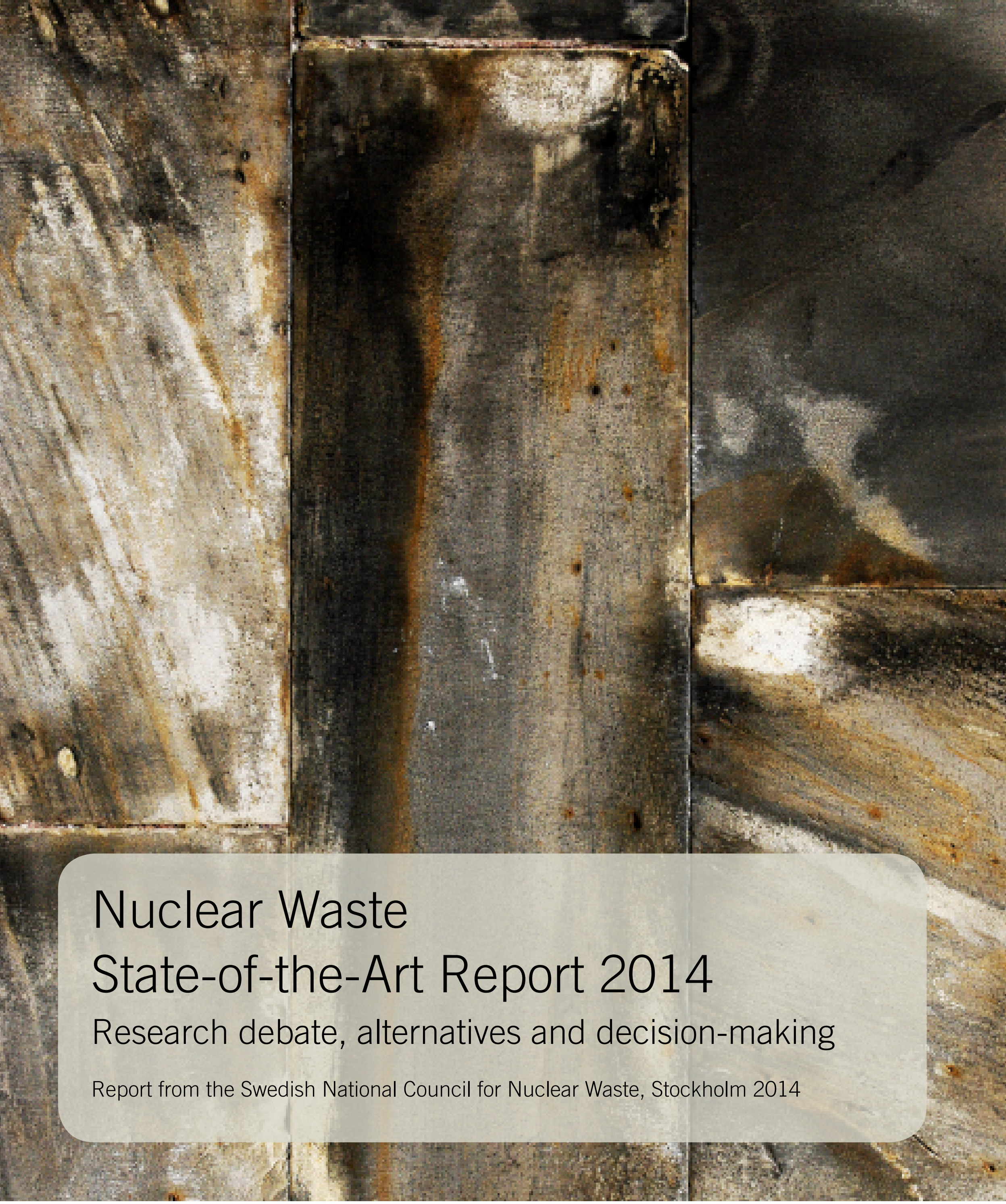


Nuclear Waste State-of-the-Art Report 2014

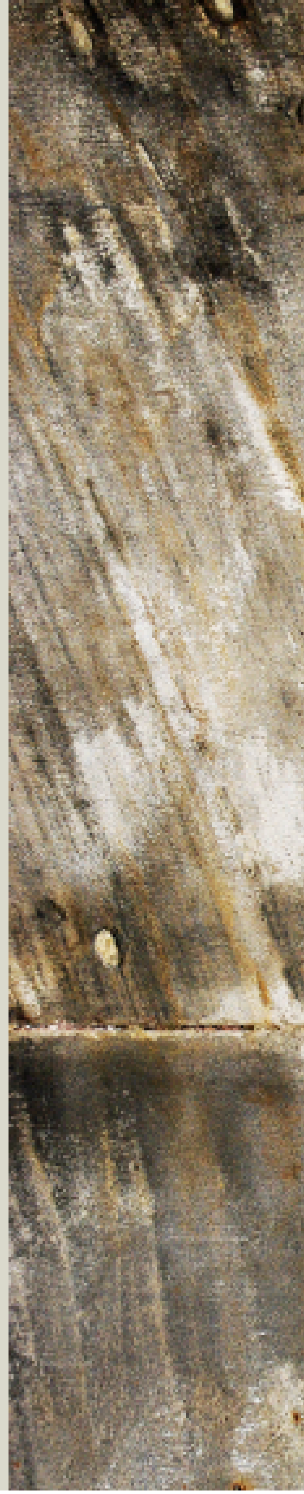
Research debate, alternatives and decision-making

Report from the Swedish National Council for Nuclear Waste, Stockholm 2014

KÄRNAVFALLSRÅDET
Swedish National Council for Nuclear Waste

SWEDISH GOVERNMENT INQUIRIES

SOU 2014:11



The Swedish National Council for Nuclear Waste is an independent scientific committee whose mission is to advise the Government on matters relating to nuclear waste and decommissioning of nuclear facilities.

In the report *Nuclear Waste State-of-the-Art Report 2014. Research debate, alternatives and decision-making* (SOU 2014:11), the Council reflects on scientific disagreement when it comes to the question of how spent nuclear fuel is to be managed. The report presents a survey of the state-of-the-art when it comes to a) the alternative method of deep boreholes for disposal of high-level nuclear waste, and b) the development of future reactor technology and the consequences of its introduction for future waste management.

The debate on the function of the bentonite and the copper as barriers in the proposed KBS-3 repository is described with reference to the research that was presented at the Council's international symposium on the engineered barriers in November 2013.

The importance of social science and humanistic research for the Swedish final repository project is discussed with reference to international research projects. The regulatory framework enabling the municipalities to influence decisions on the establishment of environmentally hazardous activities is described, along with the financing of future costs for the management and disposal of the residual products of nuclear activities.

The report can be downloaded at www.karnavfallsradet.se/en and can also be ordered by emailing to karnavfallsradet@gov.se.

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Translation of SOU 2014:11

The Swedish National Council for Nuclear Waste

Stockholm 2014

SWEDISH GOVERNMENT INQUIRIES

Swedish Government Official Reports

SOU 2014:11

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To the minister and head of the Ministry of the Environment

The Swedish National Council for Nuclear Waste is an independent scientific committee whose mission is to advise the Government on matters relating to nuclear waste and decommissioning of nuclear facilities.

In February each year, the Council publishes its independent assessment of the current state of the art in the nuclear waste field. The assessment is presented in the form of a state-of-the-art report.

The purpose of the report is to call attention to and describe issues which the Council considers important and to present the Council's viewpoints on these issues.

The Swedish National Council for Nuclear Waste hereby submits to the Government this year's state-of-the-art report (the fourteenth in this series) entitled "Nuclear Waste State-of-the-Art Report 2014. Research debate, alternatives and decision-making" (SOU 2014:11).

This report is endorsed by all members and experts in the Swedish National Council for Nuclear Waste. English versions of the reports on the state-of-the-art in the nuclear waste field for 1998, 2001, 2004, 2007, 2010, 2011, 2012 and 2013 are also available. The Council will publish an English translation of this year's report in the spring of 2014.

Stockholm, 14 February 2014

Carl Reinhold Bråkenhielm
Chairperson

Holmfridur Bjarnadottir
Administrative Director

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1 Introduction

A number of changes have taken place in the composition of the Swedish National Council for Nuclear Waste during 2013. In June 2013, the Government appointed Carl Reinhold Bråkenhielm chairperson to succeed Torsten Carlsson. Council member Karin Högdahl was in turn appointed Deputy Chairman. In the autumn, the Council got a new member, Sophie Grape, a researcher in nuclear physics at Uppsala University.

1.1 The work of the Swedish National Council for Nuclear Waste in 2013

The Council's work in 2013 has mainly been concerned with the ongoing review of the Swedish Nuclear Fuel and Waste Management Co's (SKB) application for a licence to build a final repository for spent nuclear fuel and nuclear waste. The Council submitted its viewpoints to the Land and Environment Court at Nacka District Court on 27 September with clarifications of previously submitted viewpoints on the need for supplementary information in the application: *Statement of opinion regarding the Swedish Nuclear Fuel and Waste Management Co's (SKB) response to the Swedish National Council for Nuclear Waste's requests for supplementary information in the application for a licence under the Environmental Code for facilities in an integrated system for final disposal of spent nuclear fuel and nuclear waste (M 1333-11)*. The viewpoints touch upon several of the issues to which the Council has previously called attention. The viewpoints concern in particular the application as a basis for decision-making, and the fact that the material submitted to the Swedish Radiation Safety Authority (SSM) as a part of the licensing under the Nuclear Activities Act is more extensive than the material which the Land

and Environment Court has received for licensing under the Environmental Code.

The Council has monitored relevant research in the nuclear waste field during the year and arranged an international scientific symposium in November 2013 on the function of the engineered barriers according to the KBS-3 method, i.e. the copper canisters and the bentonite clay. The symposium followed up the Council's 2009 seminar, which dealt with the question of whether copper can corrode in pure oxygen-free water.

During the year the Council has intensified its dialogue with the Riksdag's (the Swedish Parliament) party groups and committees regarding nuclear waste management, and this work will continue during 2014. The Council has also conducted a survey among the members of the Riksdag to find out how much they know about final disposal of radioactive waste and spent nuclear fuel. The purpose is to determine what information activities are needed. The results of this survey will be reported in the spring of 2014.

The international dialogue is an important part of the Council's activities. During the year the Council has exchanged information with organizations in other countries, visited the Nuclear Decommissioning Authority (NDA) in Harwell, England, and been represented by its members at various international conferences. The Council has also participated actively in the work of the OECD's Nuclear Energy Agency with nuclear waste management, above all in an expert group that works with matters relating to the intergenerational preservation of knowledge on nuclear waste (Preservation of Records, Knowledge and Memory, RK&M) and in the Forum on Stakeholder Confidence, chaired by the Council's administrative director.

1.2 Future work of the Swedish National Council for Nuclear Waste

In her annual meeting with the Council, the Environment Minister expressed her expectation and wish that the Council should continue to study and clarify nuclear waste issues for a broad target group including concerned government authorities, the nuclear power industry, selected municipalities, interest organizations, politicians and the mass media. The Ministry also considers it important that the Council monitor developments in the management of nuclear waste and spent fuel in other countries.

The management of nuclear waste and spent nuclear fuel requires political decisions at the national and municipal levels. The Government will make the final decision after SSM's review and the Land and Environment Court's ruling. Municipalities play a key role in the process and will have an opportunity to exercise their veto against a final repository and an encapsulation plant within their boundaries.

SKB's application deals with arcane and complex questions of a technical, sociological and ethical nature. Mastering the final disposal issue requires knowledge acquisition and a long-term commitment on the part of decision-makers. One of the Council's main tasks is to support national and local decision-makers in their task by elucidating issues that are considered important. In its future efforts, the Council will try to communicate more clearly with these decision-makers through seminars and other forms of regular contact.

1.3 The content of this year's state-of-the-art report

This year's state-of-the-art report reflects the Council's work during 2013. The following areas have been given particular attention:

1.3.1 Scientific controversies in the field of nuclear waste and alternatives

The report begins with a reflective chapter on the handling of scientific controversies in the field of nuclear waste. Here the Council discusses questions concerning the societal importance of scientific research, with examples of how scientific uncertainty and dissension in the field of nuclear waste have been handled.

Chapters 3 and 4 provide an update on previously debated issues concerning the status of research regarding two alternative methods for disposal of spent nuclear fuel: Deep Boreholes and reprocessing of spent nuclear fuel combined with the development of new reactor technologies.

Chapter 3, *State-of-the-art for Deep Boreholes*, reports the status of current research and development of the Deep Boreholes method.

Chapter 4, *State-of-the-art for future nuclear fuel cycles and Generation IV systems for Sweden*, refers back to the Council's 2012 seminar on the subject of recycling of spent nuclear fuel. The Council reflects on the potential promise and limitations of reprocessing and recycling of spent nuclear fuel and possible implications of the introduction of future nuclear power systems.

1.3.2 Remaining questions concerning the engineered barriers

Chapter 5 sheds light on the issue of the long-term safety of the KBS-3 repository. The chapter takes as its point of departure the new research findings presented at the Council's international symposium on engineered barriers on 20–21 November 2013 and the discussion that took place there among scientists and audience members. The focus was on how the interaction between the barriers is expected to work in a repository environment in both the short and long term. The long-term integrity of the copper canister is threatened by e.g. corrosion, creep (slow deformation of the metal) and hydrogen embrittlement due to absorption of hydrogen gas. Bentonite in the form of compacted blocks and pellets plays a key role in deposition holes and backfill. An impervious barrier is formed when the bentonite absorbs groundwater and swells. The most serious threats are erosion and changes in the bentonite due to temperature differences between the canister and the surrounding rock. The properties of both the copper canister and the bentonite were discussed, not least the ability of the bentonite to protect the copper canister under the varying environmental conditions that are expected to prevail during the life of the final repository.

1.3.3 International commitment to social science research

Chapter 6 provides an overview of completed, ongoing and planned research projects in the fields of the social sciences and the humanities related to the management of nuclear waste.

Extensive European research projects are being pursued in these fields today, including several interesting and goal-driven initiatives within EURATOM's Seventh Framework Programme for research, the OECD Nuclear Energy Agency and the European Commission.

The research projects financed by the European Commission's research programmes have been applied projects aimed at contributing to a solution of the waste problem by seeking a better understanding of different actors' roles and opportunities to participate in the decision-making process.

The NEA's work has involved an exchange of experience in committees and expert groups made up of participants from national authorities, organizations and the nuclear power industry, as well as researchers in the social sciences and humanities.

The ambition of the report is not to be all-encompassing, but to discuss and describe in brief terms the most important current international and European activities from a Swedish perspective.

1.3.4 Municipal decision-making on the nuclear waste issue

Chapter 7 describes the legal framework for the municipal veto in conjunction with the Government's licensing of environmentally hazardous activities. The chapter explains the rules for municipal influence in national physical planning from the late 1960s, provisions regarding the municipal veto of Government rulings in the Building Act, municipal influence under the Natural Resources Act, and provisions in the Environmental Code. Finally, the premises of the municipal veto are also discussed.

1.3.5 Financing of the residual products of nuclear power

The last chapter of the report (Chapter 8) deals with financing of the future costs for management and disposal of residual products from nuclear activities. The discussion has recently been brought to the fore in connection with the Swedish Radiation Safety Authority's overview of the financing system, which was carried out on behalf of the Government and submitted on 4 June 2013. The chapter describes the system for financing of decommissioning and waste management and presents a discussion of the grounds for and design of the financing.

2 Scientific controversies in the field of nuclear waste

Science is the foundation of today's society. Telecommunications, transportation, medicine and agriculture are just some examples of the areas of application of scientific knowledge. Scientific research drives technological development, and scientific experts are called to assist in commercial projects and government studies. In its 2012 Research Bill, the Swedish Government wrote: "Research of high quality contributes to the welfare of citizens, the development of society, the competitiveness of industry and sustainable development." Research-dependent social projects are stimulated and driven by new knowledge and discoveries, of which the Government Bill gives some interesting examples:

> Fleming's discovery of penicillin, Banting's and Best's discovery of insulin, the invention of the transistor, the interpretation of the Rosetta Stone, Niels Bohr's theory of how electrons revolve around an atomic nucleus in fixed orbits, and Arvid Carlsson's discoveries concerning neurotransmitters (which led to drugs for the treatment of Parkinson's disease) are examples of innovative research where scientists saw solutions where no one had seen them before. Ground-breaking research findings have transformed our lives and been of enormous importance for the development of society and industry.[1]

SKB's RD&D programme[2] offers examples of how less spectacular scientific discoveries and findings are guiding the design of a future final repository. One example is the Greenland Analogue Project (GAP), which will furnish new knowledge of how a thick ice sheet

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[1] Gov. Bill 2012/13:30. *Forskning och innovation*, p. 15.
[2] The RD&D programme is an account of the Swedish Nuclear Fuel and Waste Management Co's programme for research, development and demonstration of methods for the management and disposal of nuclear waste.

affects groundwater movements and hydrochemical conditions in a final repository during periods of glaciation.[3]

The importance of scientific research for the societal progress in general and for the final repository project in particular is readily apparent. At the same time, there are two factors in scientific research that have repeatedly created problems for the social and political application of scientific findings. These factors are scientific uncertainty concerning the results, and disagreement on how to interpret them, as exemplified by the debate on climate change. Scientific uncertainties and controversies also make it difficult for the general public to find its way in the discussion concerning the management of spent nuclear fuel.

One example is the discussion about the copper canisters that will contain the spent nuclear fuel, according to SKB's KBS-3 concept. In recent years, certain research results have indicated that copper corrodes in pure oxygen-free water, and the Swedish National Council for Nuclear Waste has addressed this issue in state-of-the-art reports and scientific seminars. A goal has been to contribute to a resolution of the scientific controversy that has dominated the debate in recent years. At the latest symposium, new findings were reported from various laboratory experiments (see Chapter 5 in this report). The ensuing discussion shows that the different parties interpret these results differently, depending on their previously adopted standpoints.

In this context it may be fruitful to compare the scientific controversy regarding copper corrosion with some other scientific controversies regarding the management of spent fuel. There is quite a bit of relevant research, and SKB's social science research programme (2004–2011) has contributed new knowledge in, for example, the area of decision processes and governance.[4,5] An example is the discussion of spent nuclear fuel as resource or waste, which is the topic of a report by Arne Kaijser and Per Högselius.[6] This discussion mainly concerns the risks and potential of nuclear power and thereby revisits issues that were at the centre of the Swedish political debate in the 1970s and '80s. Other social science

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[3] SKB (2013), RD&D programme 2013. Programme for research, development and demonstration of methods for the management and disposal of nuclear waste.
[4] SKB (2009), Samhällsforskningen 2004–2009 *Teman, resultat och reflektioner*.
[5] Söderberg, O. (2012), *SKB:s program för samhällsforskning 2004–2011. En utvärdering.* SKB P-12-14.
[6] Kaijser, A. och Högselius, P. (2007), *Resurs eller avfall? Politiska beslutsprocesser kring använt kärnbränsle.* SKB R-07-37.

research that touches on controversial issues in the natural sciences is presented in Mats Andrén's and Urban Strandberg's anthology entitled *Kärnavfallets politiska utmaningar* (2005)[7], exemplified by a chapter written by Evert Vedung[8].

A more personally formulated description of the dramatic meeting between nuclear power and politics can be found in KTH professor Karl-Erik Larsson's autobiography *Vetenskap i kärn-kraftens skugga* (2000)[9]. In his preface, he writes the following:

> During the five decades encompassed by the period 1950–2000, science, technology, politics and different worldviews have become entangled in the most controversial high-tech project to be undertaken since the Second World War: NUCLEAR POWER. My life has been sucked into the force field between pro-progress optimists and anti-progress pessimists. Like alpine peaks towering over a barren peneplain where wars of opinion are being waged, the summits of scientific research in physics look down upon us from their aeries of logic, creativity and imagination.[10]

This quote also suggests an important perspective in the current controversy concerning copper corrosion. Naturally, it is not possible in any simple way to divide advocates and adversaries of the KBS-3 method into pro-progress optimists and anti-progress pessimists. There is, however, good reason to be open to the possibility that non-scientific factors can influence and reinforce opposing scientific viewpoints.

In this context, we will briefly describe two other scientific controversies connected with the nuclear waste issue and compare them with the current controversy on copper corrosion. It is far from an exhaustive comparison and perhaps more of a rough draft for a multidisciplinary research programme on natural science in the shadow of nuclear waste. In conjunction with these two examples, we will discuss some more theoretical matters, but space does not permit a more comprehensive theoretical perspective on the complex interaction between science, technology, politics and different worldviews.

It should also be emphasized that the selection is somewhat arbitrary and that there are other controversies that could be singled out. An inroad into a broader discussion of developments

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[7] Andrén, M. och Strandberg, U. (eds.) (2005), *Kärnavfallets politiska utmaningar.*

[8] Vedung, E. (2005), "Det högaktiva avfallets väg till den rikspolitiska dagordningen" i Andrén, M. och Strandberg, U. (eds.)

