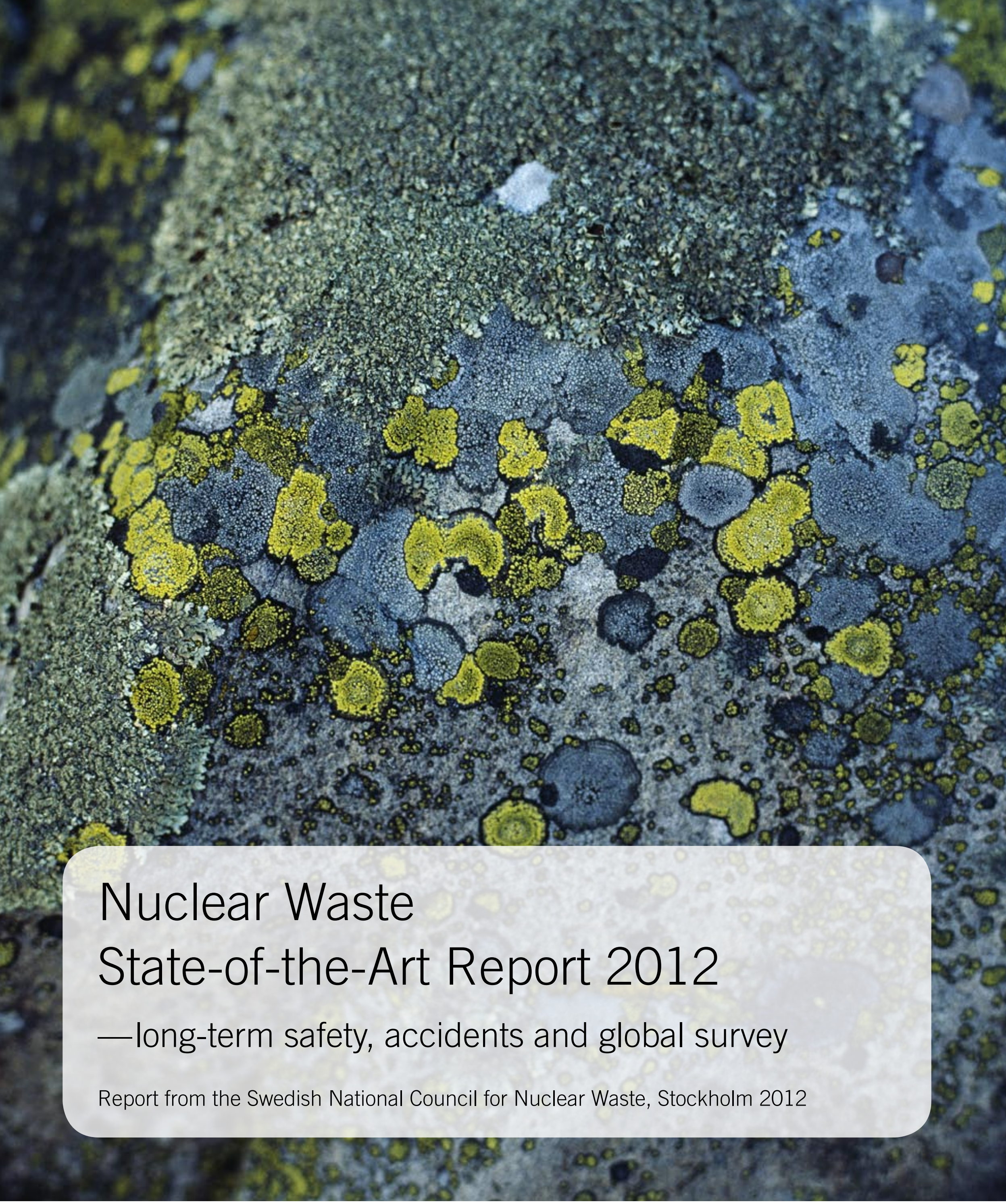

Nuclear Waste State-of-the-Art Report 2012

—long-term safety, accidents and global survey

Report from the Swedish National Council for Nuclear Waste, Stockholm 2012

KÄRNAVFALLSRÅDET
Swedish National Council for Nuclear Waste

SWEDISH GOVERNMENT INQUIRIES

SOU 2012:7

Nuclear Waste State of the Art Report 2012 – long-term safety, accidents and global survey