[9] Larsson, K.-E. (2000), *Vetenskap i kärnkraftens skugga*

[10] Ibid.

in the USA is a recently published book by environmental scientists William and Rosemarie Alley entitled *Too Hot to Touch: The Problem of High-Level Nuclear Waste* (2013)[11]. The book also provides insight into the relationship between science and politics. There is a special reason why we will soon return to this book.

2.1 The controversy surrounding the Dry Rock Deposit (DRD) method

The first example has to do with the choice of disposal method, i.e. the question of how the spent nuclear fuel is to be safely managed. The Swedish National Council for Nuclear Waste has in different contexts explored alternatives to the KBS-3 method, for example Deep Boreholes, which involves emplacing the nuclear fuel in boreholes 3–5 kilometres beneath the ground surface.[12,13] The Deep Boreholes alternative has been advocated by e.g. the Swedish NGO Office for Nuclear Waste Review (MKG).

The Council examined this alternative at a special seminar and followed up this seminar with a study by Professor Karl-Inge Åhäll[14]. The most recent developments are dealt with in a special contribution to this report (see Chapter 3). In recent years, the Council has also drawn attention to another alternative: reprocessing and reuse of spent nuclear fuel in new reactors. A special seminar was arranged in the autumn of 2012, and the alternative is the subject of further attention in the state-of-the-art report for 2013[15] and in the present report (see Chapter 5).

In addition to Deep Boreholes and reuse of spent nuclear fuel in new reactors, there is also another and less well-known scientific controversy concerning the DRD method. *DRD* is an abbreviation of Dry Rock Deposit and involves building a dry repository near the ground surface. In a case file appendix to the Land and Environment Court at Nacka District Court (281 in file M 133-

[11] Alley, W. and Alley, R. (2013), *Too Hot to Touch: the Problem of High-Level Nuclear Waste.*
[12] Swedish National Council for Nuclear Waste *Deep boreholes – An alternative for final disposal of spent nuclear fuel?* Report 2007:6e.
[13] SOU 2007:38 *Nuclear Waste State-of-the-Art Report 2007 – responsibility of current generation, freedom of future generations.* Swedish National Council for Nuclear Waste.
[14] Åhäll, K.-I. (2011), *Deponeringsdjupets betydelse vid slutförvaring av högaktivt kärnavfall i berggrunden, en karakterisering av grunda och djupa slutförvar.*
[15] SOU 2013:11, *Nuclear Waste State-of-the-Art Report 2013. Final repository application under review: supplementary information and alternative futures*. Swedish National Council for Nuclear Waste.

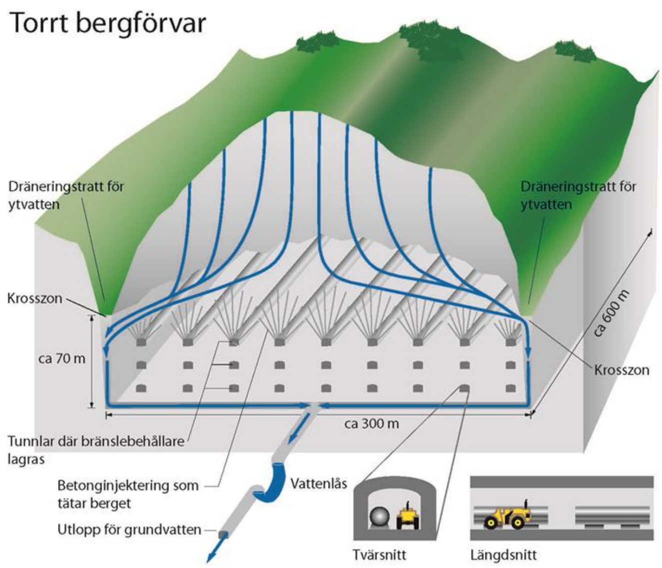
11)[16], the method is described as follows by associate professor Nils-Axel Mörner (former head of the paleogeophysics and geodynamics department at Stockholm University):

> A DRD repository is a dry repository above the groundwater table. The rock is drained through artificial crushed zones. The repository is located in an area with high relief (preferably far from the coast). The access tunnel is closed effectively, but the waste remains accessible and monitorable (including by continuous recording of parameters such as radiation and corrosion).[17]

As is evident from Milka's statement of opinion to the Land and Environment Court (case file appendix 143)[18], the DRD method is an accessible and monitorable alternative to the KBS-3 method. The method is thoroughly described by Nils-Axel Mörner. Some of its main features are illustrated in the figure show:

[16] Land and Environment Court, M1333-11. Case file appendix 281, Mörner, N.-A., *Dry Rock Deposit*.
[17] Mörner, N.-A. (2003), *Paleoseismicity of Sweden: A Novel Paradigm*, p. 10.
[18] Land and Environment Court at Nacka District Court, M1333-11. Case file appendix 143. *Milkas yttrande om SKB AB:s ansökan om tillstånd enligt miljöbalken och kärntekniklagen till anläggningar i ett sammanhängande system för slutförvaring av använt kärnbränsle och kärnavfall.*

Figure 2-1 The DRD method



Source: Case file appendix 281. Dry Rock Deposit. A later design proposal. Revised by Jonas Nilsson, Miljöinformation AB.

It should be noted that the DRD method as described in case file appendix 281 can be designed in different ways: either as a so-called no action alternative, a new interim storage facility, a long-term storage facility until the next ice age, or as a final repository. Similar methods in the USA (e.g. negotiated, monitored, retrievable storage facilities, NMRS) are intended to serve as interim storage facilities for about 100 years. [19,20] This also applies to dry cask storage facilities, which are already in use in the USA.

According to Mörner's statement of opinion to the Land and Environment Court (case file appendix 281), the KBS-3 method is unacceptable for above all three reasons. In the first place, the copper canisters will corrode; in the second place, there is a risk of methane gas explosions after the next ice age; and in the third place, there is a high probability that a KBS-3 repository will be

[19] Schrader-Frechette, K. (1993), *Burying Uncertainty. Risk and the Case against Geological Disposal of Nuclear Waste*. Berkeley.
[20] Alley, W. and Alley, R. (2013), Chap. 8, Chap. 9.

damaged by future earthquakes. The risks of methane gas explosions and earthquakes are more thoroughly clarified in case file appendices 143 and 282[21], but were also explained in 2003 in Nils-Axel Mörner's monograph *Paleoseismicity in Sweden – a Novel Paradigm*[22]. Evidence is offered there purporting to show that the Swedish crystalline basement has been subjected to methane gas explosions, the last of which is said to have occurred about 2,000 years ago, giving rise to a 20 metre tsunami wave. Under high pressure and low temperature, the methane in the rock is transformed into methane ice, and this methane ice is transformed explosively to gaseous form when the temperature rises again after the ice age.

We will first deal with SKB's objections to the DRD method and then SKB's comments on Mörner's criticism of the KBS-3 method. SKB dealt with the DRD alternative (as a long-term storage facility) in a supplement to RD&D programme 1998 (2000)[23]. There the method is described and rejected in the following manner:

> In the DRD concept, containers with fuel are placed in a self-draining rock cavern built in a rock formation that projects up above a surrounding depression ... After deposition the rock cavern is closed. No drainage pumping or cooling is required. The idea is to minimize the need for maintenance and monitoring so that storage can take place for a long time.
>
> The uncertainties that are associated with the dry storage systems in operation today also apply to DRD. High temperatures and the presence of oxygen make it difficult to demonstrate that the containers will remain intact for thousands of years.[24]

The DRD concept is also dealt with in SKB's application for a final repository according to the Nuclear Activities Act in Appendix CM. The difference from the judgement in RD&D-K 2000 is that the fuel canisters are assumed to be designed so that they remain unaffected during the storage period. SKB also judges that the DRD method (if it works as intended) will be the least resource-demanding variant of monitored storage, but that some kind of

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[21] Land and Environment Court at Nacka District Court, M1333-11. Case file appendix 282. Mörner, N.-A., *Collapse of the Methodology applied in Sweden and Finland for the Deposition of High-level Nuclear Waste*.
[22] Mörner, N.-A. (2003).
[23] SKB (2000), *Integrated account of method, site selection and programme prior to the site investigation phase,* [RD&D-K], p. 55.
[24] Ibid., p. 55.

monitoring will nevertheless be needed (to prevent illicit trafficking in the spent fuel), as well as some maintenance. For this reason, the method is rejected.

> Long-term dry and wet storage require continuous inspection and maintenance. The DRD concept also requires monitoring and some form of maintenance. This means that none of the methods satisfies the requirement of the Nuclear Activities Act on final disposal of spent nuclear fuel, viz. that the final repository should provide the requisite safety without monitoring and maintenance.[25]

This SKB argument against the DRD method is tenable provided that the Nuclear Activities Act truly only approves a final disposal method that does not require monitoring and maintenance and if the DRD method truly requires monitoring and maintenance in the sense intended by the law. This is a legal question that should not be particularly difficult to decide. In other words, there should be good prospects for settling this part of the controversy.

The scientific controversy surrounding the DRD method primarily concerns the cited arguments against the KBS-3 method, i.e. the risk of postglacial methane explosions and earthquakes during the long time period (at least 100,000 years) that is required to protect human beings and other biological life forms from the spent nuclear fuel's ionizing radiation. The risk of earthquakes is dealt with thoroughly in SKB's application under the Nuclear Activities Act.[26] It is evident there that SKB, citing different research results, in no way disputes that extensive postglacial earthquakes may occur.[27]

> [T]he induced instability following the disappearance of the stabilising ice cover is likely to have triggered release of tectonic strain energy accumulated over periods of time much longer than one glacial cycle. This would mean that the large postglacial earthquakes were powered mainly by tectonic stresses, but triggered by endglacial instability. There is also agreement that the fault displacements took place as a reactivation of existing fracture zones rather than new fracturing.[28]

[25] SKB (2011), *Ansökan om tillstånd enligt lagen (1984:3) om kärnteknisk verksamhet till uppförande, innehav och drift av en kärnteknisk anläggning för slutförvaring av använt kärnbränsle och kärnavfall, bilaga MV*, p. 56.
[26] SKB (2010), *Geosphere process report for the safety assessment SR-Site*, TR-10-48, p. 87.
[27] Lagerbäck, R. et al. (2005), *Forsmark site investigation. Searching for evidence of late- or postglacial faulting in the Forsmark region. Results from 2002-2004.* SKB. R-05-51.
[28] SKB (2010), *Geosphere process report for the safety assessment SR-Site,* TR-10-48, p. 88.

The question that is particularly relevant to the final repository's safety is whether new rock fractures can be expected as a result of seismic activity in the final repository or its immediate vicinity. According to SKB, this does not appear to be the case. This would mean that the case file appendix's most persuasive argument against the KBS-3 method would be disqualified. The second argument – the risk of postglacial methane explosions – is not dealt with in SKB's application. Clarity on this issue could help to settle the scientific controversy.

In summary, it can be concluded that this controversy is about at least two different things. Firstly, it is about how to interpret the Nuclear Activities Act and the alleged requirement that the final repository must be safe without requiring inspection and maintenance. It should be pointed out that there is no such requirement in the Nuclear Activities Act. However, there is a section in the Swedish Radiation Safety Authority's regulations stating that: "Safety after the closure of a repository shall be maintained through a system of passive barriers".[29] This can be interpreted as a requirement that the barriers must not require monitoring and maintenance, but this requires a more convincing argument. The advocates of a DRD repository (as a final repository) could assert that it can be designed so that it utilizes passive safety functions wherever possible[30] and furthermore add that it makes monitoring and inspection more easily possible than a KBS-3 repository.

Secondly, the controversy raises certain empirical geological questions concerning the occurrence of postglacial methane explosions and earthquakes. The first question is of a legal nature and should be able to be decided by an analysis of the Nuclear Activities Act and its travaux preparatoires (legislative history). The second question is of an empirical-scientific nature: Can reliable evidence be found of postglacial methane gas explosions of the kind described by Nils-Axel Mörner? And if so, what importance do such seismic events have for the planned final repository in Forsmark and its long-term safety?

The title of Mörner's monograph – *Paleoseismicity in Sweden - a Novel Paradigm* (2003) – is a reference to Thomas Kuhn and his paradigm theory[31], and this theory could be used as a key to

[29] SSMFS 2008:21. Section 2.
[30] SSMFS 2008:1, Chap. 4, Section 2.
[31] Kuhn, T. (1962) 1973, *The Structure of Scientific Revolutions*.

settling the conflict. In brief, the theory entails that Kuhn distinguishes between normal science and extraordinary science. Normal science is paradigm-driven, i.e. governed by a certain basic theoretical construct that is assumed by scientists as common ground. This common ground is interwoven with social and economic conditions. Eventually anomalies are discovered, i.e. observations that cannot be accommodated within the traditional paradigm. When the weight of these anomalies becomes too great and alternative explanations are put forth, a scientific revolution occurs. The traditional theory is abandoned in favour of a new paradigm. An example is the switch from a geocentric to a heliocentric view of the solar system. In relation to the old paradigm, new extraordinary science emerges and eventually becomes the new normal science.

Kuhn's theory was developed primarily to interpret dramatic scientific paradigm changes, but it has also been suggested to explain less spectacular changes. An example is offered by Barbara McClintock, who was awarded the Nobel Prize in physiology and medicine in 1983. She contributed to a new view of the interaction between a gene and its surroundings, which initially met with resistance in the scientific community, but which subsequently achieved a broad breakthrough.

Another example of such extraordinary science could be the basic hypothesis in Mörner's 2003 monograph, namely that Sweden – in contrast to the conventional view – is a high-seismic region and "that there were probably more and bigger earthquakes here than in any other region on Earth today". The theory of Sweden as a high-seismic region could integrate anomalies such as methane gas explosions, which cannot be accommodated in the traditional geological paradigm.

Now, it is not at all certain that the conflict around the theory of Sweden as a high-seismic region should be interpreted as a conflict between normal geological science and extraordinary geological science. An alternative is to interpret it as a conflict within normal geological science. The controversy does not concern the basic assumptions of geological science, but rather other issues. What could this be?

It is possible to distinguish between three different levels of inquiry in empirical science. The first level pertains to the design of the empirical investigation, e.g. the choice of instruments or apparatus and chemical analysis methods. The second level pertains to the measurement results. The third level pertains to the interpretation and explanation of the results. Against this background, it is possible to distinguish between three different kinds of scientific disagreement: a) disagreement about the experimental design, b) disagreement about the measurement results, and c) disagreement about how to interpret or explain the results. The question is then whether the controversy concerning the theory of Sweden as a high-seismic region stems from disagreement on a), b) and/or c). Does the controversy hark back to differences of opinion regarding the design of relevant geological investigations? Or does it spring from conflicting measurement results and whether the geological facts presented in support of the theory of Sweden as a high-seismic region are in fact true? A third possibility is that the disagreement has to do with the theory itself, so that the geological facts can be explained in by some other means than by the theory of Sweden as a high-seismic region. To put it simply: Are the results truly anomalies in the system, or can they be explained within the framework of normal geological science?

2.2 The controversy surrounding chlorine-36 in Yucca Mountain

The American final repository programme is currently on hold, but Yucca Mountain in the state of Nevada had previously been selected as the site for a final repository. There were considered to be good technical reasons for this site, not least that it is located in a dry region, the Nevada desert, far from population centres and from water. The absence of water was an important reason for choosing the site, since water can carry radionuclides from a repository deep down in the rock out to the biosphere. Geological studies of water-bearing rock were therefore given high priority. In the USA, the federal government and the Department of Energy (DOE) bear ultimate responsibility for nuclear waste disposal. In 1966, the DOE finished excavating a research tunnel in Yucca Mountain and a group of scientists from Los Alamos began studying the water flows in the rock. They found numerous fractures in the tunnel roof and elevated levels of chlorine-36.

This was very unexpected, since chlorine-36 is an isotope with a half-life of about 300,000 years.[32] It exists naturally, but only in very small quantities. Larger quantities are a by-product of nuclear weapons testing and are a part of the “bomb pulse” from the detonations some 50 years ago. The bomb pulse gave rise to elevated levels of chlorine-36 all over the world. The presence of elevated levels of chlorine-36 deep down in Yucca Mountain was thus a sign that water had travelled from the surface down to the test tunnel in less than 50 years! The scientists explained this by pointing out that water flows slowly through pores, but much faster through fractures. In other words, Yucca Mountain was wetter than had been thought, making it a less suitable site for a final repository than had previously been assumed.

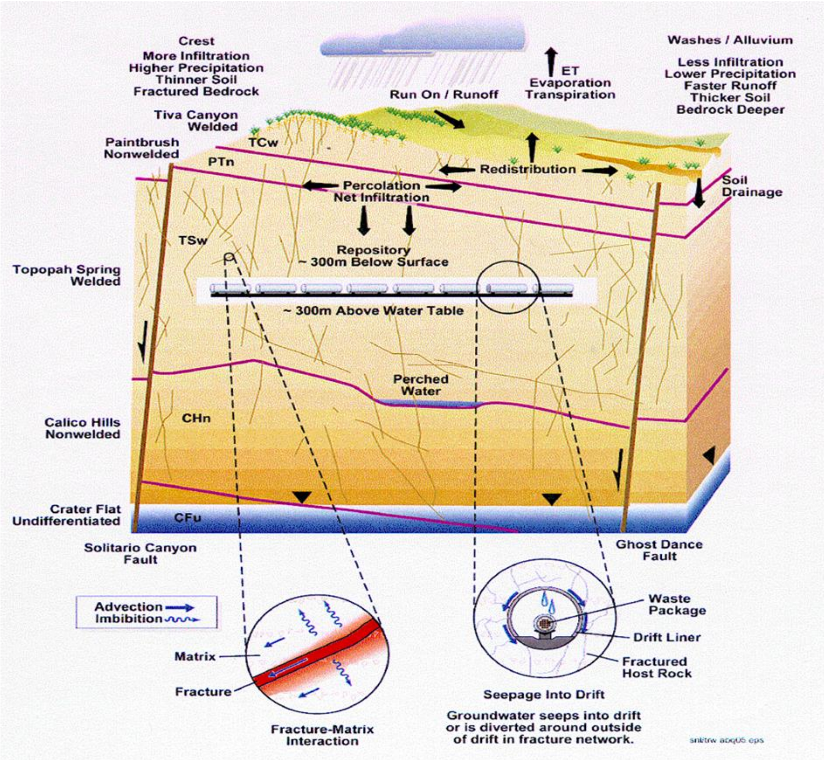
What has to be considered is that there are a number of different factors that complicate the sampling for chlorine-36. In the first place, the tests are not standardized, and in the second place they are based on mass spectrometry. This is a powerful technique, but it has to find one chlorine-36 isotope among a trillion ordinary chlorine atoms. There is a risk of contamination and other types of measurement error.

The DOE was troubled by the results of the Los Alamos study and commissioned another laboratory (Lawrence Livermore National Laboratory outside San Francisco) to conduct a new investigation. Using a different method, they found no traces of chlorine-36 from the test tunnel in Yucca Mountain. Due to the contradictory results, the scientists from Los Alamos and Livermore were brought together for a third study. They arrived at a methodological consensus, divided up the samples and analyzed them in their respective laboratories. The results were the same: the Los Alamos group found chlorine-36 from the bomb pulse, while the group from Livermore failed to find any. In an attempt to break the deadlock, the DOE ordered a fourth study from an independent group of scientists at the University of Las Vegas. They found chlorine-36 in some of the samples, but the results were not considered reliable due to the fact that they were obtained in a laboratory that did not meet purity standards.

[32] SOU 2004:67 Nuclear Waste State-of-the-Art Report 2004 – Section II Handling the Risks of Nuclear Waste. An Overview of Methods, Problems and Possibilities. Swedish National Council for Nuclear Waste.

In summary, four studies using four different methods have proved adequate to the task. The question of whether chlorine-36 is present in Yucca Mountain remains unanswered.

Figure 2-2 General description of the geological conditions in Yucca Mountain



Source: Grischa Metlay and Daniel Metlay.

So much for the scientific process. Interwoven with the scientific process there is a legal process, which, while interesting, does not really shed any light on the scientific controversy. In any event, the DOE – despite objections from the Nuclear Waste Technical Review Board (NWTRB, the USA's equivalent of the Swedish National Council for Nuclear Waste) – decided not to conduct any more studies and to leave the question of chlorine-36 unresolved.

Without closer study of the details in the question of chlorine-36 it is of course impossible to say anything about the nature and causes of the scientific controversy with any certainty. But there is a theoretical perspective on how experimental studies are embedded in their social context known as the "experimenter's regress". This way of interpreting scientific controversies of a certain type harks back to arguments first put forward in antiquity and discussed by the skeptical philosopher Sextos Empiricos (c. 200 AD). The idea was revived during the 16th and 17th centuries and can be interpreted in different ways, but is perhaps best described as a research psychology hypothesis, namely that what an experimenter regards as valid and credible results are results that have been obtained with the aid of a accurate and reliable instrument. But how does the experimenter determine whether his instrument is accurate and reliable? The answer is: by knowing that the instrument gives valid and credible results! In other words, the individual experimenter is caught in a feedback loop of circular reasoning.[33] Or to take an example from the case in question: The Los Alamos laboratory claims it has detected the presence of chlorine-36. On what grounds? The results were detected by accurate and reliable instruments. But how do we know the instruments are accurate and reliable? Because the results are valid and credible.