Translation of SOU 2012:7

The Swedish National Council for Nuclear Waste Report

Stockholm 2012

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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 the month of February every year, the Swedish National Council for Nuclear Waste publishes its independent assessment of the current state of the art in the nuclear waste field, known as a state-of-the-art report. The purpose of the report is to shed light on issues which the Swedish National Council for Nuclear Waste considers particularly relevant and clarify the Council's viewpoints on these issues.

The Swedish National Council for Nuclear Waste hereby submits this year's state-of-the-art report (the twelfth in this series) entitled "Nuclear Waste State-of-the-Art Report 2012 – long-term safety, accidents and global survey" (SOU 2012:7).

The work of the Swedish National Council for Nuclear Waste during 2011

In March 2011, the Swedish Nuclear Fuel and Waste Management Co (SKB) submitted its applications for a final repository for spent nuclear fuel to the Land and Environment Court at Nacka District Court and to the Swedish Radiation Safety Authority, SSM. The Council called attention to the submission of the applications in a report describing the environmental court's process for handling applications [i] and at an open seminar on the same subject on 12 May 2011.

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[i] Report 2011:2 Tillståndsprövningen enligt miljöbalken och kärntekniklagen. (Licensing under the Environmental Code and the Nuclear Activities Act, in Swedish only).

During 2011, the Swedish National Council for Nuclear Waste has identified questions regarding SKB's final repository programme that require further examination and presented its viewpoints in its review of SKB's programme for research, development and demonstration (RD&D programme)[ii].

The engineered barriers are important guarantees of the long-term safety of the final repository for high-level nuclear fuel. The Council therefore held a symposium on 15 June 2011 for the purpose of establishing how well SKB has made use of existing knowledge concerning bentonite, buffer and backfill, and how this has affected the content, preparation and design of the barriers.

The Council has furthermore participated actively in the joint international work and followed the development of other countries' management of nuclear waste and spent nuclear fuel.

In this year's state-of-the-art report, the Council has focused on the following areas:

- the function of the engineered barriers during the life of the repository
- the role of the safety assessment in different phases
- international perspectives, above all regarding the nuclear accident in Fukushima.

The present report is endorsed by all members and experts in the Swedish National Council for Nuclear Waste.

Chapter 2, "Safety assessment for design, construction and deposition," was prepared by Clas-Otto Wene (member), while Chapter 3, "From initial state to target state in the final repository for spent nuclear fuel", was prepared by Willis Forsling (member) and Hannu Hänninen (expert). Ingvar Persson (expert) and Mats Harms-Ringdahl (member) prepared Chapter 4, "From Chalk River to Fukushima – accidents that have influenced the nuclear power legislation." Chapter 5, "Survey of other countries' final repository programmes," was prepared by Ingvar Persson (expert), Holmfridur Bjarnadottir (administrative director), Peter Andersson (administrative officer) and Karolina Brogan (assistant administrative officer). The text was edited by Isabel Runebjörk.

English versions of the reports on the state-of-the-art in the nuclear waste field for 1998, 2001, 2004, 2007, 2010 and 2011 are

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[ii] See the Swedish National Council for Nuclear Waste's Review of the Swedish Nuclear Fuel and Waste Management Co's (SKB's) RD&D Programme 2010, which was submitted to the Ministry of the Environment in June 2011.

also available. The Council intends to publish an English translation of the 2012 report later this year.

Stockholm, 29 February 2012

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Contents

1 Introduction

Two events in particular during 2011 influenced the public debate concerning nuclear waste and nuclear power in Sweden and the world. In Sweden it was SKB's licence application for a final repository for spent nuclear fuel, while internationally it was the nuclear accident in Fukushima.