According to Harry Collins, the experimenter's regress can only be broken by a social negotiation in interaction with the surrounding research environment. In view of the social forces and economic conditions that are at work in a research environment, this leads to serious objections to the scientific rationality of the work.[34]

Can the experimenter's regress be used to interpret the controversy concerning the presence or absence of chlorine-36 in Yucca Mountain? An answer to this question would require deeper insight into the research environments where the conflicting studies were conducted. Furthermore, it would also probably require a broadening of Collins' theory with reference to other factors that are not based on a radical dichotomy between social conventions and objective science. Interpretation of scientific data takes place in an interplay between the researcher and the social the environment, but it does not entail that requirements on reproducibility (replication of the experiment by other scientists) and

[33] Collins, Harry (1985) 1992. *Changing Order. Replication and Induction in Scientific Practice*, p. 84.
[34] Franklin, Allan (1994), "How to avoid the experimenters' regress", *Studies in History and Philosophy of Science* 25, p. 465.

compatibility with previous research and ultimately with the current scientific worldview are reduced entirely to a question of social and political correctness.[35,36]

With these reservations, the theory of the experimenter's regress could be a fruitful and interesting working hypothesis for interpreting the controversy concerning chlorine-36 in Yucca Mountain. The question is then how to describe the interplay between the experimental and social processes in the different research environments – and how the subsequent processing of the different research groups' results was formulated in a dialogue with the laboratories' management bodies, scientific journals and the funders of the project.

2.3 Application to the Swedish controversy concerning copper corrosion

Superficially, the recent controversy about copper corrosion resembles the unresolved question of chlorine-36 in Yucca Mountain. Different research groups use different methods and arrive at different results regarding whether copper really corrodes in oxygen-free water or not. In Chapter 5 of this report, the Swedish National Council for Nuclear Waste observes that it has not so far been possible to set up a reliable material balance, which is necessary in order to determine whether copper really corrodes in oxygen-free water and that the reaction is not just limited to the surface. The Council further states that "disagreement on copper corrosion in oxygen-free water must not degenerate into an attempt to demonstrate possible errors in experimental design and apparatus when the results do not agree with the experimenter's own opinion".

This is a reference the theory of the experimenter's regress. The results have been deemed to be reliable based on the conviction that the instruments used have performed as they should. According to the theory, a circular argument arises if the experimenter's conviction regarding the performance of the instruments is verified by reference to the results that are generated. It is

[35] Hesse, M. (1986),"Changing concepts and stable order", *Social Studies of Science* 16, pp. 714-726.
[36] Godin, B. och Gingras, Y. (Godin, B. och Gingras, Y. (2002),"The experimenters' regress: from skepticism to Argumentation", *Studies in History and Philosophy of Science* 33, pp. 137–152.

difficult to say whether this has been the case in the various laboratory experiments cited at the Council's symposium in November 2013[37]. However, other laboratories' experimental designs or apparatus have been questioned with reference to the fact that they have not generated the "right" results. This is a variant of the very phenomenon that has been described in the theory of the experimenter's regress. Criticism and counter-criticism are the life-blood of science, but it is important that they be based on objective criteria and not on the assumption that one's own results are the only reliable ones. The first rule of what could be called the scientific spirit is to be skeptical and self-critical: Always be prepared to question both the basic assumptions of your thinking and the results of your research. Always consider the possibility that your hypothesis is wrong; observing this rule is the first step out of the experimenter's regress.[38]

The first case had to do with the scientific controversy concerning the DRD method. This controversy exemplifies Thomas Kuhn's theory of paradigm-driven science and the tension-filled relationship between normal science and extraordinary science. One possibility is that the theory that Sweden is a high-seismic region is just such extraordinary science which could accommodate anomalies that cannot be accommodated in normal geological science. But there is another possibility: that the controversy is actually a conflict within normal geological science. The controversy concerning the theory of Sweden as a high-seismic region could be interpreted as a) disagreement on the experimental design, b) disagreement on the measurement results, and/or c) disagreement on the interpretation or explanation of the results. The question is then whether the controversy boils down to disagreement about a), b) and/or c). Could this shed some light on the scientific controversy about whether copper corrodes in pure oxygen-free water or not?

There is much to say for the idea that the controversy can to some extent be interpreted as a difference of opinion on the experimental design. This has to do with the choice of materials in reaction vessels and seals, tubes, couplings and membranes, as well as the purity and pre-treatment of the copper. It also has to do

[37] Swedish National Council for Nuclear Waste's symposium: *New insights into the repository's engineered barriers*, Stockholm, 20-21 Nov. 2013. Material can be downloaded at www.karnavfallsradet.se.
[38] Jeffner, A. (1995), *Religionen och vetenskapens anda*, i Bergmann, S. et al., p. 176.

with discussions concerning the execution of the experiments, including different analysis methods with respect to the metal surface and the solution, and how to protect the copper coupons from being oxidized in air when they are removed from the reaction vessel for analysis. At the same the discussion also has to do with the actual measurement results. This includes, for example, the scope of hydrogen gas evolution, which is much higher in some experiments than in others without evidence being found of corresponding changes on the surface of the metallic copper.

Finally, the controversy seems to above all be about how to interpret the results. Can the established thermodynamic equations used in normal chemical science be used to interpret what is happening? Or are we faced with something heretofore unknown that needs to be integrated in our otherwise extensive knowledge of the properties of copper in an aqueous environment? Naturally, scientists must be open to the possibility of new scientific findings, but more evidence is required than has so far been demonstrated. An unexpectedly high hydrogen gas evolution is an interesting result from one carefully executed experiment, but is not in itself proof that copper corrodes in pure oxygen-free water.

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Land and Environment Court at Nacka District Court, M1333-11, case file appendix 281. Mörner, N.-A., *Dry Rock Deposit.*

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3 State-of-the-art for Deep Boreholes

3.1 Introduction

Geological repositories for high-level nuclear waste can be designed in different ways, for example deposition in boreholes several kilometres deep. The method was proposed back in the 1970s and has been discussed ever since as a possible alternative to shallower geological repositories, e.g. the KBS-3 method.

3.2 Advantages and disadvantages of nuclear waste disposal in deep boreholes

The emplacement depth for the Deep Boreholes concept is 3–5 km below the ground surface in what is known as crystalline basement rocks, which consists above all of granite and different types of gneiss.

There are several advantages with a geological repository in Deep Boreholes.[1] The permeability of the bedrock at these depths is very low and the groundwater has higher salinity and thereby density, which means that its ability to transport radionuclides to the ground surface is greatly impaired. Nor is there much free oxygen, which can otherwise lead to oxidation of the waste canisters. The lack of oxygen also means that the solubility and thereby the mobility of e.g. actinides is reduced.

Since the geological conditions are such that the mobility of radionuclides is very low, any actinides that may escape from damaged canisters remain in the near-field for as long as it takes for the radiation to decay to normal background levels (1 million years).

[1] Åhäll, K.-I. (2011), *Deponeringsdjupets betydelse vid slutförvar av högaktivt kärnavfall i berggrunden – en karakterisering av grunda och djupa förvar*.

Moreover, the repository itself is smaller and the construction time considerably shorter than for repositories built according to the KBS-3 method. Approximately 45 deposition holes would be required for Sweden's nuclear waste, which would occupy a surface area of about 2–4 km^2.[2]

The method is not fully developed, however. In-depth rock mechanical investigations are required to evaluate whether any problems might arise with e.g. drilling and lining of the deep boreholes and emplacement of the waste.[3] Furthermore, our knowledge of the geological conditions at a depth of 3–5 kilometres in Swedish bedrock is insufficient, and it is unclear how the risks associated with the deposition process will be managed.

3.3 European deep drilling projects

Of the 12 European deep drilling projects begun in the 21st century, only four have been carried out in crystalline bedrock: in Outokumpu, Lund, Soultz-sous-Fôrets and Basel. The deep borehole in Outokumpu was drilled for research purposes, while the drilling projects in Lund, Soultz-sous-Fôrets and Basel were done either to extract geothermal energy or to investigate the potential of this resource. Of these projects, only the deep borehole in Outokumpu (2,500 metres) is drilled in bedrock that is relevant for Swedish conditions.[4] But the diameter of the borehole there was only 216 mm, which is much less than is required for boreholes for a final repository for spent nuclear fuel (430–445 mm). In other words, no full-scale boreholes have been drilled that fully correspond to those in a deep repository of this type. Nevertheless, a great deal of information on conditions at great depths has been obtained.

Results from the deep drilling projects found that there are far fewer fractures at greater depths, but that the number of fractures is also dependent on the composition (lithology) of the bedrock.[5,6]

[2] Åhäll, K.-I. (2011).
[3] Odén, A. (2013), *Förutsättningar för borrning av och deponering i djupa borrhål.* Report SKB P-13-08, pp. 1–76. Svensk Kärnbränslehantering AB, Stockholm.
[4] Marsci, N. & Grundfelt, B (2013), *Review of geoscientific data of relevance to disposal of spent nuclear fuel in deep boreholes in crystalline rocks.* Report SKB P-13-12, pp. 1–30, Svensk Kärnbränslehantering AB, Stockholm.
[5] Juhlin, C. and Sandstedt, H. (1989), *Storage of nuclear waste in very deep boreholes; Feasibility study and assessment of economic potential*. Report SKB TR-89-39, pp. 1–92 + Appendix.

For a final repository, it is important that the rock has few fractures at the emplacement depth, since fractures can conduct water and thereby facilitate the movement of radionuclides. Salt-water-bearing fractures have been found at very great depths (c. 2,200 metres) in the deep borehole at Outokumpu (2,500 m), but this water is not in hydrological contact with water-bearing fractures at shallower levels.[7] Colonies of microorganisms were found in all water-bearing fractures, even in the deepest parts of the borehole. The size of the populations decreases with the depth, but they sometimes include bacteria that reduce sulphate to sulphide[8], which can have an adverse effect on buffer and canister.[9]

3.4 Drilling of deep boreholes

One problem that has been noted in the drilling of deep boreholes is that rock fragments break out from the borehole walls. The risk of these so-called “breakouts” is greatest during the drilling process before the holes have been lined (cased). Moreover, in large-diameter boreholes, breakouts linked to planar structures in the rock (structure-controlled breakouts) can occur already at shallow levels.[10] The breakouts can cause jamming of the drill, breakage of the drill rod and problems with the lining.[11] If the hole collapses during the drilling process, this can be fixed fairly easily. During the drilling of the approximately 6,000 m deep borehole Gravberg-1 in Siljan, severe breakouts that occurred at about 400 m were stabilized by filling the hole in the collapsed section with cement.[12] The question is whether this is a suitable solution in deep boreholes intended for nuclear waste.

Another problem that can arise is deformation of the boreholes. The risk is insignificant at a depth of 5,000 metres in fracture-poor rock, since deformation there is primarily elastic. The borehole simply resumes its original form. But if the rock is fractured at

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[6] Ekman, L. (2001), *Project Deep Drilling KLX02 – Phase 2. Methods, scope of activities and results. Summary report.* Report SKB TR-01-11, pp. 1–181 + Appendix.
[7] Marsci, N. och Grundfelt, B. (2013).
[8] Ibid.
[9] SOU 2010:6 *Swedish National Council for Nuclear Waste, Nuclear Waste State-of-the-Art Report 2010 – challenges for the final repository programme*, Swedish National Council for Nuclear Waste, Stockholm: Fritzes (2010).
[10] Odén, A. (2013).
[11] Ibid.
[12] Ibid.

these depths, the borehole can also be deformed permanently (plastically), causing deviations of up to 3–4 mm. Moreover, very slow shear movements (creep) can occur along microfractures. Creep deformation and structure-controlled collapse can occur at all depths in highly fractured rock, and if the lining is damaged this can lead to problems after drilling as well.[13]

The risk of borehole deviation (i.e. that the borehole is increasingly diverted laterally with increasing depth) is considered to be very small. The use of guided drilling to prevent deviation has been developed considerably during the last two decades. The guiding method that was developed in the 1990s for the 9,000 metre deep KBT hole in Germany worked well down to levels corresponding to the depth of a nuclear waste repository. The KBT hole is straight and vertical down to about 5,000 m, but the diameter of the borehole down to this level is only 375 mm at its maximum.

3.5 Computer simulations

Even though no full-scale in-situ tests have been done, the deep boreholes method has been tested by various kinds of computer simulations. The simulations have above all focused on the interaction between thermal, hydrological, chemical and mechanical processes and how they affect the repository. In many cases the results are not in complete agreement, which may be due to the use of different kinds of programming tools (software) and boundary conditions (input data).

It is important to realize that simulations are simplifications of reality and only provide a general picture of the processes, since they do not take site-specific boundary conditions into account. Similar results from different simulations show that final repositories in deep boreholes are not as dependent on the canisters' remaining undamaged as are repositories nearer the ground surface. It has also been found that after deposition, the temperature in the repository increases and reaches a maximum value after around ten years, and that this causes some flow of water upward in the boreholes.[14,15]

[13] Ibid.
[14] Arnold, B.W. och Hadgu, T. (2013), "Thermal-hydrological modeling of a deep borehole disposal system". *IHLRWMC 2013*, Albuquerque, NM, April 28–May 2, 2013, pp. 481–488.

The models, which have simulated North American conditions, also show that if the boreholes are located closer than 200 m from each other, a second, lower heat pulse occurs after 10,000–15,000 years. This heat pulse is caused by interaction of the heat generated by the waste in individual boreholes, but the way in which this heat pulse affects the water flow differs in the different models. Some models have shown that this second heat pulse can lead to a disruption of the salt water stratification and the upward flows can last for up to 100,000 years[16,17], while other models show that the lighter heated water is not able to rise in the holes.[18] In other words, more and better computer modelling is needed before the method with deep boreholes can be considered reliable. Planned simulations will focus on, among other things, how the mobility of radionuclides from a depth of 5,000 metres is affected by variations in water flows and temperature connected to rock mechanical properties.[19]

3.6 Conclusion

A final repository for nuclear waste in deep boreholes has many advantages associated with the favourable geological conditions at the planned repository depth. The Swedish National Council for Nuclear Waste can also conclude that the concept complies with the Non-Proliferation Treaty, since the waste is virtually irretrievable, but that the method is not yet fully developed. There are knowledge gaps regarding how the interaction between different processes (thermal-hydrological-rock mechanical) affects the mobility and thereby the transport of e.g. actinides. In addition, several difficult questions remain concerning e.g. how the risks associated with the deposition process should be managed.

[15] Lubchenko, N., Baglietto, E. & Driscoll, M.J.(2013), "Towards the development and application of borehole virtual reality simulation tool", *IHLRWMC 2013*, Albuquerque, NM, April 28–May 2, 2013.
[16] Arnold, B.W. och Hagdu, T. (2013).
[17] Lubchenko et al (2013).
[18] Bates, E.A., Baglietto, E., Driscoll, M.J. and Buongiorno, J. (2013), "Onset and stability of natural convection in deep drillhole" *IHLRWMC 2013*, Albuquerque, NM, April 28–May 2, 2013.
[19] Lubchenko, N. et al (2013).

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4 State-of-the-art for future nuclear fuel cycles and Generation IV systems for Sweden

One of the fundamental premises for the development of a method for disposal of the Swedish nuclear power waste has been that those who have enjoyed the benefits of the nuclear-generated electricity are also obliged to manage the waste without burdening future generations. The plan is that the spent nuclear fuel will be disposed of in the bedrock, without recycling. Technically speaking, however, there are other possibilities involving reprocessing or recycling of spent nuclear fuel. The purpose of this chapter is to shed light on some possibilities and limitations with these alternatives, and to touch upon the possible implications of the introduction of future nuclear power systems.

4.1 Possible reprocessing and recycling of spent nuclear fuel for Sweden

In its previous state-of-the-art reports, the Swedish National Council for Nuclear Waste has dealt with future reactor technology and the consequences of its introduction for the future final repository[1,2], since technology development in the reactor and nuclear fuel field is predicted to be of crucial importance for whether the waste that is being generated in the reactors of today and the immediate future can be regarded as a resource for future generations or not.

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[1] SOU 2011:14, *Nuclear Waste State-of-the-Art Report 2011 – geology, barriers, alternatives.* Swedish National Council for Nuclear Waste.

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

If the spent nuclear fuel is not regarded as waste, it can be managed by reprocessing or recycling, which is compatible with the Environmental Code. Reprocessing and recycling can be done in several different ways and take advantage of the fact that only a small fraction of the energy content in the fuel is utilized today. The fuel that is removed from the reactor consists for the most part of fertile[3] uranium (^{238}U). There is also some fissile[4] uranium (^{235}U) and plutonium, fission products and small quantities of fertile so-called residual actinides. The fission products are to be regarded as waste in all fuel cycles, while uranium, plutonium and the residual actinides can be reused to different degrees in different recycling alternatives.

The most complete recycling alternative is based on future nuclear power systems and new Generation IV technology. With such technology it would also be possible to recycle not only ^{235}U and plutonium, but also ^{238}U, which is regarded as waste today, as well as actinides such as curium, americium and neptunium. This would result in simplified waste management, since several hard-to-handle substances would have been transmuted. Furthermore, the long-lived waste quantities are reduced and the storage times are shortened to roughly a thousand years for those substances, mainly fission products, that must still be regarded as waste.

Future nuclear power systems of this type should, as the name suggests, be regarded from a system perspective where the nuclear power reactor, with its spectrum of fast neutrons (thereof the name “fast reactor”), is associated with facilities for fuel recycling and fuel fabrication. The Generation IV International Forum (GIF)[5], initiated by the US DOE, has recommended six different nuclear power systems for further research and development. A common feature of these systems is that they offer great advantages in terms of sustainability and resource management, safety and accessibility, as well as economic competitiveness. Furthermore, the systems must be associated with as little risk as possible that fissionable material will end up in the wrong hands in order to be able to compete with other energy technologies.

The reprocessing that is possible for today’s light water reactors (Generation II, III and III+) is currently being pursued on a

[3] A fertile nucleus can be converted to a fissile nucleus by capture of a neutron with sufficiently great energy.
[4] A fissile nucleus can be split (fissioned) by thermal neutrons, i.e. neutrons with low energy.
[5] Generation IV International Forum, http://www.gen-4.org/ (downloaded 23 January 2014).

commercial basis only in France. The process entails that plutonium and uranium are separated (partitioned) from other waste products (fission products and residual actinides). In France, the waste is vitrified before final disposal, the recovered uranium is stored and the plutonium is used for fuel fabrication. The new fuel is called MOX (Mixed OXide) fuel and consists of recovered plutonium and (often) depleted uranium, and can be used once again in today's light water reactors. Reprocessing is debated from a non-proliferation perspective, since it separates material that could be attractive for non-peaceful purposes, but it can entail economic advantages assuming high raw material prices, and resource-efficiency advantages since about 20% less uranium needs to be mined.[6] Viewed from a final disposal perspective, the storage times for the new nuclear waste are not affected, nor is there any marked decrease in the waste volumes, since the decay heat is roughly the same. However, management of the new waste will be more costly, and SKB estimates that the price of reprocessing compared with direct disposal will increase by around 75%.[7] So far, reprocessing of spent nuclear fuel has not been done on any large scale in Sweden. However, a small quantity of spent nuclear fuel has been reprocessed at BNFL in Sellafield (UK) for use in the Oskarshamn Nuclear Power Plant, under an agreement signed by OKG in the late 1960s.

There are different opinions as to whether direct disposal in a geological repository is better or worse than reprocessing and recycling of fuel from a proliferation viewpoint. In a final repository in which the spent fuel from our light water reactors has been deposited, the isotope composition of the stored plutonium will change with time. At the same time, the fission products' radiation barrier, which is the predominant source of the gamma radiation emitted by the spent nuclear fuel, declines, since the fission products have a much shorter half-life than uranium and plutonium. It can therefore be argued that the risk of the material ending up in the wrong hands does not decrease with time. On the other hand, reprocessing and recycling of spent nuclear fuel carries a risk that technologies and processes that can be misused will be spread to the wrong parties, and sensitive material thereby risks

[6] Forsström, H. (2013) *Utveckling av snabba reaktorer. Påverkan på det svenska systemet för hantering av använt bränsle*, Report SKB P-13-33.
[7] Ibid.

ending up in the wrong hands.[8] Added to this is a risk that export-controlled equipment intended for civilian reprocessing will be acquired by parties whose purpose is to manufacture nuclear weapons. In the study *Upparbetning av utbränt kärnbränsle – En studie med fokus på exportkontroll* ("Reprocessing of spent nuclear fuel – a study with a focus on export control," in Swedish), Andersson et al. give an account of possible nuclear proliferation risks entailed by reprocessing and consequences for Swedish export control.[9] It was to guard against the proliferation risk that the president of the United States in 1977 banned the reprocessing of nuclear waste in the USA, hoping that the rest of the world would follow suit. This did not happen, and the ban was lifted in 1999.

4.2 Managing resources or reducing waste quantities?

As mentioned previously, recycling of spent nuclear fuel can reduce the need for natural uranium and the quantity of waste in the final repository, but at a rather high cost. If one wishes to pursue recycling further, different types of fast reactors are available. They originate for the most part from the 1950s and 1960s and exist in different designs, where a distinction can be made between *breeders* and *burners* (based on whether they create or consume fuel). Breeders are reactors with a conversion ratio of at least 1, where 1 corresponds to a reactor in equilibrium that produces as much fuel as it consumes. A breeder reactor with a conversion ratio higher than 1 thus produces more fuel than it consumes, while a burner reactor, which always has a conversion ratio lower than 1, consumes more fuel than it generates. The areas of application for the different reactors are thus different and their operation has different purposes. A breeder reactor is sustainable and resource-efficient, while a burner reactor is mainly used to reduce the quantity of waste – particularly unwanted radiotoxic isotopes.

[8] Bathke, C.G. et al. (2012), "The attractiveness of materials in advanced nuclear fuel cycles for various proliferation and theft scenarios", *Nuclear technology*, vol 179, No 1.
[9] Andersson, P. et al., (2013),*Upparbetning av utbränt kärnbränsle – En studie med focus på exportkontroll* Swedish Radiation Safety Authority. Report SSM 2013:32.

4.3 Current research on fuel reprocessing and Generation IV technology of relevance to Sweden

A number of countries – such as France, Russia, India, the USA, China and South Korea – have made large investments in Generation IV technology. Several of these countries are exploring the possibility of using fast reactors and/or closed fuel cycles, as described in Hans Forsström's report (2013).[10] Furthermore, the LEADER (Lead-cooled European Advanced DEmonstration Reactor) project within EURATOM's Seventh Framework Programme during the period 2010–2013 has succeeded the previous project ELSY (European Lead-cooled SYstem). The project's ambition was to develop a conceptual design for a large-scale lead-cooled reactor called ELFR (European Lead Fast Reactor) and a small-scale demonstration facility for the same purpose called ALFRED (Advanced Lead Fast Reactor European Demonstrator).[11,12] Belgium also has advanced plans to build a Generation IV reactor for transmutation of nuclear fuel by 2023.[13]

A national research collaboration between Chalmers, KTH and Uppsala University was started four years ago, funded by the Swedish Research Council. The project has gone under the name *GENIUS*[14] , and its purpose is to study various aspects of the Generation IV system technology.

The focus for Chalmers has been the actual process for recycling of the spent nuclear fuel, in particular the *GANEX process*.[15] The research at KTH has centred on the design of a lead-cooled fast reactor and the development of corrosion-resistant fuels and materials for this, while the focus of the research at Uppsala University has been on finding new detector materials, reactor instrumentation, sensitivity analysis and estimating and minimizing the risk that strategic material will be diverted from the future nuclear power systems. Research results from the GENIUS project

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[10] Forsström, H. (2013).
[11] Alemberti, A. et al., (2009), *European Lead-Cooled Fast Reactor*, FISA 2009, Prague 22–24, June 2009.
[12] http://www.leader-fp7.eu/ (Downloaded 4 February 2014).
[13] Aït Abderrahim, H. et al., *MYRRHA – A multi-purpose fast spectrum research reactor, Energy Conversion and Management.*
http://www.sciencedirect.com/science/article/pii/S0196890412000982
[14] The GENIUS collaboration, http://genius.kth.se. (Downloaded 23 January 2014).
[15] Aneheim, E. (2012), *Development of a Solvent Extraction Process for Group Actinide Recovery from Used Nuclear Fuel*.

have already been published on the project's website, and more will be published there during the current year.[16]

The use of a lead-cooled fast reactor and a Swedish closed fuel cycle is also examined in a study initiated by the Swedish National Council for Nuclear Waste[17] , with the conclusion that use of such a system can reduce both waste quantities and storage times for the Swedish final repository. This report is available on the Swedish National Council for Nuclear Waste's website.

The SKB report *Utveckling av snabba reaktorer. Påverkan på det svenska systemet för hantering av använt bränsle*[18] ("Development of fast reactors. Impact on the Swedish system for management of spent fuel," in Swedish) explores when and how Generation IV reactors could be implemented in Sweden, with a focus on management of the spent nuclear resulting from this implementation. In this scenario, SKB imagines a Swedish fast reactor system during the period 2060–2100 consisting of light water reactors powered by plutonium and uranium fuel (MOX) and fast breeder reactors; after 2100 only the fast reactors remain.

4.4 Identified research needs for Generation IV in Sweden

Whether or not nuclear power is to be a part of energy production in Sweden after today's reactors have been taken out of service is still an open question, as is the question of what technology would be used if the answer is yes. Several problems remain to be solved if a future implementation of Generation IV is to be possible, and they will require extensive research initiatives that must be preceded by a build-up of scientific expertise. The following areas must be researched, among others:

- development of new durable materials
- studies of different reactor-physical processes to ensure safe and efficient power production in new reactor systems

[16] http://genius.kth.se/
[17] Zakova, J. and Wallenius, J. (2013), *Införandet av en sluten kärnbränslecykel i Sverige, Version 1.0*, Tillgänglig: http://www.karnavfallsradet.se/publikationer/rapporter/externa-rapporter. (Downloaded 23 January 2014).
[18] Forsström, H. (2013).

- development of nuclear-chemical processes and demonstration facilities for reprocessing and recycling
- development of systems for management of the risks of misuse of materials and technologies for non-peaceful purposes
- consequence analyses of whether and how possible future nuclear power systems can be introduced and integrated with existing nuclear power, and what impact this will have on the final disposal of spent nuclear fuel
- political support and acceptance in society for continued nuclear power operation via Generation III and III+ reactors in the foreseeable future

In this context it is also important to examine non-proliferation aspects, i.e. the question of nuclear safeguards, since introduction of Generation IV systems is automatically associated with new types of nuclear facilities and activities associated with recycling. A study examining some of these aspects, ordered by SSM, has recently been carried out by FOI and has resulted in two reports.[19,20]

How soon the possible commercial operation of Generation IV reactors in Sweden could become a reality is not solely a technical question, but also an important political question. Considering only the technical aspects, there are different opinions on how soon a Generation IV system could become a reality, depending on what assumptions are made and the scope that is considered. GIF estimates that commercial Generation IV systems can be implemented as soon as 2030–2040, while others are more cautious and mention longer time perspectives.[21]

Regardless of whether Generation IV facilities are implemented in the future and if so what types, a final repository for spent nuclear fuel will be required. The question is how this repository can best be utilized: to hold the waste from today's reactors, or to hold smaller waste quantities for shorter times with Generation IV systems in possible combination with Generation III and III+ reactors?

[19] Andersson, P. et al., (2013) *Upparbetning av utbränt kärnbränsle – En studie med fokus på exportkontroll.* Rapport SSM 2013:32.
[20] Andersson, P. et al., (2013) *Fjärde generationens reaktorer – en analys med fokus på icke-spridning och exportkontroll.* Rapport SSM 2013:18.
[21] Generation IV International Forum, http://www.gen-4.org (Downloaded 23 January 2014).

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Alemberti, A. et al. (2009), *European Lead-Cooled Fast Reactor, FISA 2009*, Prague 22–24, June 2009.

Andersson, P., Ardhammar, M., Nielsen, F. and Peterson, J. (2013) *Upparbetning av utbränt kärnbränsle – En studie med focus på exportkontroll* ("Reprocessing of spent nuclear fuel – A study with a focus on export control," in Swedish). Report SSM 2013:32.

Andersson, P., Meister, M., Nielsen, F. and Sunhede, D. (2013), *Fjärde generationens reaktorer – en analys med fokus på icke-spridning och exportkontroll* ("Fourth generation reactors – an analysis with a focus on non-proliferation and export control," in Swedish). Report SSM 2013:18.

Aneheim, E. (2012), *Development of a Solvent Extraction Process for Group Actinide Recovery from Used Nuclear Fuel*. Doctoral thesis, GeoEngineering, Chalmers University of Technology, Gothenburg.

Bathke, C.G. et al., (2012) "The attractiveness of materials in advanced nuclear fuel cycles for various proliferation and theft scenarios". *Nuclear technology*, vol 179, No 1.

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Generation IV International Forum, http://www.gen-4.org/. (Downloaded 23 January 2014).

The GENIUS collaboration, http://genius.kth.se/. (Downloaded 23 January 2014).

The LEADER project, http://www.leader-fp7.eu/

SOU 2011:14, *Nuclear Waste State-of-the-Art Report 2011 – geology, barriers, alternatives*. Swedish National Council for Nuclear Waste. Stockholm: Fritzes (2011).

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

Zakova, J. and Wallenius, J. (2013), *Införandet av en sluten kärnbränslecykel i Sverige* ("Introduction of a closed nuclear fuel cycle in Sweden," in Swedish). Available: http://www.karnavfallsradet.se/publikationer/rapporter/externa-rapporter/. (Downloaded 23 January 2014).

5 Corrosion, erosion and rock stresses – new insights about the long-term safety of the final repository

On 20–21 November 2013, the Swedish National Council for Nuclear Waste held a symposium on the engineered barriers in the final repository for spent nuclear fuel, where the barriers, together with the surrounding rock, are supposed to provide protection for the deposited fuel.[1] The purpose of the symposium was to examine current research on the copper canister and the bentonite buffer in particular, and report new insights on the importance of the barriers for long-term safety. Questions concerning the long-term protective properties of the copper canisters and the bentonite buffer were in particular found to require a great deal of research and development work. Interest is great, since many other countries have also opted for geological disposal of their high-level waste.

The KBS-3 method, which is proposed in Sweden and Finland, is, however, unique in that the deposited fuel will be protected by passive barriers that are supposed to function throughout the disposal period (>100,000 years). The isolating capability of the surrounding rock will be further augmented by artificial (engineered) barriers to enhance safety. Four years ago (in November 2009), the Swedish National Council for Nuclear Waste held an international seminar that focused on the copper canister and the threats and stresses to which it will be exposed in the final repository through

[1] Swedish National Council for Nuclear Waste's symposium: *New insights into the repository's engineered barriers*, Stockholm, 20-21 Nov. 2013. Material can be downloaded at www.karnavfallsradet.se

corrosion and hydrogen absorption.[2] Some researchers have seriously questioned the long-term integrity of the copper canister by showing experimentally that hydrogen gas evolves when copper coupons are placed in pure water in an oxygen-free environment. The results have been interpreted as showing that copper corrodes in a way not previously known that could have devastating consequences for the copper canister as an impervious barrier in the final repository. Since then there has been a lively and occasionally infected discussion between the Swedish Nuclear Fuel and Waste Management Co (SKB), a few established scientists and environmental organizations.

The Swedish National Council for Nuclear Waste has kept an open mind throughout while critically reviewing the interpretation of the results – open in the face of new independent research but skeptical when the results challenge established thermodynamic relationships and their importance in predicting the long-term evolution of the final repository. Thermodynamics is an important tool for modelling chemical processes, not least when it comes to the fate of the engineered barriers over the extremely long time spans in question.

The 2013 symposium was held in English (as was the one in 2009) so that we could invite foreign scientists as speakers and thereby obtain an international overview of these issues. The focus this time was on how the barriers are expected to interact in a repository environment in both the short and long term. This means that the properties and function of the bentonite buffer were also dealt with in terms of their ability to protect the copper canister under the varying environmental conditions expected to exist during the disposal period.

5.1 Corrosion of the copper canister, hydrogen absorption and creep

The first day of the symposium was devoted to the properties of the copper metal and its long-term durability in the canisters that are to contain the spent nuclear fuel. The threats to the canister that were discussed were different types of corrosion, hydrogen

[2] Swedish National Council for Nuclear Waste (2009), *Mechanisms of Copper Corrosion in Aqueous Environments; A report from the Swedish National Council for Nuclear Waste's scientific workshop on November 16, 2009.* Report 2009:4.

absorption and creep, all three of which affect the mechanical strength of the material. Corrosion of copper in oxygen-free (anoxic) water has in particular been a hot topic of discussion in recent years. Since 2009, several new projects have been initiated and funded by above all the Swedish Radiation Safety Authority (SSM) and SKB. The projects that have been funded by SSM concern thermodynamic modelling of copper corrosion in groundwater containing sulphide and chloride ions as a function of concentrations and the acidity (pH) of the water under above all oxygen-free conditions, and continued and repeated studies of copper corrosion in oxygen-free water done at Studsvik AB and the Royal Institute of Technology (KTH). SKB has funded a new study of copper corrosion in pure oxygen-free water at Uppsala University and at MICANS (Microbial Analytics Sweden AB) in Gothenburg, as well as research at KTH on the influence of γ-radiation on copper corrosion. The results of all these projects were reported at the symposium.

The first day began with a presentation[3] that provided a thermodynamic basis for the environmental preconditions for corrosion of copper in pure water. In summary, thermodynamic calculations show that it is only under very extreme conditions (negligible concentrations of copper ions in the water and an extremely low hydrogen gas pressure) that corrosion of copper in pure oxygen-free water is theoretically possible. The question is therefore whether it is probable or possible that such conditions can be expected to occur in the final repository in the long term.

New results were then presented by research groups at KTH[4] and Uppsala University[5] and the results were compared. A number of experiments have been conducted at different university research institutes, and in all cases hydrogen is evolved, although in highly varying quantities, while other corrosion products are very difficult to document. In other words, a reasonable material balance is lacking, and much more hydrogen is evolved than appears to correspond to the corrosion process itself.

[3] Macdonald, Digby, "Some pressing challenges in assuring the integrity of high level nuclear waste isolation systems". *New insights into the repository's engineered barriers*, Stockholm, 20-21 Nov. 2013.
[4] Szakálos, Peter, "Copper corrosion and its implications for the KBS-3 concept". *New insights into the repository's engineered barriers*, Stockholm, 20-21 Nov. 2013.
[5] Boman, Mats, "Corrosion of copper in molecular oxygen free water". *New insights into the repository's engineered barriers*, Stockholm, 20-21 Nov. 2013.

In all cases, copper coupons as thin as a sheet of paper (0.1 mm) have been used, which means that a large portion of the copper atoms have been exposed to the surrounding water. This greatly accelerates the process so that results can be achieved in a reasonable period of time, but the experimental design also has significant disadvantages. The results of the experiments at Uppsala University differ from the results of similar experiments at KTH, Studsvik and MICANS in Gothenburg in that hydrogen gas evolution was much lower. This could possibly be because the purity of the copper was higher in the Uppsala experiment (99.9999%, compared with 99.95% elsewhere). An experiment where copper coupons of various degrees of purity and pretreatment were compared under otherwise identical experimental conditions led to great differences in hydrogen gas production.[6] A large contact surface means that even small quantities of impurities take on great importance, since a relatively high proportion of them come into contact with the water and have an opportunity to react.

Another important factor is how different types of surface preparation affect the results. The method used in the Uppsala experiments gives a much smoother surface than in all previous corrosion experiments and could be another reason why hydrogen gas evolution is lower. A very smooth surface affects the total surface area at the molecular level, but has no impact on the thermodynamics of the reactions. A copper corrosion process in water must lead to an increase in the concentration of copper ions on the metal surface and/or in the water. Analyses have been done of many different metal ions in low concentrations in the solution after the experiments, but the copper concentration has without exception been extremely low. This suggests that the hydrogen gas comes from a reaction on the surface.

The importance of reactions on the surface of the copper metal in explaining the causes of hydrogen gas evolution has been shown by the Swedish National Council for Nuclear Waste in its state-of-the-art reports for 2010[7] and 2011[8]. A scenario was also described there showing that the copper atoms in the interface with the surrounding water can split the water by means of the reaction

[6] Hedin, Allan, "Long-term integrity of the KBS-3 canister". *New insights into the repository's engineered barriers*, Stockholm, 20-21 Nov. 2013.
[7] SOU 2010:6 *Nuclear Waste State-of-the-Art Report 2010 – challenges for the final repository programme.* Swedish National Council for Nuclear Waste.
[8] SOU 2011:14, *Nuclear Waste State-of-the-Art Report 2011 – geology, barriers, alternatives*. Swedish National Council for Nuclear Waste.

≡ Cu + H_2O ⇔ ≡ + ½H_2. This reaction mechanism is described in the literature[9], and even if it is limited to including the copper atoms in the interface with the surrounding water, a great deal of hydrogen gas can be generated if the surface area is large enough.

Copper corrosion under the influence of γ-radiation in oxygen-free conditions has been investigated and the results were presented at the symposium.[10] The most important radiation source in the final repository is Cs-137, with a half-life of about 30 years, which means that the γ-radiation acts on the canister for around 100 years. Both the total radiation dose and the dose flow increase copper corrosion in an oxygen-free environment. To accelerate the reaction, the dose flow in the experiment has been much higher than is expected in the final repository, and even if the total dose is equivalent to the expected dose, it is difficult to draw any definite conclusions at this point about the long-term importance of the radiation for corrosion of the copper canister. Continued research is warranted in view of reactions in welded joints as described in the following paragraph.

Regarding absorption of hydrogen in copper and its importance for the mechanical strength of the metal, a research study was presented at the symposium that gave a detailed picture of the mechanisms for how hydrogen behaves in the metal.[11] Solubility, diffusion and penetration of hydrogen in copper are all slow processes, which means that it takes a very long time for the metallic copper to become hydrogen-saturated. Most of the hydrogen is in molecular form while only a small portion occurs as atomic hydrogen in solid solution with copper. Absorbed hydrogen adversely affects the mechanical properties of the copper metal and can cause damage to the surface. A continuous supply of hydrogen under high pressure causes increased creep and further damage to the surface of the metal. The research indicates a further need to study hydrogen absorption in both the copper metal and in welded joints exposed to γ-radiation.

Creep entails a slow deformation of metal, such as copper, that is subjected to a more or less constant external force. A small addition of phosphorus to the metal reduces creep to acceptable

[9] Protopopoff, E. and Marcus, P.N. (2005), "Potential-pH diagrams for hydroxyl and hydrogen adsorbed on a copper surface", *Electrochimica Acta*, 51, pp. 408–417.
[10] Leygraf, Christofer, "Radiation induced corrosion of copper for spent nuclear fuel" *New insights into the repository's engineered barriers*, Stockholm, 20-21 Nov. 2013.
[11] Hänninen, Hannu, "Hydrogen absorption on copper and implication for long-term safety". *New insights into the repository's engineered barriers*, Stockholm, 20-21 Nov. 2013.

levels in the copper canister. The fact is that we still do not know the reason for this, even though there are a number of hypotheses. The speaker deemed that SKB has still not presented convincing evidence that the copper canister has sufficiently good creep properties.[12]

The first day of the symposium was concluded by SKB's presentation of possible threats to the long-term function of the barriers, according to calculations in the most recent safety assessment.[13] These include different types of corrosion of the copper canister and erosion of the bentonite buffer. The differences in purity between the coupons used in previous corrosion tests at KTH and Studsvik (99.95%), at MICAN (99.99%) and at Uppsala University (99.9999%) were presented, along with other differences in the experimental conditions such as background oxygen level and methods for cleaning and treatment of the copper surface. There appears to be a connection between both the purity of the metal and the method of surface treatment on the one hand and the hydrogen generated in the experiments on the other hand. A mechanism for corrosion of copper in water can only be demonstrated by establishing a credible material balance, since the hydrogen formed must be balanced by other corrosion products containing copper ions. No such material balance has yet been demonstrated.

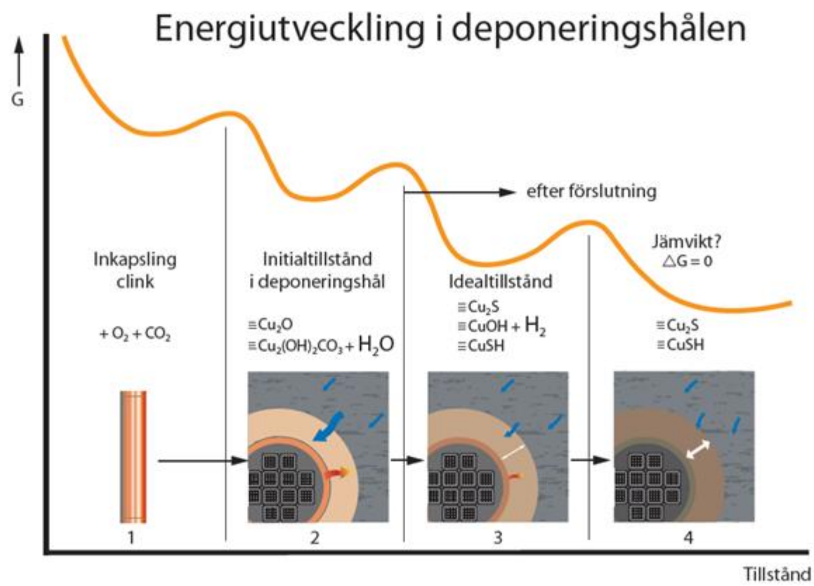
The Swedish National Council for Nuclear Waste notes opinions continue to differ on the long-term performance of the copper canister as a tight barrier in the final repository. This applies above all to corrosion, but also to other processes such as hydrogen absorption and creep.