This year's state-of-the-art report consists of two parts:

- Part 1: "From here to eternity," sheds light on SKB's application, with a focus on the long time perspective and the functions of the safety assessment.
- Part 2, "International survey," deals above all with the nuclear disaster in Fukushima, but also provides international perspectives on the final repository issue and describes different countries' final repository programmes as well as the new EU directive.

1.1 The long perspectives in SKB's applications

On 15 March 2011, SKB submitted its applications for construction of a facility for final disposal and an encapsulation plant for spent nuclear fuel according to the KBS-3 method to the Swedish Radiation Safety Authority (SSM) and the Land and Environment Court at Nacka District Court.

The first stage of the review consists of identifying the need for supplementary information, for which reason SSM and the Land and Environment Court have forwarded the application to a large number of reviewing bodies. The Swedish National Council for Nuclear Waste has received the application for consideration and comment from the Land and Environment Court in compliance with the Environmental Code, and will submit its viewpoints on 1 November 2012.

The KBS-3 method is based on a multiple barrier system that has to function for more than 100,000 years. When the engineered barriers (copper canister, bentonite buffer, backfill) are in place in site the final repository, they are characterized at first by an initial state, and following a series of natural processes, a target state is achieved which will then persist for the duration of the life of the repository. These processes proceed under varying conditions in different parts of the repository, which means that the barriers reach their target state at different times. In recent years, the Swedish National Council for Nuclear Waste has given its view of the different roles of the barriers in the final repository, in particular the integrity of the copper canister and the function of the bentonite clay, and described the challenges to the KBS-3 method that been posed by the results of independent research groups. A particular challenge is corrosion of the copper canister, and the Council has during the year reiterated how important it is that the buffer can fulfil its function in protecting the copper canister.

In this year's state-of-the-art report, we discuss the concepts of initial state and target state and how the function of the barriers is affected by the transition from one state to another.

Furthermore, we examine the double role of the safety assessment in the final repository project: its internal role as a tool for the control and organization of the project within SKB, and its external role in society's licensing process. The chapter focuses on the safety assessment's internal role and its importance for the design premises and for project control and organization and addresses three questions:

- Will SKB succeed in translating the safety assessment into a realistic and (in-situ) verifiable building code?
- How does SKB manage to analyze the dynamic in the transition from an initial state to a stable target state?
- What kind of organization is needed to ensure for more than a half a century that the building code is realized in the initial state?

1.2 The nuclear accident in Fukushima and a global survey

On 11 March 2011, Japan was shaken by an earthquake with subsequent tsunami that resulted in a disastrous accident at the nuclear power plant in Fukushima. The accident had a great impact on the international debate concerning nuclear power and led to international cooperation on stress tests of nuclear power plants. The accident also had an impact on national nuclear power policy, particularly in Germany and Switzerland. This year's state-of-the-art report gives an account of the sequence of events during the accident and its aftermath, as well as the impact it has had on the international debate surrounding nuclear power.

The International Atomic Energy Agency, IAEA, has identified Sweden, Finland and France as the countries that have come farthest in the process of developing and licensing a repository for spent nuclear fuel, and the review of SKB's application is being followed with great interest internationally. More knowledge about other countries' final repository programmes (and how they are progressing) is also important for being able to follow and give viewpoints on the Swedish programme. This year's state-of-the-art report therefore gives a brief description of the final repository programmes in several European countries and the USA.

2 Safety assessment for design, construction and deposition

2.1 The roles of the safety assessment

As the Swedish National Council for Nuclear Waste has pointed out, SKB gives the safety assessment a double role in the nuclear waste system: "an internal role as a management tool within SKB and an external role in society's licensing process" (1). The external role is well documented in a development process that extends over decades and where SR-Site in SKB's application is the most recent link in a long chain of safety assessments. The internal role is less well documented and elucidated, at the same time as this role will be broadened and take on new importance in connection with the construction and operation of a final repository. In the present state-of-the-art report, as in previous commentaries, the Swedish National Council for Nuclear Waste therefore focuses on this internal role (1), (2).