When the canister has been deposited in the final repository, it will be exposed to a number of external factors that will affect its properties in the long term. After encapsulation of the spent fuel and closure, the canister will have a temperature of about 100^0 C due to the decay heat emitted by the fuel, which will then decline gradually over a period of about 800 years. During the boat trip from the encapsulation plant in Oskarshamn to the final repository in Forsmark, the metal surface will corrode in contact with surrounding air, forming a layer of copper oxide (Cu_2O) and copper

[12] Pettersson, Kjell, "The creep ductility problem of copper". *New insights into the repository's engineered barriers*, Stockholm, 20-21 Nov. 2013.
[13] Hedin, Allan, "Long-term integrity of the KBS-3 canister". *New insights into the repository's engineered barriers*, Stockholm, 20-21 Nov. 2013.

carbonate ($Cu_2(OH)_2CO_3$). When the canister has been deposited, it will be surrounded by the bentonite buffer, which gradually absorbs groundwater from the surrounding rock over a period of several hundred years while the pressure between rock and canister increases (see Fig. 5.1). Uneven water saturation and swelling of the bentonite can lead to stress corrosion cracking and galvanic corrosion, but since the surface of the canister is already oxidized, this could mean that it is more protected than a pure metal surface would be. Copper corrosion in pure oxygen-free water would entail formation of the same type of corrosion products that are already present on the surface, which should have an inhibiting effect on the reaction. The Council thinks that SKB should further investigate these conditions.

Figure 5-1 Energy state in the final repository



Comment: The x-axis illustrates the changing state in the deposition holes and the y-axis describes changes in the Gibbs free energy (G)

5.2 Erosion of bentonite buffer and backfill and influence of rock stresses on strength

The Swedish National Council for Nuclear Waste notes that the bentonite buffer may be fabricated into blocks under high pressure by isostatic or uniaxial pressing. Before water absorption from the surrounding rock has got under way, the buffer will be exposed to decay heat from the canister. This means that the bentonite clay nearest the canister will dry out over a number of centuries before it is saturated by groundwater. This state can be designated as the target state, since it is only after this time that the buffer has achieved its optimal density and permeability. Then the oxygen molecules have also been consumed and the environment is oxygen-free.

Water absorption in the bentonite also creates a high and stable pressure against the canister and the surrounding rock (see Fig. 5.1). It is of crucial importance for the long-term safety of the repository that the buffer prevents groundwater from reaching the copper canister and dampens the effect of minor movements in the rock.

Some new insights concerning the properties of the bentonite clay and the buffer and their behaviour in the repository environment were presented at the Swedish National Council for Nuclear Waste's symposium in November 2013. The rock stresses in the final repository in Forsmark are high, which has been observed by the Council in previous reports. One of the speakers noted the risk that when the hot canister has been deposited, it could cause fracturing of the rock walls in the deposition holes, after which water-saturated bentonite clay could penetrate into the fractures, eroding the bentonite.[14] This scenario is not a new one for SKB. One possible countermeasure, said the speaker, would be to bore the deposition holes at an angle of about 45^0 to the vertical plane in order to reduce the effect of the rock stresses on the canister. However, this means that the copper canister and buffer must be enclosed in so-called supercontainers to enable them to be deposited. One disadvantage of this solution is that additional material (steel or bronze) must be brought into the repository, which could make it even more complicated to predict the long-term evolution of conditions. Furthermore, the package of canister

[14] Pusch, Roland, "Physical/chemical stability of the buffer clay in a KBS-3V repository". *New insights into the repository's engineered barriers*, Stockholm, 20-21 Nov. 2013.

and buffer in a supercontainer will weigh nearly twice as much as the canister alone, making them more unwieldy to handle.

Agence Nationale pour la Gestion Des Déchets Radioactifs (ANDRA) is a French state enterprise charged with responsibility for managing the French radioactive waste.[15] In a presentation, ANDRA described its experience with bentonite from the development of the French final repository for spent nuclear fuel.[16] Bentonite clay and other clay minerals are used in the French repository for similar purposes as in the KBS-3 method, by taking advantage of their properties such as homogeneity, capacity for ion exchange and absorption, swelling in water and low diffusion. The bentonite in the repository comes into contact with both steel containers and concrete, and how this affects its function in the short and long term at different temperatures is currently being studied. The Council believes that the results of these studies can provide valuable information for the design of the Swedish final repository.

Bentonite erosion may be a long-term threat to the function of the buffer in the final repository, and new research from Finland was presented at the symposium.[17] Erosion is greatest at low ionic strengths and low concentrations of calcium ions (Ca^{2+}) in the groundwater. The ratio between sodium and calcium ions (Na^{+}/Ca^{2+}) in the bentonite is an important factor and must not be too high. The risk of erosion is greatest after an ice age when meltwater can be transported down to repository level. According to the Swedish National Council for Nuclear Waste, the uncertainty is greatest in the backfill, since the water flow in deposition tunnels and shafts is much more difficult to control, at the same time as the bentonite quality is lower in the backfill and the proportion of pellets higher. Other important parameters that affect erosion are the groundwater's flow rate and ionic strength and the bentonite's mineral composition.

SKB gave an account of fabrication and installation of buffer blocks of bentonite in deposition holes and deposition tunnels.[18]

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[15] ANDRA also conducts research on final disposal in granite as well as on partitioning and transmutation and long-term surface storage of waste after conditioning.
[16] Michau Nicolas, "Chemical stability of bentonite and claystone under repository conditions in the French context: interactions between clay materials and cement, iron and glass". *New insights into the repository's engineered barriers*, Stockholm, 20-21 Nov. 2013.
[17] Schatz, Tim, "Chemical erosion of bentonite components in the KBS-3V design". *New insights into the repository's engineered barriers*, Stockholm, 20-21 Nov. 2013.
[18] Luterkort, David, "Production of bentonite components and operational issues". *New insights into the repository's engineered barriers*, Stockholm, 20-21 Nov. 2013.

According to SKB, there is a need to find an optimal method for compaction (isostatic or uniaxial pressing), maintain a suitable environment during storage and transport of finished units, prevent damage to the bentonite during deposition of the canister and follow developments during the initial period in the deposition holes. The possibility of artificial watering of the bentonite as proposed by the Swedish National Council for Nuclear Waste is also being investigated. The logistics will be important, not least since bentonite of different qualities will be used in deposition holes and for backfilling deposition tunnels.

One presentation included an account of requirements, development and evaluation of buffer and backfill in the programme to build a final repository in Finland.[19] Goals for the safety and function of the buffer and backfill have been defined in a similar manner as in Sweden. A number of uncertainty factors for the long-term evolution of the buffer have also been evaluated, e.g. buffer erosion and canister corrosion, errors in the calculation model and data and the radiological consequences of a canister failure. There are uncertainties regarding the future evolution of the repository, but long-term safety is not believed to be threatened at present. Research continues within the area. The Swedish National Council for Nuclear Waste's impression is that intensive research is currently being conducted in Finland on the long-term properties of the bentonite and that broad cooperation exists between Posiva Oy (SKB's counterpart in Finland) and SKB.

5.3 Energy state in the final repository

The long-term safety of the KBS-3 method is largely based on ensuring that the interaction between barriers, copper canister, bentonite buffer and surrounding rock meets the requirements of the safety assessment. The interaction between the barriers is particularly important in view of the fact that the long-term evolution of the environment in the final repository will include periods of drying-out and water saturation of the buffer and the backfill together with slow changes of the copper canister due to corrosion, hydrogen absorption and creep. The function of the

[19] Snellman, Margit, "Performance of the buffer and uncertainty management in the Finnish safety case TURVA-2012". *New insights into the repository's engineered barriers*, Stockholm, 20-21 Nov. 2013.

bentonite buffer as a protective barrier is affected by e.g. erosion, mineral transformation, ion diffusion, colloid transport and oxygen consumption.

The initial state of the bentonite buffer entails that it has been compacted under high pressure to blocks and pellets before it is deposited in the boreholes. Before water absorption from the surrounding rock has got under way, the buffer will be exposed to the decay heat emitted by the canister. This means that the bentonite clay nearest the canister will dry out over a number of centuries before it is saturated by groundwater. The new state can be called the target state because the environment has been altered from oxic to anoxic (oxygen-free) due to the fact that oxygen molecules in the bentonite have been consumed by impurities and the density of the buffer has increased due to swelling of the bentonite clay.

How long the process takes from initial state to target state will vary considerably between different deposition holes due to the fact that the water input varies and cannot be controlled. Differences between individual deposition holes in the time it takes for the buffer to become water-saturated are probably up to a factor of 100 times. In addition, the difference in temperature between canister and rock will last for 800–1,000 years and disturb the whole water saturation process. Furthermore, the transition from initial state to target state includes numerous other phases that affect the final repository in the long term (Fig. 5.1).[20]

5.4 The Swedish National Council for Nuclear Waste's summarizing viewpoints

Research on the engineered barriers has in recent years focused increasingly on fundamental material issues such as the chemical and physical properties of copper and bentonite clay. Metallic copper has proved to be able to split water molecules to form molecular hydrogen (H_2) and hydroxide ions ($OH–^-$) without generating copper ions (Cu^+) to an equivalent extent. This means that it has not so far been possible to set up a reliable material balance, which is necessary in order to determine whether copper

[20] Forsling, Willis, "On the long-term durability of the engineered barriers in the repository". *New insights into the repository's engineered barriers*, Stockholm, 20-21 Nov. 2013.

really corrodes in oxygen-free water and that the reaction is not just limited to the surface.

This problem has been mentioned by the Swedish National Council for Nuclear Waste in its state-of-the-art reports for 2010 and 2011. Disagreement on copper corrosion in oxygen-free water must not degenerate into an attempt to demonstrate possible errors in experimental design and apparatus when the results do not agree with the experimenter's own opinion. It would represent a failure on the part of the scientific community if copper corrosion in oxygen-free water cannot be handled in a way that instils confidence in the public. Moreover, when it is deposited the copper canister will already have a layer of corrosion products on the surface, which will undoubtedly influence further events in the repository and put the question of copper corrosion in a new light. The Swedish National Council for Nuclear Waste has in a previous state-of-the-art report (2012)[21] described a hypothetical evolution of an oxidized copper canister after deposition and recommends further research in this area.

The buffer in the deposition holes protects the copper canister against corrosive substances in the groundwater and minor shear movements in the surrounding rock. The bentonite buffer is in turn threatened by a number of processes such as erosion (which reduces its mass), ion exchange and mineral alteration, long-term drying-out prior to water saturation, uneven inflow of water leading to uneven swelling and stresses in the canister, freezing and thawing of blocks and pellets in the backfill, etc. All of this can be expected to occur even if the evolution of the bentonite buffer in the repository proceeds as expected. The Swedish National Council for Nuclear Waste has in a number of previous state-of-the-art reports (2010, 2011, 2012) described possible consequences of all these events and recommends in its state-of-the-art report for 2013[22] that SKB supply water to the deposition holes artificially to even out any differences between dry and wet deposition holes. A wireless system for verifying processes in the buffer in some deposition holes with respect to e.g. water saturation at different levels, pressure on the canister, oxygen consumption and temperature at different distances from the canister would provide valuable

[21] SOU 2012:7 *Nuclear Waste State-of-the-Art Report 2012 – long-term safety, accidents and global survey*. Swedish National Council for Nuclear Waste.
[22] SOU 2013:11 *Nuclear Waste State-of-the-Art Report 2013. Final repository application under review: supplementary information and alternative futures*. Swedish National Council for Nuclear Waste.

information on the future evolution of these parameters. A long-lasting drying-out with subsequent mineral transport and alteration in the buffer, as well as an uneven water inflow, could damage the canister in the long term.

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6 Social science research in an international perspective

6.1 Introduction

The problems of building a final repository for spent nuclear fuel are not exclusively of a technical and natural-scientific nature. They are also of a socio-scientific and humanistic nature. How, for example, is nuclear waste management influenced by the discussions of reactors of a completely new design, known as Generation IV reactors, which are described in this report (see Chapter 4)? What does the internationalization of SKB's KBS-3 method entail for the handling of the nuclear waste issue internationally and in Sweden? What ethical perspectives arise as a consequence of the long time perspectives? Finding answers to relevant questions of this kind requires humanistic and social science methods and analyses.

Extensive research activities are currently being pursued in the social sciences and humanities in Europe, including several interesting and goal-driven initiatives within the framework of the OECD Nuclear Energy Agency (NEA), the European Commission and Euratom's Seventh Framework Programme for research. One example of current European research in the social sciences is the Commission's programme Horizon 2020.[1] This stands in sharp contrast to activities in nationally funded Swedish projects in the area, which are of much more modest proportions. This is particularly unfortunate in view of the fact that SKB's licence applications for construction of a Swedish final repository for spent nuclear fuel are currently being examined by the Swedish Radiation Safety Authority and the Land and Environment Court at Nacka District Court.

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[1] http://ec.europa.eu/programmes/horizon2020/en (downloaded 2 May 2014).

For this reason it would be desirable if Swedish researchers in the social sciences and humanities, who have in many ways been in the forefront internationally, could now obtain resources to continue their successful work.[2] This wish is also in accordance with Olof Söderberg's evaluation of SKB's social science research programme between 2004 and 2011, where he draws the conclusion that: "It is clearly in the interests of society that research from a humanistic and social science perspective be conducted on topics related to nuclear waste." He further concludes that there will "probably be a need for further research on nuclear-waste-related topics from a humanistic and social science perspective."[3] In spite of this, SKB has decided not to follow up its endeavours with new social science research programmes or equivalent initiatives.

The following account reviews concluded, ongoing and planned research projects in the social sciences and humanities concerned with problems related to the management of nuclear waste. The ambition of the report is not to be all-encompassing, but to discuss and describe in brief terms the most important current international and European activities from a Swedish perspective.

6.2 European projects

6.2.1 The COWAM projects

On the European level, research initiatives have primarily been funded via the European Atomic Energy Community's (Euratom) framework programme for research and education in the nuclear energy field. In the same way as European research funding in general, the initiatives take the form of successive framework programmes.

An early initiative was the first COWAM project (Construction Waste Management), which ran between 2000 and 2003. It was called "Nuclear waste management from a local perspective. Reflections for a Better Governance" and was funded by Euratom's fifth framework programme for research and education in the

[2] In addition to SKB's social science programme, the research project "Currents Trends and Coming Challenges in the Management of High Level Radioactive Waste. A Comparison of France, Germany, India, Japan, Russia, Sweden, UK, and the U.S.," financed by Formas 2008-2012, should particularly be noted.
[3] Söderberg, Olof (2012), *SKB:s program för samhällsforskning 2004–2011. En utvärdering.* ("SKB's programme for social science research 2004-2011. An evaluation," in Swedish). SKB P-12-14, p. 74.

nuclear energy field. The result was a European network of actors concerned with the management of radioactive waste in Europe. The network included local actors, experts, implementers and regulators who participated in seminars within the network. The purpose was to set up an arena for local actors to exchange experience, express viewpoints on relevant issues for radioactive waste management and develop a common frame of reference.

The second COWAM project, COWAM II, was focused during the following three years 2004 to 2006 on networking and collaborating on research in the field. The purpose of the following COWAM IN PRACTICE between 2007 and 2009 was to support ongoing processes relating to radioactive waste management with a focus on the national processes in Spain, the UK, Romania, Slovenia and France.

6.2.2 From RISCOM to MoDeRn

The EU's Fifth Framework Programme included funding of RISCOM II (Transparency and Public Participation in Radioactive Waste Management) between 2000 and 2003, which was an attempt to increase transparency in the different national radioactive waste programmes based on experience from the Swedish site selection process. The project was coordinated by SKI and had eleven participating organizations in Sweden, Finland, France, the Czech Republic and the UK. This was followed by ARGONA (Arenas for Risk Governance), which was funded between 2006 and 2009 via the sixth framework programme. The purpose here was to show how processes for participation and transparency can be linked to political processes and legal structures and how new processes can be integrated in the national nuclear waste programmes. 14 organizations participated in the ARGONA project, which was led by Sweden starting in 2006 (first by SKI and after 2009 by the Swedish Radiation Safety Authority, SSM). The different sub-projects worked with participation processes, environmental impact assessments, legislation and policy, institutional aspects, the role of actors in the process and opportunities for influence, etc.

The OBRA project (European observatory for long-term governance on radioactive waste management) was also funded by the sixth framework programme between 2006 and 2008. The project explored the possibility of establishing a European networking platform aimed at providing different stakeholders with information and knowledge on spent nuclear fuel and long-lived radioactive waste, e.g. independent expertise and exercise tasks. The project was intended to develop a centre of excellence (Observatory) that could generate and maintain knowledge over a long time concerning various issues on a municipal and regional level in Europe. The task was also to facilitate networking between universities and support work within technical and social science disciplines associated with nuclear waste management.

More recently, the RISCOM model has once again been used in a project called IPPA (Implementing public participation approaches in radioactive waste disposal), which was funded by Euratom's seventh framework programme between 2011 until the beginning of 2014. Here the purpose was to encourage increased participation in the nuclear waste programmes in Poland, the Czech Republic, Romania and Slovenia.

A project that was partially funded by Euratom's seventh framework programme and the OECD was MoDeRn (Monitoring Developments for Safe Repository Operation and Staged Closure), an interdisciplinary project for the development and possible implementation of monitoring of nuclear waste disposal activities. The project ran between 2009 and 2013 and involved eighteen different partner countries from the EU as well as the United States, Japan and Switzerland, with very active participation on the part of Sweden. An important result of the project has been the importance of analyzing monitoring technologies as a confidence-building technique in itself without reference to social and institutional factors. Questions regarding what should be monitored, how data from monitoring should be sorted and who should do it are all of both a socio-scientific and a technical nature at the same time. As consequence of such insights it has been pointed out that monitoring programmes should be designed with such flexibility that they can be adapted to changing rules and regulations for the construction of a final repository for nuclear waste. The importance of ensuring that the content and design of the monitoring programmes are completely open and transparent to the public is also emphasized here. Hence, monitoring of the final repository for nuclear waste can very well be used to create confidence in different chosen disposal solutions, but the monitoring must then be regarded and designed just as much as a social activity as a technical one. Consequently, the monitoring must also be adapted to innovations and newfound knowledge within both of these spheres.[4]

6.3 Current European projects

6.3.1 InSOTEC

Yet another three-year European research project concerned with nuclear waste was started in 2011 – InSOTEC (International Socio-Technical Challenges for Implementing Geological Disposal) with funding from the European Commission via Euratom. The project will be concluded in the summer of 2014, which means that this account concerns an ongoing project.

The main purpose of InSOTEC is to investigate the relationships between technical and social challenges with regard to high-level nuclear waste management, particularly in relation to geological disposal. The basic principle is that social and political requirements shape technical solutions just as much as technical and scientific values and judgements shape social, legal and political processes. A number of different activities are included in InSOTEC in order to investigate technical and social perspectives on nuclear waste management both nationally and internationally. A cornerstone has been a dozen or so studies of different national decision-making processes related to nuclear waste management, as well as a compilation of the results.[5] To this can be added a number of case studies where different socio-technical mechanisms have been investigated more specifically, for example site selection processes and potential for retrieval of nuclear waste.

One factor that is regarded as particularly characteristic of the nuclear waste problem and the solutions that are proposed is the discussions of retrieval of nuclear waste that have influenced views of geological disposal in different countries, even where such requirements do not exist today. Another observation has to do with how long-term political and other control of final disposal has

[4] MoDeRn Deliverable D1.3.1, Available:
http://www.modern-fp7.eu/fileadmin/modern/docs/Deliverables/
MoDeRn_D1.3.1_Basis_for_Stakeholder_info.pdf (downloaded 2 May 2014).
[5] Available: http://www.insotec.eu/publications/file-cabinet (downloaded 2 May 2014).

become a very urgent research area as different geological repositories are planned and built in a number of countries.[6]

From a Swedish perspective, it is of course interesting to take note of an exhaustive account of the socio-technical challenges when it comes to geological disposal of spent nuclear fuel.[7] Two challenges in particular are identified here. The first is upholding an arrangement where political values are given priority over geological considerations in the site selection process. Another has to do with the financing of a final repository, a challenge that has also attracted the attention of numerous other actors and has been given particular coverage in the media.

6.4 Planned European projects

6.4.1 Technical platforms in Europe

A number of EU countries have financial problems today. The main ingredients in the form of stagnating economies and doubts about the future of the common currency are well known. All of this detracts attention from the EU's ambitious development goals, one of which is that the EU aims to catch up with Japan and the United States within the next few years in the field of technical innovation. South Korea still leads the pack, but since 2008 the EU is closing in on the USA and Japan. One problem faced by the EU compared to these countries is that the EU is perceived as being composed of many independent states that can sometimes have difficulty coordinating their different research and innovation initiatives.

In order to increase supranational coordination and cooperation in the EU while strengthening common objectives in different areas, the European Technological Platforms (ETPs) have been created. The ETPs are meeting places where industry, customers and science can develop long-term research projects and innovation strategies. More specifically, the task is to define research priorities, for example ones that can be the subject of applications to the EU's framework programme Horizon 2020 for research and

[6] InSOTEC deliverable D1.2. Available: https://docs.google.com/viewer?a=v&pid=sites&srcid=aW5zb3RlYy5ldXxpbnNvdGVjfGd4OjMzZDVlYTQ3Y2Y5ZDFiNmY (downloaded 2 May 2014).
[7] Available:http://curie.ornl.gov/system/files/documents/SEA/WP1_MS11_CR_Sweden_Final.pdf (downloaded 2 May 2014).

innovations up to 2020. The technological platforms are described as “key elements in the European innovation ecosystem,” but it is emphasized that these platforms are neither owned nor led by the EU, but are independent organizations.

One platform is IGD-TP (Implementing Geological Disposal Technology Platform), which was formed in 2009 to increase co-production of knowledge at both the European and national levels. The IGD-TP is open for participation by all stakeholders. Nevertheless, Greenpeace EU Unit withdrew from the work in 2012, citing their claim that the platform did not foster open discussions. The IGD-TP has expressed a vision that the first geological repositories for spent nuclear fuel, high-level waste and other long-radioactive waste will be operating safely in Europe by 2025. But this vision has also been criticized for entailing far too strong a commitment to geological disposal as a method.

6.4.2 PLATENSO

Another project funded by the European Commission from 2013 via the seventh framework programme is PLATENSO (Building a platform for enhanced societal research related to nuclear energy in Central and Eastern Europe), which may be the first non-technological platform. The objective of PLATENSO is to strengthen research institutions in countries in Central and Eastern Europe so that they are better equipped to participate in EU projects in the area. There are 19 research institutions participating in the project, with a certain focus on Central and Eastern Europe. Cooperation between these institutions and equivalent institutions in different EU countries is an important step in the development of the platform.

Initially the PLATENSO project will focus on summarizing lessons learned from other similar projects (such as the EU projects ARGONA and InSOTEC). The project will then

1. develop inter-institutional networks focused on social science research related to nuclear power and nuclear waste
2. formulate research strategies
3. explore a special scenario concerning the design of Generation IV nuclear reactors and the social background and consequences of such new reactor types.

Nuclear waste management is an important part of this work, not least via studies of the prerequisites for ethically and socially acceptable site selection processes, and Sweden is deemed to be in a position to share valuable experience in this area.

6.5 Activities within the framework of the OECD Nuclear Energy Agency (NEA)

6.5.1 Forum on Stakeholder Confidence

Within the OECD Nuclear Energy Agency there are number of expert groups, some of which are relevant to social science and humanistic perspectives on the nuclear waste field. The Forum on Stakeholder Confidence (FSC) was created in 2000 at the instigation of the Nuclear Energy Agency (NEA), which is the OECD's agency for matters relating to nuclear energy. The FSC provides an opportunity for an exchange of international experience of the societal aspects of radioactive waste management. It also provides an opportunity for discussion of how to carry on a fruitful dialogue with the public and create confidence in the decision-making process.

The members of the FSC come from 18 countries and represent government organizations, regulators, scientists and industry. Discussions at the FSC's annual meetings deal with radioactive waste management, and the Forum also arranges a national workshop for knowledge enhancement and dialogue between members, decision-makers and the public.

In addition, the FSC has conducted studies and published a number of reports containing reviews, recommendations, evaluations and overviews. Some reports deal with general issues such as important concepts and terms in the final disposal field or guiding principles for the final disposal process. Others examine more specific questions, such as participation and decommissioning of nuclear facilities, stepwise decision-making, and different techniques for stakeholder participation. A number of reports have to do with different aspects of the site selection process, such as volunteerism, municipal decision-making, consultations and participation. The institutional premises for radioactive waste management and evaluation of the role of regulators in radioactive waste management have also been among the issues highlighted by the organization.

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

Another expert group within the OECD/NEA is concerned with "Preservation of Records, Knowledge and Memory across Generations" (RK&M) and has been meeting since 2011 to work with these issues. The group consists of representatives from the OECD who – together with scientists and experts, industrial representatives and state officials, as well as municipal representatives and participants from stakeholder organizations in different countries – work with questions concerning how nuclear waste disposal records can be made traceable and accessible for future generations. Sweden has is represented by individuals from SKB, the Swedish National Council for Nuclear Waste and Östhammar Municipality, as well as researchers from Linnaeus University. Experts from various fields are also invited to present different perspectives on preservation of knowledge and records over very long periods of time.

The group has taken a very broad approach and has so far done the following: conducted a survey on how the information preservation efforts have progressed in different countries; produced a standardized glossary of terms in the area; set up an online RK&M reference book or Wiki; conducted a survey and evaluation of different kinds of markers for final repositories; conducted a survey of different organizational structures for knowledge preservation; deal with potential cultural heritage aspects; etc. Intensive efforts have been made by members of the group, and their results were presented in December 2013 with concrete proposals on what aspects should be carried further to a possible step 2, subject to a decision by the OECD. A major conference is also planned to be held in September 2014 in Verdun, France.

The work that has been done is very ambitious and broadly conceived. This means it could potentially contribute to laying a foundation in the future for a transnational standard for the work of documenting knowledge on nuclear waste and rendering it accessible in a form that can be transferred from generation to generation. It is of great value that Swedish representatives continue to participate in this work, not least from SKB, which has not conducted any in-depth studies in the field as yet.

6.6 Conclusions for Sweden from the international projects

As summarized above, extensive European research activities are being pursued in the field of the social sciences and humanities. This contrasts starkly with the absence of such activities in Sweden since SKB's social science programme was concluded in 2011. There are really only two national projects in the field of nuclear waste management. One is a project at Stockholm University, "Hågkomstens politik: Omstridda kulturarvsprocesser vid Ignalina och Barsebäcks kärnkraftverk" ("The politics of remembering: Contested cultural heritage processes at Ignalina and Barsebäck nuclear power plants," in Swedish), on how memories of closed nuclear power plants are created and changed over time by cultural heritage processes in Barsebäck in southern Sweden and Ignalina in Lithuania, funded by the Swedish Research Council. The other is an SKB-funded project, "Etthundratusen år fram och bakåt i tiden: Arkeologi möter Kärnbränsleförvaring" ("One hundred thousand years forward and back in time: Archaeology meets Nuclear Waste Disposal," in Swedish), being pursued at Linnaeus University for the purpose of investigating how archaeological knowledge and experience can be made useful in a future perspective.

The fact that Swedish social science and humanistic research has virtually been left fallow is particularly unfortunate in view of SKB's licence applications and the fact that the project of building a final Swedish repository for spent nuclear fuel has become increasingly concrete in recent years. This means that the remaining challenges in realizing a Swedish final repository are today more of a socio-scientific and humanistic than of a natural-scientific and technical nature. For this reason, it would be desirable for Swedish researchers in the social sciences and humanities, who have often been in the forefront of their fields internationally, could once again be engaged to meet these remaining challenges.

Urgent research tasks are, for example, to investigate how the design of new reactors influences the nuclear waste issue, both in Sweden and abroad. What can the development of Generation IV breeder reactor technology require in terms of future competence development in the field of nuclear fuel management, possible research reactors, construction of various facilities for reprocessing and other management of spent nuclear fuel? What are the non-proliferation aspects and the costs?

Another question is the internationalization of SKB's KBS-3 method and how the Swedish, German and Finnish stakeholders are linked to how the company influences the handling of the nuclear waste issue internationally. Since 2007, SKB has also participated actively in the European Technology Platform for Implementing Geological Disposal (IGD-TP), a context that further strengthens the collaboration between different European organizations for the purpose of creating a geological repository. An urgent matter is to investigate how the international collaboration has influenced the design of decision-making processes and of different national geological repositories, in view of the fact that each country has its own special political institutions as well as its own special geological conditions.

The socio-scientific nuclear waste research also explores questions concerning the design of environmental impact assessments in different countries. How can legislation and its application be compared and, based on such comparisons, critically analyzed and improved? In this context, Swedish research concerning different actors in the nuclear waste area and their mutually dependent relationships is also of interest.

Current inquiries in the sociology of science have focused attention on the changed status of science in society and growing expectations on the focus, methods and results of research (the latter more problematic). In particular, scientific controversies within nuclear waste management have had repercussions on public confidence in the feasibility of safe disposal of nuclear waste. In the 1980s, differences of opinion concerning the nature of the bedrock and its suitability for a final repository came to light. In recent years copper corrosion has been hotly debated. Communication of scientific results to a broader public, the public's interpretation of these results and the scientists' replies to these interpretations is an important topic of social science research. What does this communication look like, what obstacles exist to successful communication, and how can these obstacles be overcome?

In connection with the Swedish National Council for Nuclear Waste's treatment of SKB's licence application, the need for social science research has emerged as being particularly urgent.[8] This applies in particular to a closer study of how the results of the scientific safety assessment can have the intended impact in project management and project organization during the execution phase of the final repository project. This question is central in the Swedish process, but could also be a subject for international inquiry in e.g. the PLATENSO project. In summary, social science research in the field of nuclear waste management is seen to be a vital and important field of research in the European arena. Against this background, the Swedish National Council for Nuclear Waste would like to emphasize the importance of engaging social scientists and humanists in Sweden in current studies and future initiatives in this area.

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7 The municipal veto in connection with the Government's assessment of environmentally hazardous activities

7.1 Introduction

Rules regarding the Government's permissibility assessment of environmentally hazardous activities and the veto power of municipalities in connection with this trace their origin to the national physical planning that was carried out during the 1970s in particular. In this chapter we present the rules that have applied through the years for the municipal veto.

Via provisions granting them the power of veto, the municipalities have been given the means to exercise decisive influence when it comes to allowing environmentally hazardous activities to be conducted within the municipality. In some cases, municipalities have actually exercised their veto.

The scope of compulsory permissibility assessment and the municipal veto in connection with this have varied through the years. Nuclear facilities have always been included, however. When the provisions were enacted in 1972, the special Government assessment and the municipal veto power associated with it applied to e.g. "atomic power plants" and "plants for reprocessing of atomic fuel" – activities which at that time were the subject of heated debate in Sweden.

Aside from these rules, the municipalities bear responsibility, via their planning monopoly, for the planning of land use in the municipalities.

7.2 National physical planning

National physical planning took place from the late 1960s up to 1987. This national planning included inventorying, documentation, referral for consideration and decisions concerning Sweden's geographical natural resources and existing land and water use. The planning ceased in 1987 when the Natural Resources Act entered into force.[1] No national physical plans were drawn up; instead, the Riksdag adopted geographic guidelines for management of land and water that applied to the unharnessed rivers, coastal and archipelago areas, agricultural land and reindeer herding, etc.[2] Special guidelines applied to the unbroken mountain areas.[3]

The intention was that the results of the inventorying and subsequent analysis and decisions would come to expression in the municipal planning. Two major reports were published during the course of the work: *Hushållning med mark och vatten* ("Management of Land and Water Resources," in Swedish) (SOU 1971:75) and *Hushållning med mark och vatten 2* ("Management of Land and Water Resources 2," in Swedish), parts 1 och 2, (SOU 1979:54 and 1979:55).

7.3 Provisions on special siting assessment and municipal veto in section 136 a of the Building Act

In connection with the national planning work, the Building Act was amended.[4] New rules were introduced – Section 136 a – with provisions regarding Government assessment of industrial or similar activities that were covered by the guidelines for national physical planning.[5] The purpose was to ensure management of land and water resources of great importance from a national viewpoint.

The intention was, based on the national physical planning guidelines, to provide a comprehensive and uniform assessment of the siting of industrial activities that lay claim to or alter the character of natural resources that are particularly scarce and that can be expected to be the subject of competing claims.

[1] Act (1987:12 on Management of Natural Resources.
[2] Gov. Bill 1972:111.
[3] Gov. Bill 1977/78:31.
[4] Building Act (1947:385).
[5] Gov. Bill 1972:111 App. 2.

The main reason given for making the Government responsible for this assessment was that no one else but the Government could conduct a comprehensive assessment that takes into account e.g. environmental, labour market and regional policy aspects. Above all, it was considered important that the decision be made by a body that could be held politically responsible. Government assessment was required for industrial or similar activities that are of essential importance for management of the nation's collective land and water resources.

There were already provisions in the Environment Protection Act concerning environmentally hazardous activities for the prevention of water pollution, air pollution, noise and other disturbances caused by the use of land, buildings or facilities. The National Franchise Board for Environment Protection assessed matters relating to a licence for the activity.[6] This assessment considered whether the activity could lead to a significant deterioration in living conditions for a large number of people, or whether significant loss could arise from a nature conservancy viewpoint or a similar public interest could be substantially harmed.[7] The Government (the Crown) could, however, issue a licence for the activity if it was "of particular importance for industry or for the locality or otherwise from a general viewpoint".

But decisions under the Environment Protection Act offered only limited options for siting of environmentally hazardous activities. Against this background, options were discussed to supplement national physical planning with means to regulate the siting of individual industrial establishments with great environmental impact. The solution chosen was to introduce into the Building Act rules for "special siting assessment by the Government in the case of industry with great environmental impact, the result of which is binding with regard to siting in connection with detailed physical planning and the application of the Environment Protection Act".[8]

The new provision in the Building Act meant that "the establishment and siting of such industrial activities or similar activities that are of essential importance for management of energy, timber or the nation's collective land and water resources"

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[6] See Sec. 9, Environment Protection Act (1969:387).
[7] See Sec. 6, second paragraph, first point, Environment Protection Act (1969:387).
[8] SOU 1971:75 *Hushållning med mark och vatten: inventeringar, planöverväganden om vissa naturresurser, former för fortlöpande fysisk riksplanering, lagstiftning*, pp. 478 ff.

would be assessed by the Government. These activities were enumerated in a ten-point list that included iron and steel works, large sawmills, refineries, cement plants, etc. Among the stipulated activities were two kinds of nuclear facilities: "atomic power plants" and "plants for reprocessing of atomic fuel".

It was in this context that rules on a municipal veto of Government decisions were introduced into the legislation. A licence could only be granted by the Government if the municipality endorsed it. The travaux préparatoires stated that: "in view of the impact that environmentally hazardous activities of this scope can have on the surrounding countryside, a siting licence should in principle not be granted unless the municipality in which the activity is to be sited has endorsed this".

The municipal veto provided for in Section 136 a of the Building Act has been exercised in four cases of major industrial sitings. However, the municipal veto has most likely influenced site selection in many other cases as well. When a company has, via contacts with the concerned municipalities, ascertained their attitude towards a planned siting, they generally tend to focus their plans on sites that meet with municipal approval.[9]

The municipal veto been used in the following cases:

- The municipality of Nynäshamn refused to endorse an application by the Swedish State Power Board to build a fossil-fuelled power station in the Norvik area (Government decision of 12 June 1975).
- The municipality of Västervik refused to endorse an application by the Swedish State Power Board to build a gas turbine station on the island of Lusärna (Government decision of 2 December 1976).
- The municipality of Varberg refused to endorse an application by Petroleumlagring Tre AB to build a facility for emergency oil stocks in Varberg (Government decision of 22 December 1977).
- The municipalities of Falköping and Skövde refused to endorse an application by Luossavaara-Kirunavaara AB for a licence to conduct certain research and production activities including mining of not more than 1.1 million tonnes of alum shale per year at Ranstad (Government decision of 19 January 1978).

[9] Gov. Bill 1989/90:126.

7.4 Municipal influence under the Natural Resources Act

The Building Act from 1947 was replaced by a new Planning and Building Act[10], certain parts of which entered into force on 1 January 1990 and the rest on 1 April 1990.[11] The Act (1987:12) on Management of Natural Resources etc. (Natural Resources Act) was passed in connection therewith. Provisions regarding Government assessment of certain environmentally hazardous activities were transferred from Section 136 a of the Building Act to the new Natural Resources Act. Rules were formulated concerning which sectoral interests/values and which geographic areas are to be taken into account.[12] Rules were introduced into the Act concerning the Government's permissibility assessment of industrial facilities and other facilities.[13]

The Government Bill pointed out the importance of guaranteeing the municipalities a strong influence over the local environment. Increasing the influence of the municipalities was held up in the Government Bill as one of the most essential purposes of the draft Planning and Building Act. According to the Government Bill, municipalities should therefore also have a great influence over industrial establishments that may be subject to assessment by the Government under the Natural Resources Act. In principle, a licence for such a facility should not be granted unless the municipality in which the facility is intended to be located has endorsed this.

The Government Bill also discussed the question of whether restrictions should be placed on the municipal veto power regarding certain facilities or activities of national importance. But in the light of the negative comments received from the referral bodies concerning such restrictions, no such provision was made in the Act.

[10] Planning and Building Act (1987:10).
[11] Gov. Bill 1985/86:1 draft of new Planning and Building Act.
[12] Gov. Bill 1985/86:3.
[13] Cf. Act (1987:12) on Management of Natural Resources etc. (Natural Resources Act).

7.5 Veto valve introduced

In connection with a revision of the Natural Resources Act a few years after it had entered into force, the question of restrictions in the municipal veto power was raised once again. The changes made in connection with the revision entailed that the Act was broadened to include major facilities for the final disposal of hazardous waste as well as certain facilities associated with energy supply.

As before, the municipal veto was emphasized and said to be an expression of the strong position municipal self-government should enjoy in a democracy. It was considered only natural that the municipalities should have a very strong say in the establishment of major industrial facilities, even if they were of great importance for the nation as a whole. A licence for establishment should therefore as a rule not be granted unless the municipal council endorsed it.

In other words, the municipal veto was retained as a principal rule. But a way for the Government to issue a licence even if the municipal council has refused to endorse it was introduced in the Act and came to be called the veto valve. The power to override the municipal veto could be exercised if it was particularly urgent from a national viewpoint that a certain facility or activity be implemented. The requirement that it must be particularly urgent that the facility in question be located within the country gave expression to the restrictiveness that was to apply to the judgement of whether an activity could be exempted from the municipal veto.

Exemptions from the municipal veto could be made regarding:

- interim storage or final disposal of nuclear material or nuclear waste
- large incineration plants
- large wind farms
- large facilities for final disposal of environmentally hazardous waste
- large facilities for storage of natural gas

However, the option for the Government to issue a licence for a facility despite the refusal of the municipal council to endorse it did not apply if another site had been designated for the activity in another municipality that was likely to approve a siting there, or if another site had been deemed more suitable.[14] The Government Bill stressed that it should not be possible to force a facility on a municipality if another municipality accepts it on a site that is suitable, even if a siting in the former municipality would be more suitable. Only if there is no willing municipality with a suitable site would it be possible to override a municipal veto.[15]

According to the provisions, if there is no willing municipality that can designate a suitable site, an exemption from the veto power may nevertheless not be made if another site is deemed to be more suitable than the one to which the exemption pertains. In such a case, an application cannot be endorsed; instead, the premises for granting a licence to the other, more suitable site must be assessed. In this connection, the possibilities for the applicant to conduct the activity on another site than the one to which the application pertains must of course be accorded great importance.

The Government Bill states the following with regard to the Government's assessment:

> As the licensing authority, the Government is obliged to ensure that an activity is established on the most suitable site for the purpose. This means that the Government can demand that the applicant produce documentary evidence supporting this claim, see section 2.6.
>
> At the same time, the Government must, in its decision, present concrete and substantial reasons why another site is deemed more suitable than the one to which the application pertains. In view of the nature of these matters, there is reason to assume that in such a matter the Government will have access to information regarding suitable alternative sitings.
>
> The alternative siting of an activity will in turn be treated as a special licensing matter. The question of the applicability of the veto rules can thereby arise even if the alternative site is located in the municipality in question.[16]

7.6 Provisions under the Environmental Code

The Natural Resources Act ceased to apply when the Environmental Code entered into force on 1 January 1999. The provisions regarding the Government's permissibility assessment of certain environmentally hazardous activities and the municipal veto were

[14] Cf. Chap. 4 Sec. 3 of the Act (1987:12) on Management of Natural Resources etc. (Natural Resources Act).
[15] See Gov. Bill 1989/90:126, p. 25.
[16] See Gov. Bill 1989/90:126, p. 26.

introduced into the Environmental Code at that time. Basic provisions concerning the management of land and water areas are found in Chapter 3 of the Code, while Chapter 4 contains special provisions concerning land and water management in certain areas in Sweden. The provisions regarding the Government's permissibility assessment and the municipal veto are found in Chapter 17 of the Environmental Code.

7.6.1 The Government's compulsory permissibility assessment

Certain activities in Sweden may not be commenced without permissibility first being examined by the Government. This is compulsory for some activities. They are listed in Chap. 17 Sec. 1 and are:

- nuclear installations that are subject to assessment by the Government and plants for the extraction of uranium-bearing materials or other substances that can be used for the production of nuclear fuel[17]
- public navigation channels
- geological storage of carbon dioxide, if the activity does not pertain to storage for research purposes of less than 100,000 tonnes of carbon dioxide

It is clearly stated in the section that the Government shall assess the permissibility of new activities. Even though the section states that it is the facility that is to be assessed, it is clear from the introduction to the section that permissibility shall also be assessed for the activity as such.

The Government's permissibility assessment of these activities is thus compulsory. But if special reasons exist, the Government may in certain cases abstain from permissibility assessment. This may include activities that are of small scope or of a less intrusive nature, or if permissibility assessment is otherwise seen to be unnecessary.[18,19,20]

[17] Facilities for nuclear activities are assessed by the Government under the Act (1984:3) on Nuclear Activities.
[18] Cf. Chap. 17 Sec. 2 of the Environmental Code.
[19] Gov. Bill 1985/86:3 pp. 134 ff. and 193.
[20] Gov. Bill 1997/98:45 p. 217 ff.