During the first part of the final repository project, the primary function of the safety assessment, in both its external and internal role, has been as a guarantor. The assessment is supposed to guarantee that it is possible to build a reasonably safe final repository – both in Swedish model bedrock and on the selected site.

In the next phase of the project, the function of the safety assessment (in its role as an internal management tool) is shifted from guaranteeing to normative and controlling. The importance of the safety assessment's normative and controlling function will gradually increase as the licensing process progresses, becoming dominant after the start of construction, providing SKB obtains a licence to build the repository (2). The safety assessment is then supposed to formulate the building code, i.e. the requirements which the final repository must meet at closure (in which case it is normative), at the same time it must control how the project organization is designed so that the safety assessment is integrated in all parts of the project management (in which case it is controlling).

The purpose of this chapter is to illustrate how the design premises that constitute the building code are derived from the safety assessment, and to outline the role of the safety assessment in the control and organization of the project.

2.2 The safety assessment during construction and operation

The functions of the safety assessment during construction and operation are combined in a dynamic relationship (see Figure 2.1 below). The building code is derived from the safety assessment, and the project organization must integrate the safety assessment in its work in order to be able to realize the desired initial state[i].

The initial state describes the properties of the final repository at closure and is the point of departure for the assessment of the repository's safety. It could be said that all work with construction and operation is aimed at leaving the repository in such an initial state that the safety assessment can then guarantee reasonable safety for a million years. Following is a brief description of the normative and controlling functions of the safety assessment during construction and operation.

2.2.1 The normative function

The safety assessment stipulates the requirements that must be met by canister, bentonite, backfill and rock in order to guarantee a reasonably safe final repository. The building code for the final repository should reflect these requirements. In the methodology developed by SKB, the safety assessment generates design premises for each of the engineered components and the rock openings (3). The design premises specify the properties which these parts must possess in order to achieve the desired initial state. Together, the design premises constitute the building code for the final repository.

[i] The SKB application defines "initial state" as follows: "Properties of the spent nuclear fuel and the engineered barriers when they are finally put in place in the final repository and are not handled further in the final repository. Properties of underground openings at the time of final deposition, backfilling and closure." (Top document – Terms and definitions).

The relationships between safety assessment, initial state and building code are complex, however. The construction time for the repository is more than a half a century, which means that the design premises at the start of construction represent a building code that will be realized over five decades in an initial state that meets the requirements of the safety assessment.

The detailed properties of the rock influence the design of the repository, but constitute an uncertainty factor that will not be resolved until the last canister has been deposited. SKB will build the final repository in accordance with the Observational Method (4), which means that the value of certain parameters will be measured continuously, and if the value deviates beyond an expected interval the design will be modified. Scientific research and technical development may alter the premises for the repository, requiring adjustments. Human error can also have consequences for the function of the repository and require adjustments.

Events and new findings may thus require changes in the building code, at the same time as the initial state will be realized progressively during the entire construction period, since SKB intends to backfill and plug deposition tunnels as the deposition holes are filled.

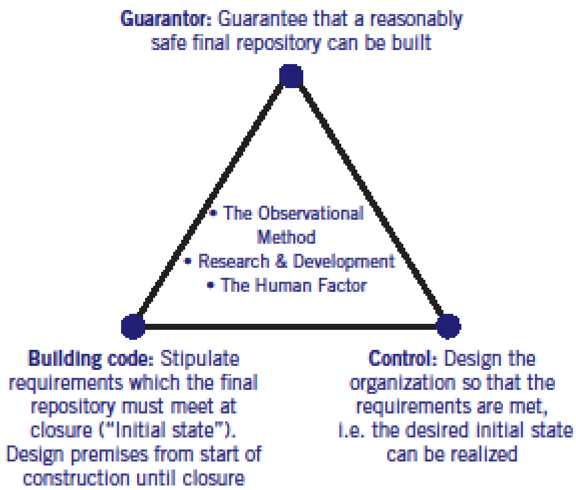
2.2.2 The controlling function

Realizing the initial state makes high demands on the project organization. It must guarantee in each phase of execution – from construction and operation to closure and decommissioning – that the desired initial state is achieved.