Among the activities mentioned in the section are "nuclear installations that are subject to assessment by the Government pursuant to the Nuclear Activities Act". Thus, new nuclear power reactors, the encapsulation plant and the final repository for spent nuclear fuel are among the facilities that are subject to compulsory permissibility assessment by the Government. But it is only possible to permit a new nuclear power reactor provided that the new reactor is intended to replace an older existing reactor and if the reactor will be located on a site where a nuclear power reactor has been in operation to generate nuclear energy after 31 May 2005.[21]

7.6.2 Permissibility assessment after reservation

In addition to the compulsory permissibility assessment, the Government may, according to Section 3 of Chapter 17, reserve the right to assess the permissibility of an activity for which assessment is not compulsory but where the activity is likely to be of substantial scope or intrusive or affects certain protected areas etc.[22]

At the request of the municipal council, the Government shall reserve the right to permissibility assessment of a new activity of one of the following kinds, if such a reservation is possible according to Section 3 and special reasons to abstain from assessment do not exist:

1. iron and steel works and other metallurgical and ferro-alloy works;
2. pulp mills and paper mills;
3. facilities for refining of crude oil or for heavy petrochemical production;
4. plants for the manufacture of basic chemicals or fertilizers;
5. cement plants;
6. incineration plants with an input power of at least 200 megawatts;
7. wind farms that require a licence under regulations issued by the Government pursuant to Chap. 9 Sec. 6;

[21] Cf. Chap. 17 Sec. 6 of the Environmental Code.
[22] Cf. Chap. 17 Sec. 3 of the Environmental Code.

8. facilities for storage of at least 50 million normal cubic metres of natural gas;
9. facilities for the treatment of hazardous waste where most of the waste that is to be treated in the facility comes from other establishments and where more than 10,000 tonnes of hazardous waste is incinerated per year or otherwise recycled or disposed;
10. facilities for the extraction of substances or materials within the areas mentioned in Chap. 4 Sec. 5;
11. construction of platforms for offshore oil or gas extraction and of anchorages or moorings for such platforms, other than temporary ones, for the purpose of repairs, conversion or some other reason;
12. hydroelectric power plants designed for an installed generator output of at least 20 megawatts;
13. water regulation facilities with a water reservoir capacity of at least 100 million cubic metres per year or 10 million cubic metres per week;
14. diversion or other removal of water from watercourses or lakes with a normal unregulated low water flow of at least 10 cubic metres per second at the point of diversion or the outlet, where the amount of water used is such that the water flow is less than four-fifths of the normal unregulated low flow;
15. groundwater sources supplying more than 10,000 cubic metres of water per day, unless nine-tenths of the water removed is restored to the groundwater reservoir;
16. regulation, diversion or removal operations apart from those already mentioned which affect any of the lakes Vänern, Vättern, Mälaren, Hjälmaren, Storsjön (in Jämtland) or Siljan, and where the water operations are likely to be substantial or intrusive;
17. airports with a runway length of at least 2,100 metres.

7.6.3 Compulsory permissibility assessment applies to important societal interests

A common characteristic of the activities that are subject to the Government's permissibility assessment is that they constitute important societal interests at the same time as they risk harming human health, entail major environmental impact or large incursions in the environment and lay claim to valuable natural resources.[23]

Competing or conflicting interests must be weighed together in order to arrive at the best solution. In many cases, private interests may be weighed against public interests, or different public interests against each other. The assessment must be carried out so that different interests can be weighed together as fairly as possible.[24]

The judgements that are made ultimately represent political standpoints, where it is only natural that the Government has the final say regarding whether the activity can be realized or not.[25] Permissibility assessment gives the Government ample opportunity to steer the activity in the desired direction from the perspectives of industrial, energy, labour market, climate and regional policy.

7.6.4 Special conditions for the activity

If the Government finds that an activity is permissible, the Government may decide on special conditions in order to satisfy public interests. If the activity involves geological storage of carbon dioxide, the Government may also stipulate conditions that are needed in response to viewpoints offered by the European Commission in conjunction with the permissibility assessment.[26]

7.6.5 A licence is required in addition to permissibility assessment

An activity may not be conducted without a licence under the Environmental Code. It is the Land and Environment Court that considers a licence application for the activity. But before a licence application is considered by the Court, permissibility must first be

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[23] See Gov. Bill 1997/98:45, p. 215.
[24] See Gov. Bill 1997/98:45, p. 437.
[25] Rubenson, S. (2008) *Miljöbalken: den nya miljörätten*, part 3, p. 145.
[26] Cf. Chap. 17 Sec. 7 of the Environmental Code.

assessed by the Government. The Government's permissibility assessment constitutes a natural part of the licensing process under the Environmental Code.

The Government's decision on permissibility is binding on the Land and Environment Court. In other words, the Court cannot reject a licence application for an activity which the Government has found permissible in an assessment according to Chap. 17. Nor can it endorse a licence application which the Government has found unpermissible in an assessment according to Chap. 17.

If, however, the Court should find that the Government has made a formal error in its handling of the matter, the Court is not obliged to issue a licence.[27]

7.6.6 The Supreme Administrative Court can review the Government's decision

The Government's decision on permissibility is subject to the Act (2006:304) on Judicial Review of Certain Government Decisions. The Supreme Administrative Court can be petitioned to conduct a judicial review to determine whether the Government's decision violates any rule of law.

The Land and Environment Court's review is independent of any review in the Supreme Administrative Court, and the Land and Environment Court does not have to await a ruling by the Supreme Administrative Court before making its own ruling on the question of permissibility.

This means that the judicial reviews may take place simultaneously. Both bodies can entertain formal objections regarding the Government's handling of the matter. If the Supreme Administrative Court should find that the Government's ruling conflicts with some point of law before the Land and Environment Court has issued a ruling, the Court is presumably bound by this decision and can therefore not issue a licence.

[27] Bjällås, U. och Persson, I. (2011), *Licensing under the Environmental Code and the Nuclear Activities Act of a final repository for spent nuclear fuel.* Report 2011:2e, p. 31.

7.6.7 The municipal veto and the veto valve

The rules governing the municipal veto according to the earlier provisions in Sec. 136 a of the Building Act and the Natural Resources Act have been introduced in the Environmental Code without any real changes.

The Government may, as a principal rule, only permit environmentally hazardous activities if the municipal council in the municipality where the facility is to be sited has endorsed this and if they do not involve water operations or transport facilities.[28]

The municipal veto has, as before, been provided with a valve. The Government may permit the activity without the endorsement of the municipal council if it is of the utmost importance for the national interest that the activities be implemented. Such cases include facilities for interim storage or final disposal of nuclear material or nuclear waste, as well as large incineration plants, wind farms, facilities for storage of natural gas and facilities for treatment of hazardous waste.[29]

New facilities that are included in a system for final disposal of nuclear material or nuclear waste are planned to be built in Oskarshamn Municipality and Östhammar Municipality. The municipal councils in these municipalities thus have the formal option of vetoing the Government's permissibility assessment.

7.7 Prerequisites for the Government to disregard a municipal veto

In order for the Government to permit an activity without the municipality's endorsement, it is necessary that no other more suitable site can be found for the activity. By "more suitable" is meant here is meant more than just suitable from a technical and economic perspective. The reasons given by the municipalities for their attitudes must also be taken into consideration. Thus, a site in a municipality that endorses the siting may be considered more suitable than a site in a municipality that opposes an establishment, even if a siting in the latter municipality entails less of an intrusion in the environment, lower costs, etc. In summary, the right of the

[28] Cf. Chap. 17 Sec. 6 of the Environmental Code.
[29] Ibid.

Government to override the municipal veto must be exercised extremely restrictively.[30]

If a municipality does not carry out the detailed development planning needed for the Government's decision to be implemented, the Government may enjoin the municipality to adopt, amend or repeal a detailed development plan or area regulations, if this is necessary to satisfy a national interest.[31] In the unlikely event the municipality fails to comply with such a planning injunction, there must be a way to otherwise adopt, amend or repeal a plan which runs counter to an urgent public interest. As a last resort, the Government is therefore empowered to prepare and adopt the necessary plan. [32]

7.8 Conclusions

Via the municipal veto, the Swedish municipalities have been given a very strong influence over the establishment of major industrial facilities, even if they are of great importance for the country as a whole. Legal rules that give the municipal council in a municipality the power to veto a Government decision can be seen as an expression of the strong position municipal self-government enjoys in our democracy. Even if the municipal veto is provided with a valve which entails that the Government may permit the activity without the endorsement of the municipal council if it is of the utmost importance for the national interest that the activities be implemented, the Government may override the will of the municipal council without good reason. The Government must first show that it is not possible to find another more suitable site for the activity.

The introductory section of the Instrument of Government (Chap. 1 Sec. 1) states that Swedish democracy is "realized through a representative and parliamentary form of government and through municipal self-government." In other words, municipal self-government has been considered so important that it has been stipulated as an instrument for realizing democracy, along with parliamentarism. The central position of municipal self-government in Sweden and its important role in the democratic system is

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[30] See Gov. Bill 1997/98:45 II p. 221.
[31] Cf. Chap. 11 Sec. 15 of the Planning and Building Act (2010:900).
[32] Cf. Chap. 11 Sec. 16 of the Planning and Building Act (2010:900).

also underscored by the fact that a separate chapter is now devoted to the municipalities since the most recent amendment of the Instrument of Government.[33] Above all, however, the municipal veto can be attributed to the "municipal planning monopoly". The planning monopoly, which entails that the municipality decides how land is to be used and developed in the municipality, has been regarded as one of the most important premises for municipal self-government in Sweden. Decisions are made close to the people affected by them and societal initiatives can be planned taking into account local conditions.[34]

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33 Cf. Chap. 14 of the Act (2010:1408) on Amendment of the Instrument of Government.
34 Cf. Planning and Building Act (2010:900).

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Proposition 1977/78:31 om riktlinjer i den fysiska riksplaneringen för vissa s.k. obrutna fjällområden (Gov. Bill 1977/78:31 on guidelines in the national physical planning for certain unbroken mountain areas).

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8 Financing of the residual products of nuclear power

8.1 Introduction

Radioactive residual products in the form of spent nuclear fuel and other radioactive waste from nuclear activities arise in Sweden mainly in connection with the production of energy in nuclear power reactors. Radioactive waste also arises in connection with decommissioning of the nuclear power plants and operation and decommissioning of other nuclear facilities.

The residual products will be managed and disposed of long after the nuclear activities have ceased operating for their purpose and long after they have stopped generating revenue. Financing of the future costs of this management and disposal of residual products from nuclear activities is regulated in the Financing Act.[1] The residual products referred to here include:

- spent nuclear fuel
- other nuclear material that will not be reused
- nuclear waste that does not constitute operational waste

Waste that arises in conjunction with the decommissioning of a nuclear facility is covered by the financing legislation. Operational waste is not covered by the financing legislation. Operational waste consists of low- and intermediate-level nuclear waste that will be managed and disposed of during the time the nuclear facility is in continuous operation for its purpose. In other words, there is no

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

need to allocate resources for the future costs for management of the operational waste.

The nuclear activities legislation constitutes a robust and predictable system for financing the future costs for management and disposal of the radioactive residual products. A fundamental principle for the financing system is that the costs for final disposal of spent nuclear fuel and nuclear waste shall be covered by those who generated the waste – the *polluter pays principle*. For the residual products of nuclear power, this means that the money comes from the revenue of the energy production. The financial challenge is to ensure that no unreasonable financial burdens are laid on future generations.

Three elements can be distinguished in the Swedish nuclear waste programme which together are supposed to guarantee that resources are available in the right amount at the right time:

- Legitimate financing, which is supposed to guarantee that the resources are available when they are needed, which means that the financing system must be able to deal with all uncertainties, both in the cost calculations and in the financing system
- Effective cost calculations, which are supposed to determine the costs for the entire programme including the uncertainties in the calculations and document a methodology for calculating the costs and estimating the uncertainties
- An authentic organization, which is supposed to handle and check cost calculations and financing

This chapter focuses on the first of the three elements, i.e. the system for legitimate financing of decommissioning and waste management. A discussion of the basic principles and design of the financing system is occasioned by the revision of the system that has been carried out by the Swedish Radiation Safety Authority (SSM) on behalf of the Government. SSM submitted a report on this work on 4 June 2013.

A credible cost analysis is a prerequisite for the legitimacy of the financing, and here the Swedish National Council for Nuclear Waste looks at the uncertainty in these calculations. The demands are great both on the methodology for handling these uncertainties and on identification of factors that can create uncertainty. SKB submitted new cost estimates in January 2014 which will serve as a basis for calculating the fee and the supplementary amount for the next three years. The Swedish National Council for Nuclear Waste is of the opinion that an elucidation of the cost calculations is an important future task.

The chapter is concluded by a discussion of the discount rate, which is a very important factor in handling the large time differences between the streams of money into and out of the Nuclear Waste Fund.

8.2 The principles for the financial system

8.2.1 Those who generate the waste shall bear all responsibility and all costs

How the waste from nuclear power should best be managed and financed has been discussed since the early 1970s. But the premises have varied through the years. For example, the Swedish strategy during the 1960s and 1970s was that the spent nuclear fuel should be reprocessed. Since 1982, the Swedish strategy has been direct final disposal of the fuel without reprocessing.

But certain fundamental principles have remained unchanged. One basic principle that has crystallized from the discussions is the principle of producer responsibility. This principle, which entails that those who have generated the waste shall also bear all responsibility and all costs associated with it, is extremely important. The reactor owners must not be allowed to shift this responsibility onto the state or anyone else.[2] It is also fundamental to the design of the legislation.

The central premise in the financing system is thus that nuclear power production shall bear the costs of waste management. This shall be accomplished by making the companies that produce nuclear power responsible for paying all costs. Another important principle is that the project is an important obligation that must be carried to completion. It is in the vital interests of society that those who are responsible for nuclear waste management must not be allowed to opt out of it.

The nuclear waste project also has other special characteristics that distinguish it from other civil engineering and industrial

[2] Gov. Bill 1997/98:145, p. 381.

projects, such as the long project period. According to the industry's current planning scenario, the time interval between when the nuclear power reactors have been shut down and cease producing electricity, so that the reactor owners cannot contribute any more to the financing of the future costs, and when the power industry's planned final repository has finally been closed is a long one. Another aspect is the time lag between when payments are made into the financing system and disbursements are paid from it.

According to the power industry's current plan of action, the reactors in Forsmark and Oskarshamn will be operated for 60 years, as will the Ringhals 3 and 4 reactors. The planned operating time for Ringhals 1 and 2 is 50 years. These times are important premises for the planning. If all the reactors have been taken out of service by 2045 and decommissioned by around 2052, SKB's three final repositories (the Spent Fuel Repository, SFR and SFL) can be closed in about 2075.[3] In other words, high costs incurred by the work of decommissioning and dismantling the reactors and building and operating the final repositories may fall due after the reactor owners are no longer able to contribute to the financing.

This means it is possible that the power companies who are responsible under current law (the reactor owners) may be out of business before all aspects of the work of disposing of the spent nuclear fuel and nuclear waste have been completed. When the reactors have ceased generating and selling electric power, these companies no longer have any positive value.[4,5]

8.2.2 Ultimate responsibility rests with the state

On 19 July 2011, the European Council decided to establish a Community framework for the responsible and safe management of spent fuel and radioactive waste – the Nuclear Waste Directive – which entered into force on 22 August 2011.[6] The Directive

[3] SKB (2013), *RD&D Programme 2013 – Programme for research, development and demonstration of methods for the management and disposal of nuclear waste, including social science research*, p. 6.
[4] SOU 2004:125 *Betalningsansvaret för kärnavfallet*. Financing Committee, section 4.
[5] Swedish Radiation Safety Authority's (SSM) report of 4 June 2013 *Förändringar i lagen (2006:647) om finansiella åtgärder för hanteringen av restprodukter från kärnteknisk verksamhet och förordningen (2008:715) om finansiella åtgärder för hanteringen av restprodukter från kärnteknisk verksamhet* (Dnr: SSM2011-4690), section 4.9.2.
[6] Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste.

formulates a number of general principles that shall apply to the management of spent nuclear fuel and radioactive waste, including that all Member States are obligated to avoid placing any undue burden on future generations and therefore that the Member States must ensure that adequate financing is available for the management of spent fuel and radioactive waste. The Member States shall also ensure that the national framework requires that adequate financial resources are available when needed for the implementation of the national nuclear waste programme.

The Swedish state bears "ultimate responsibility" for both the safety and the financing of the disposal of spent nuclear fuel and radioactive waste. The principle of the ultimate responsibility of the state is also regulated in the 1997 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (the Nuclear Waste Convention), which Sweden has ratified.[7] Under the Convention, the Swedish state has undertaken to ensure that prime responsibility for the safety of spent nuclear fuel or radioactive waste management rests with the license holder (licensee). If there is no such licence holder or other responsible party, the responsibility rests with the state.[8]

In other words, the state's responsibility has two components:

1. an overall responsibility to ensure that final disposal is implemented
2. an ultimate responsibility for final disposal in the sense that the state shall assume the role of both purchaser and financer if the nuclear power industry is not able or willing to do the job

A state assumption of rights and obligations when there is no licensee who can be held responsible requires a careful legal analysis regarding the ownership of the spent fuel. The Radiation Safety Committee has focused attention on questions associated with the property where the final repository is situated in the event of bankruptcy or liquidation of the property's owner company.[9]

When the state assumes the rights and obligations of the licensee, it is the judgement of the Radiation Safety Committee that the title

[7] SÖ 1999:60 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, Ministry for Foreign Affairs. (Nuclear Waste Convention).
[8] Cf. Article 21 of the Nuclear Waste Convention.
[9] SOU 2011:18 *Strålsäkerhet: gällande rätt i ny form,* Radiation Safety Committee. pp. 504 ff.

to the land on which the final repository is situated is transferred to the state. This ensures not just the state's direct control over both the deposited fuel and the future use of the land, but also greatly simplifies the question of post-closure safeguards with the state as landowner. After title to the land on which the final repository is situated has been transferred to the state, the state is fully responsible for all aftertreatment if the final repository should cause damage or detriment to human health or the environment in the future.

The state's ultimate responsibility does not entail any limitation of the nuclear power industry's responsibility under the Nuclear Activities Act. This responsibility can, however, in reality be said to be limited due to the fact that the formal responsibility is borne by a company that probably does not have any real ability to pay once the reactors are shut down. This mismatch between liability to pay and ability to pay over time entails a risk for the state. This is why legislation has been drafted in this area.

8.2.3 Committee on Radioactive Waste (AKA Committee)

One of the tasks of the Committee (I 1972:08) on Radioactive Waste (the AKA Committee) was to propose forms for the financing of the treatment, transport and storage of radioactive waste and of research and development programmes.[10]

In its report[11], the AKA Committee described a strategy for how to manage the nuclear waste that was based on four main points:

1. reprocessing of the spent nuclear fuel with subsequent disposal of the vitrified high-level waste (the Committee's main alternative)
2. direct disposal of the spent nuclear fuel (which was offered as an alternative)
3. central interim storage of the spent nuclear fuel awaiting reprocessing or direct disposal

[10] SOU 1976:30 *Använt kärnbränsle och radioaktivt avfall, del I* and SOU 1976:31 *Använt kärnbränsle och radioaktivt avfall, del II*. Committee on Radioactive Waste.
[11] SOU 1976:30 *Använt kärnbränsle och radioaktivt avfall, del I*, pp. 84 ff.

4. a central final repository for low- and intermediate-level nuclear waste

The Committee also asserted that the closure of nuclear facilities would give rise to hard-to-handle waste in the future. A basic premise for the AKA Committee was that all costs for the management of radioactive waste and spent nuclear fuel were to be borne by the nuclear energy producers.[12]

The AKA Committee proposed that the power companies should include the future expenses for reprocessing of the spent nuclear fuel and final disposal of the high-level waste in their cost calculations for energy production from the nuclear fuel. The same principle was also proposed to apply to low- and intermediate-level waste from nuclear power plants. The AKA Committee recommended that a tax-exempt amount corresponding to these expenses should be allocated each year to a special internal fund in the nuclear power companies' final accounts. This was to cover costs when they arose, but in the meantime the allocated funds could be used in the companies, according to the proposal. The Government presented a Bill embodying this proposal, which was passed by the Riksdag.[13]

Cost calculations that served as a basis for the nuclear power companies' allocations for the next few years were carried out by a company jointly owned by the nuclear power companies, Svensk Kärnbränsleförsörjning AB (SKBF), now Svensk Kärnbränslehantering AB (the Swedish Nuclear Fuel and Waste Management Co, SKB). The premises for the cost calculations were the proposed solutions for the management and disposal of radioactive residual products that the nuclear power companies presented within the framework of the Nuclear Fuel Safety Project (KBS).[14]

With the support of the Ordinance (1979:27) with Authorization for the National Tax Board to Issue Regulations for Calculation of Deductions for Future Expenses for Management of Spent Nuclear Fuel etc., the Board issued regulations stating that the allocations

[12] See also SOU 1980:14 *Kärnkraftens avfall: organisation och finansiering.* Utredningen om kärnkraftens radioaktiva avfall - organisations- och finansieringsfrågor, p. 23.
[13] Gov. Bill 1978/79:39.
[14] KBS was formed in 1976 as a consequence of the requirements made in the Act (1977:140) on Special Permission to Load a Nuclear Reactor with Nuclear Fuel etc. (the Stipulations Act).

should not exceed SEK 9 per megawatt-hour in the 1980 tax assessment.[15]

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

A different solution to the financing problem was proposed in the 1980 Energy Bill. In accordance with the Bill, the Riksdag passed a new law: the Act (1981:669) on the Financing of Future Expenses for Spent Nuclear Fuel etc. The act entered into force on 1 July 1981.

The act entailed a transition to the principles that now apply regarding the reactor owners' obligations and responsibility for financing. The provisions also agree in large parts with those now embodied in the Nuclear Activities Act[16] and the Financing Act.

The act defines the obligations of the reactor owners. The holder of a licence to own and operate a nuclear reactor shall be responsible for ensuring that:

- spent nuclear fuel and radioactive waste are managed and disposed of in a safe manner
- the reactor plant can be decommissioned and dismantled in a safe manner
- the research and development activities needed to fulfil these obligations are conducted

The reactor owners were required, as under current law, to draw up a plan in consultation with other reactor owners for the research and development activities needed to fulfil their obligations. The plan was also supposed to contain an overview of "necessary measures intended to be adopted during the coming five years". The plan was to be revised each year and sent in to the Government or the authority designated by the Government.[17] The authority that was originally responsible for this was the then National Board for Spent Nuclear Fuel (SKN), but in 1992 the

[15] Gov. Bill 1980/81:90, p. 316.
[16] Cf. Secs. 10, 11 and 12 in the Act (1984:3) on Nuclear Activities.
[17] According to Sec. 12 of the Nuclear Activities Act, the programme for research and development (RD&D programme) shall be prepared every third year.

duties were transferred to the Swedish Nuclear Power Inspectorate (SKI) when SKN was discontinued.

According to the act, the reactor owner was liable for the costs of fulfilling the obligations and should therefore pay a fee to the state as long as the reactor was in operation. The fee was to be based on the energy the reactor delivered and be determined on the basis of the annual plan. The fees were to be deposited in interest-bearing accounts at the Riksbank (the Swedish central bank), one for each licensee. In connection with the transition to the new financing system, the funds that had already been set aside by the licensees in their annual accounts were transferred to their respective accounts at the Riksbank.[18]

Besides being liable for the costs of fulfilling their obligations, the reactor owners were also to be liable for the state's costs for:

1. conducting supplementary research and development
2. examining matter relating to the annual fee
3. monitoring and inspecting final repositories[19]

In its statement of comment on the draft law, the Council on Legislation states that the reactor owners' obligations are not only "to implement and pay for the actual measures required, but also to be liable up to the remainder of the company's total assets for costs which the state might incur for such measures, in the event the reactor owner fails to discharge his obligations and the state is therefore compelled to implement the measures".[20]

The Council on Legislation also stated that the paid-in fees "constitute funds that belong to the state"; but that the intention is that the funds should be set aside to be used for specific purposes. The reactor owners are entitled to receive remuneration from the funds for costs for such measures as the funds are intended for. But if the reactor owners are unable to fulfil their obligations, the state must step in and assume responsibility for ensuring that the necessary measures are implemented. The Council on Legislation

[18] For several years, the reactor owners were able to borrow from the funded assets. This option was abolished by a change in the law in the mid-1980s.
[19] These obligations are equivalent today to the provisions in Secs. 4 and 6 of the Financing Act.
[20] Gov. Bill 1980/81:90, Appendix 1, Annex F, p. 637.

recommended that the state's utilization of the funds for costs incurred by the state should be stipulated in the act.[21]

8.2.5 Subsequent amendments to the Financing Act

In connection with certain changes in the regulatory organization for nuclear activities, the Riksdag decided in 1992 at the proposal of the Government to change the wording of the Financing Act.

The new Act (1992:1537) on Financing of Future Expenses for Spent Nuclear Fuel etc. does not entail any fundamental changes in the structure of the financing system.

The Nuclear Fuel Fund Committee, which was appointed in May 1993, raised the question of the reliability of the financing system in view of the fact that the Financing Act aims to ensure that nuclear power production finances all costs incurred by the management and disposal of spent nuclear fuel, long-lived nuclear waste and decommissioning waste. The report[22] proposed a system with supplementary guarantees.

The Government and the Riksdag adopted the proposals of the Nuclear Fuel Fund Committee for two supplementary guarantees in order to guarantee payments to the Fund if the nuclear power plants are shut down before the reactors have been operated for 25 years, and to pay "reasonable costs for additional measures occasioned by unplanned events". The guarantees were to be furnished by the licensees.[23]

The new scheme also entailed that the deposits in the Riksbank were transferred to the National Debt Office and came to be designated the Nuclear Waste Fund. The funds were to be managed by a special authority, the Board of Governors of the Nuclear Waste Fund, which subsequently also came to be designed the Nuclear Waste Fund.

The provisions were supplemented in 1996. The statutory arrangement that was set up then is in principle the same as that which applies today. According to the provisions, a fee based on the total cost for management and disposal of the nuclear waste

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[21] Ibid., p. 639.
[22] SOU 1994:107 *Säkrare finansiering av framtida kärnavfallskostnader.* Nuclear Fuel Fund Committee.
[23] Gov. Bill 1995/96:83.

shall be paid by the owner of a nuclear power reactor in relation to the number of kilowatt-hours of electricity delivered by the plant.

According to the law, the fee is intended to finance costs for management and disposal of the spent nuclear fuel and other radioactive waste, costs for safe decommissioning and dismantling of the nuclear power plants, and costs for related research and development. The fees are to be paid quarterly to the Nuclear Waste Fund. The reactor owner shall moreover pledge guarantees that cover a) the shortfall in the Fund that arises if all nuclear power reactors are shut down during the current year as well as the costs for decommissioning of the nuclear power plants, and b) costs for additional measures occasioned by unplanned events. The guarantees shall be pledged to the Board of Governors of the Nuclear Waste Fund, which manages them.

The act was superseded in 2007 by the Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities (the Financing Act), which is currently in force. The act applies to everyone who holds a licence to own or operate nuclear facilities that gives rise to high-level nuclear waste for which long-term disposal is required and not just reactor owners, like the previous legislation.

According to the act, nuclear waste fees shall be levied to cover the costs incurred by management of waste and decommissioning and dismantling of nuclear facilities waste up until the waste is placed in a final repository (basic cost), as well as the state's costs for administration and supervision (extra costs). The fee liability does not cease until all spent nuclear fuel and nuclear waste is contained in closed repositories. The fees shall be deposited as before in the Nuclear Waste Fund.

The new law offers better options for requiring guarantees to cover amounts that are not covered by the Fund. The guarantees consist of:

- an amount corresponding to the difference between the remaining basic costs and extra costs for the waste products that have arisen at the time of the calculation and the funds that have been set aside for these costs (the financing amount)
- an amount corresponding to a reasonable estimate of the basic cost which can arise as a result of unplanned events (supplementary amount).

The current law also entails that the process for determining fees and guarantees is more flexible and that the options for managing the risk borne by the state for the nuclear waste costs have been improved.[24]

8.2.6 Backing of the Riksdag

As the Swedish National Council for Nuclear has reported on several previous occasions, the Riksdag gave early backing to four fundamental principles relating to the management of spent nuclear fuel and nuclear waste.[25] These four fundamental principles are presented in the following section.

The division of responsibilities that emerges in these fundamental principles is reflected in the Act (1984:3) on Nuclear Activities (the Nuclear Activities Act) and in the Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities (the Financing Act).

The *first* fundamental principle is that the costs for final disposal of spent nuclear fuel and nuclear waste must be covered by revenues from the production of energy which has given rise to them. Considering the long time periods required for management and disposal, expenses will arise long after production at a plant to which the spent nuclear fuel can be attributed has ceased. This means that funds for future expenses for management and disposal of spent nuclear fuel must be continuously taken from the revenues of energy production.

This principle has been expressed in both the Financing Act and the Nuclear Activities Act.[26] The fee liability does not in practice cease until all spent nuclear fuel and nuclear waste is contained in closed repositories.

The *second* fundamental principle is that a reactor owner must take responsibility for ensuring that spent nuclear fuel and nuclear waste are managed and disposed of in a safe manner. This means that the reactor owners must ensure that the requisite measures for

[24] Gov. Bill 2005/06:183.

[25] See e.g. Gov. Bill 1980/81:90, Appendix 1, p. 319, Gov. Bill 609 and 610:60, p. 38, Gov. Bill 1997/98:145, p. 381, and the Parliamentary Committee on Industry and Trade's reports 1988/89:NU31 and 1989/90:NU24.

[26] Cf. Sec. 11 of the Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities (the Financing Act) and Sec. 13 of the Act (1984:3) on Nuclear Activities.

management and disposal are actually implemented. They must also, in addition to the actual technical operations, make sure they have an organization for the activity with sufficient financial, administrative and human resources to fulfil these obligations.

The licensee's obligations to safely dispose of the spent nuclear fuel remain in force until they have been fulfilled. The question of when the licensee can be considered to have fulfilled his obligations will depend on when the final repository has been finally closed. The second principle is regulated in the Nuclear Activities Act.[27]

A *third* fundamental principle is that the state bears overall responsibility for spent nuclear fuel and nuclear waste. Long-term responsibility for management and disposal of spent nuclear fuel and nuclear waste should rest with the state. After the repositories[28] have been closed, some form of responsibility for and supervision of the repositories will have to be maintained for some time to come. A state authority may assume responsibility for the closed repositories.

When it comes to this principle, the Government has declared that it is only natural that the state should bear ultimate responsebility for ensuring that an activity that is regulated in the Nuclear Activities Act should function satisfactorily even in the very long term.[29] As mentioned above, the state also has a formal ultimate responsibility via Sweden's ratification of the 1997 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (the Nuclear Waste Convention) and via the EU's Nuclear Waste Directive.

On 11 December 2008, the Government decided to appoint a special investigator to review the legislation in the area of nuclear activities and radiation protection.[30] According to the terms of reference for the investigation, the need for and possible formulation of a statutory regulation of the long-term responsebility for the closed final repository for spent nuclear fuel was to be considered.

The special investigator's report proposed that a statute be passed regulating the state's ultimate responsibility for the spent

[27] Cf. Secs. 10, 11, 12, 13 and 14 of the Nuclear Activities Act.
[28] This refers to a) the already existing final repository for radioactive operational waste (SFR in Forsmark), b) a planned final repository in Forsmark for spent nuclear fuel, and c) additional final repositories that may be needed for decommissioning waste.
[29] Gov. Bill 1997/98:145, p. 381, fourth paragraph.
[30] Utredningen om en samordnad reglering på kärntekniks- och strålskyddsområdet (Radiation Safety Committee).

nuclear fuel.[31] Such a statute has several advantages, according to the investigation. The state's responsibility is clarified via the proposed statute. Such a statute can create security for concerned actors such as the municipality where the fuel will be disposed of, its inhabitants, property owners and even the power industry. Systematic state supervision eliminates the risk that the licensees will become less motivated to fulfil their responsibility to find a solution for disposal of the spent fuel. A state assumption of rights and obligations when there is no licensee who can be held responsible requires a careful legal analysis regarding the ownership of the spent fuel. The Government is still considering the investigator's proposal.

A *fourth* fundamental principle, which has been established repeatedly by the Riksdag, is that every country must take responsibility for the spent nuclear fuel and nuclear waste generated in that country.[32] From this it follows that final disposal of spent nuclear fuel and nuclear waste from nuclear activities in another country may not occur in Sweden other than in exceptional cases.

This fourth principle emerges from Section 5 a, second paragraph of the Nuclear Activities Act. This principle is also expressed in the EU's Nuclear Waste Directive, which prescribes that radioactive waste shall be disposed of in the Member State in which it was generated, unless an agreement has been concluded between member states to use a disposal facility in one of them.[33]

On 19 December 2013, the Government submitted a draft text of a Government Bill to the Council of Legislation proposing amendments to the Nuclear Activities Act incorporating the provisions in the Nuclear Waste Directive in Swedish legislation. These amendments would entail that a licence is required for disposal of nuclear material abroad if this material comes from an activity in Sweden. Such a licence would moreover only be granted if the advantages from a nuclear safety radiation protection viewpoint of disposal abroad clearly outweigh the advantages of disposal in Sweden. Moreover, such a licence may only be granted if Sweden and the other country have an agreement on such disposal.

[31] SOU 2011:18 *Strålsäkerhet: gällande rätt i ny form*, Radiation Safety Committee, p. 493 ff.
[32] See Gov. Bill 1992/93:98, p. 29.
[33] Cf. Article 4 of Council Directive 2011/70/Euratom of 19 July 2011.

8.3 Cost calculations

8.3.1 Uncertainties in cost calculations

The time for construction, operation and closure of a facility for final disposal of spent nuclear fuel is estimated to be around 70 years, based on current planning of the operating time of the nuclear power reactors. According to the current timetable from SKB, the facility will be ready to receive the first canister by the mid-2020s and the last canister about 50 years later. After that the repository will be backfilled and closed.

Altogether, it is thus a very long project period, which is a strong contributing factor to the high cost uncertainty in the nuclear waste programme – the longer the time horizon considered, the more uncertain is the future. In the scenario with an operating time of 50 or 60 years for the nuclear power reactors, there will be no payments to the Nuclear Waste Fund after 2045.

As in the case of other industrial and civil engineering projects, there is a risk that the cost and revenue streams may not match each other as well as they are presented in the calculations. The Financing Act and the Financing Ordinance have therefore been drafted on the assumption that considerable cost uncertainty exists. There is a high level of complexity in the cost calculations that serve as a basis for calculation and determination of fees and guarantees, which is reason for caution in the calculation of expected costs and associated uncertainty margins for the nuclear waste programme.

The same measure of caution is also warranted in the review of the cost bases and the Government’s different decisions on fees and guarantees. The nature of the project – where the lowest cost outcome is limited while the highest cost outcome is in theory almost unlimited – makes it reasonable to assume that the cost uncertainty is asymmetric. This implies a relatively higher probability of large cost increases than of large cost savings.

The nuclear power industry carries out cost calculations regularly. The Swedish Radiation Safety Authority (SSM) has compared the most recent calculation from 2011 with the calculation from 2008 and thereby found that the expected total future costs have increased by about 38 percent in real terms between these two years. The fact that the calculations cover different time periods and pertain to different price levels had then been taken into account.[34]

According to SSM, the increased costs can be considered in relation to the uncertainty analysis that is performed. In the uncertainty analysis performed in the 2008 calculation, the 90th percentile, i.e. the value for which the probability is 90 percent that it will not be exceeded, was about SEK 85 billion. The expected value of the total future costs in the calculation from 2011 is SEK 94 billion. This clearly illustrates the great uncertainty that exists in the cost calculations.

The large uncertainties underscore the importance of a well-documented methodology for handling the calculations. Both SKB and SSM use a method called successive calculation[35], which can be characterized as an expert-based Delphi method supported by statistical assumptions. The methodology is used by other organizations in Sweden, such as the Swedish Transport Administration, for cost calculations for large infrastructure projects. The calculation is carried out by a project group, which is responsible for detailed scenario analysis. An analysis group of diverse composition identifies uncertainty factors and judges possible outcomes of the identified uncertainties. By means of statistical methods, the outcomes are plotted in a total cost curve for the whole programme. This cost curve shows the probabilities of different total costs and provides a basis for calculating the fee to the Nuclear Waste Fund and the supplementary amount.

The term "successive" refers to the fact that the analysis process is repeated by using the results from the preceding uncertainty analysis as input to the analysis group (feedback). The analysis is thus successively refined, but the question is to what extent genuinely new factors are introduced by these iterations. The end result is based on the subjective evaluations of the analysis group, but it is difficult to see how such evaluations can be avoided considering the long time horizon. A diversely composed analysis group is, however, extremely important to prevent the end result from being weighted in one direction and to guarantee an unbiased assessment of even extreme scenarios.

It was mentioned above that the analysis indicates an asymmetry in the uncertainties, i.e. it is easier to identify factors that

[34] SSM's report of 4 June 2013, dnr SSM2011-4690.
[35] Probability curve for different cost outcomes.

lead to large cost increases than to large cost reductions. However, it is important for programme control and resource management to analyze the opportunities for cost reductions. One question is how lessons gained from experience and new technological developments can be utilized to reduce costs during the course of the project. This question assumes special importance due to the long time horizon, which encompasses several generations of active persons, and due to the opportunities for learning within and between national programmes for e.g. decommissioning of nuclear power plants. Learning curves offer a means for calculating and checking the effects of learning. There is a very extensive body of international literature on learning curves, and it is the Council's opinion that the possibilities of using this method to quantify the effects of learning in the cost estimates should be analyzed.

8.3.2 The discount rate – an important factor in calculating the nuclear waste fee

In order to be able to calculate the size of the fees that need to be paid into the Nuclear Waste Fund to finance the expected future costs for management and disposal of spent nuclear fuel and nuclear waste, it is necessary to determine the discount rate to be used in the calculations. There are a number of models for determining what discount rate[36] is appropriate to use in different contexts.

The fundamental principle in this context is that the discount rate should be equal to the Nuclear Waste Fund's expected rate of return.[37] An important factor in the calculation is thus the real rate of return that can be expected on the Fund's assets.[38] The real rate of return on the Fund's assets is dependent on how the assets are invested. As good a prediction as possible should be made of the real return that can be expected from the investment portfolio.

The fees to the Nuclear Waste Fund must be large enough so that the amount that is paid, together with the expected future

[36] The discount rate is the interest rate that is used to compare the value of payments that are separated in time and extend over a long period of time. It should reflect the yield requirement, with reference to both actual capital costs and the risks associated with investments.
[37] Gov. Bill 1995/96:83, pp. 23-24.
[38] The real interest rate is the rate of return obtained after adjustment for inflation.

return, is enough to finance the expected future costs. This means that the rate of return on the Fund's assets must be equal to the interest rate on the liabilities, and that the same discount rate should be used for calculating the present value of assets and liabilities – in other words, a balance sheet.

The calculation of the nuclear waste fee is closely linked to how a discount rate curve that reflects the Nuclear Waste Fund's expected return is plotted. If discount rates that are higher than the Fund's expected rate of return are used to calculate the nuclear waste fees, the fees will be too low and the paid-in fees, together with the return from the Nuclear Waste Fund, will not suffice to finance the expected future costs.

The nuclear waste fee for each licensee is determined at each calculation occasion so that the value of the assets is equal to the value of the liabilities. The fee is calculated based on expected values of all components of the balance sheet.

The licensees' liability consists of the discounted value of the expected expenses that are associated with the obligations that follow from the Nuclear Activities Act. The expected expenses are calculated as probability-weighted averages. The value of the asset (the fee) is calculated with the same discount rate curve as the liability.

8.4 Conclusions

How the waste from nuclear power should best be managed and financed has been discussed since the early 1970s. The premises have varied through the years. But certain fundamental principles have remained unchanged. One of these principles is that the costs for final disposal of spent nuclear fuel and nuclear waste must be covered by revenues from the production of energy which has given rise to them.

The nuclear waste project has special features that distinguish it from other civil engineering and industrial projects. One such feature is the long project period. Spent nuclear fuel and nuclear waste will be managed and disposed of long after the nuclear activities have ceased operating for their purpose and long after they have stopped generating revenue.

The long project period is a strong contributing factor to the high cost uncertainty in the nuclear waste programme – the longer the time horizon considered, the more uncertain is the future. As in the case of other industrial and civil engineering projects, there is a risk that the cost and revenue streams may not match each other as well as they are presented in the calculations. The probability of large cost increases is higher than the probability of cost savings.

The Financing Act and the Financing Ordinance have therefore been drafted on the assumption that considerable cost uncertainty exists. According to the law, the fee liability for those who have generated the waste does not cease until all spent nuclear fuel and nuclear waste is contained in closed repositories.

The fees are deposited and managed in the Nuclear Waste Fund. An important factor in the cost calculation is the real rate of return that can be expected on the Fund's assets.

The Swedish state bears "ultimate responsibility" for both the safety and the financing of the management and disposal of spent nuclear fuel and radioactive waste. The state's responsibility has two components: to make sure that final disposal is realized, and to assume the role of purchaser and financer if the nuclear power industry is not able or willing to do the job.

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Sweden's international agreements (SÖ)

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

Government Bills (all in Swedish)

Proposition 1978/79:39 om avdrag för framtida utgifter för hantering av kärnbränsle (Gov. Bill 1978/79:39 on deductions for future expenses for management of spent nuclear fuel).

Proposition 1980/81:90 om riktlinjer för energipolitiken (Gov. Bill 1980/80:90 on guidelines for national energy policy).

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1988/89:NU31

1989/90:NU24

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 the holder of a licence to own or operate a nuclear reactor shall prepare or have prepared according to Section 12 of the Act (1984:3) of the Act on Nuclear Activities.

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

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

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

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

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

The committee's task shall be regarded as completed when the Government has made a decision on the licence 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 approve 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)