In order for the repository to conform to the building code, the project organization must have adopted and integrated the safety assessment in its work. A project that extends over several generations of employees also makes special demands on the continuity of the organization and the transfer of knowledge and experience. An important question is how competence in safety assessment is to be preserved and developed, including how the safety assessment controls the construction and operation activities.

The rock, research and development, and the human factor are examples of factors that require the project management's attention during the long construction period and that can necessitate a safety assessment with new boundary conditions, requiring an update of the building code and the design premises, which may in turn require changes in the project organization. In view of the long construction period, it appears highly likely that the actual initial state at closure will deviate from the design premises that applied at the start of construction.

Figure 2.1 Interaction between the three functions of the safety assessment: as a guarantor and as a basis for the building code and project control



2.3 From guarantor to building code

Design premises are required for the (engineered) components in the final repository that influence long-term safety. SKB identifies five such components for KBS-3 (3):

- Canister
- Buffer
- Deposition holes
- Deposition tunnels and their backfill
- Main tunnels and central area etc., and repository closure

The properties of the rock are not a design premise, but they do constitute a boundary condition for the five components. If the rock turns out to have other properties than planned, the design premises may have to be modified. As pointed out in the preceding section, the rock is a very important factor, which can result in deviation of the initial state that is finally realized from that originally intended.

Figure 2.2 From safety assessment to building code. ("S" stands for the conclusions that are drawn concerning long-term safety and that are documented in published reports, for example SR-Can.)

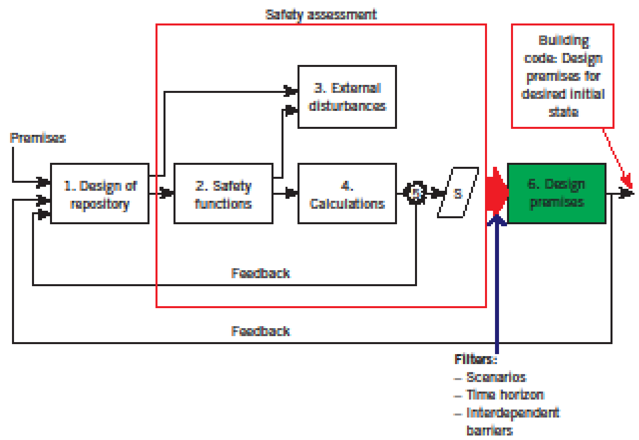


Figure 2.2 illustrates schematically the steps from design of repository and safety assessment to design premises in order to achieve an initial state that will guarantee safety (3). Safety is assessed in accordance with the recommendations for SSM's regulations (5).

The safety assessment is based on a given design of the final repository and assumed properties of the barriers when the repository is closed. Safety functions and external disturbances are two important elements in the safety assessment:

- The safety functions comprise the normative part of the safety assessment. They describe the properties of the barriers that must be preserved during the entire assessment period, i.e. for a million years.

– The repository will be subjected to external disturbances, for example a new ice age and earthquakes. The disturbances generate alternative scenarios that are used to calculate the repository's safety under conditions other than those that prevail in the base scenario. The outcomes of the calculations are compared with values of performance indicators for the safety functions – for example density and swelling pressure of the buffer. If the indicators lie outside the permissible interval, or near the limits, there is reason to return to previous steps and modify the repository design or test new scenarios.

The methodology for the safety assessment has been discussed in previous state-of-the-art reports, and we will not go further into it here. The focus here is instead on the development work currently under way to arrive at a new building code, which is indicated in Figure 2.2 by a thick red arrow to step 6.

2.3.1 The relationship of the design premises to the safety functions

The design premises are related to the safety functions and their indicators, but they must not be confused with each other:

– The safety functions impose order and provide access to the huge amount of data generated by the safety assessment calculations. This can be utilized to find the most important properties to be regulated by the building code. The safety functions are supposed to keep track of all the barriers, including the geosphere, from closure "for all time onward".

– The design premises, on the other hand, are a tool for project management and project organization during the execution phase. They are supposed to guide the work with the five components in the repository, so that the desired initial state can be realized.

In some cases, a group of safety functions can be taken over directly in the repository's building code. According to SKB, this applies to the chemical conditions in the deposition holes (3). The design premises for these conditions are taken over directly from the geosphere's safety function R1, which is supposed to guarantee that the rock provides good chemical conditions from a safety viewpoint. In most cases, the functions for the geosphere comprise boundary conditions for the design premises. This applies, for example, to location of and water inflows to deposition holes and excavation of deposition tunnels.

A design premise may reflect several safety functions. This applies, for example, to the density of the water-saturated buffer. This density must lie within an interval that meets the requirements from at least three different safety functions: prevent colloid transport, eliminate microorganisms and dampen high shear forces on the canister. Given the design premises, it is possible to relate these to the safety functions. But a credible building code requires a systematic methodology in order to derive a collection of design premises that are complete and mutually consistent.

Three filters for sorting and extracting information from the safety assessment can be identified:

- Scenarios: According to SKB, the safety assessment in SR-Can shows that scenarios with canister corrosion due to buffer erosion and canister failure (due to shear movements) entail the greatest risks (6). A number of sub-scenarios related to buffer and rock lead to corrosion and canister failure. According to SR-Can, the corrosion and canister failure scenarios, together with sub-scenarios, thus comprise the base cases that serve as a point of departure in formulating the building code.
- Time scale: The Swedish Radiation Safety Authority's recommendations constitute the second filter (5). The Authority recommends a quantitative risk criterion for the first 100,000 years. A quantitative risk criterion is not considered meaningful for the time after that. The Authority states: "The assessment of the protective capability of the repository should instead be based on a discussion of the calculated risk combined with several supplementary indicators of the protective capability of the repository such as barrier functions, radionuclide fluxes and concentrations in the environment" (5). SSM's regulations stipulate that the "best available technology be taken into consideration" (5). The building code must be designed so that the risk criteria are fulfilled and the best available technology is chosen.
- Mutually dependent barriers: The design premises for individual components must take account of the function of the whole

barrier system. The depth of the repository and the design of the buffer influence the isostatic load on the canister. Possible future shear forces on the canister are dependent on e.g. how the layout of the deposition area and the deposition holes has been adapted to the properties of the buffer and the rock.

In the same way as in the work with the safety assessment, it may be warranted in the work with the building code for the initial state to go back to earlier stages, for example to the safety assessment or to the basic design of the final repository.

Additional scenarios may need to be investigated to verify the requirements on the initial state, and the requirements on a component may require adjustments in the repository design. In previous sections, examples were given of external factors such as uncertainty regarding the properties of the rock, new research and development, and human error that may require going through the whole process from repository design and safety assessment to building code once again.

2.3.2 Reflections concerning methodology and results

The work of formulating design premises for KBS-3 on the proposed site in Forsmark has just begun. The currently proposed design premises will most likely be revised and elaborated, as will the methodology described in Figure 2.2.

A positive response to SKB's application will make the methodology, and what has here been called the building code, large and central themes in the work with the final repository. The Swedish National Council for Nuclear Waste therefore considers it important to keep track of developments in the field. Based on the currently documented methodology and results, the Swedish National Council for Nuclear Waste makes the following reflections:

- Realistic design premises: One might ask how realistic the proposed design premises are. For example, the requirements on the buffer are very strict. The quantity of deposited bentonite per deposition hole should be such that the density of the water-saturated buffer is in the range of 1950–2050 (kg)/m^3, which allows a 5 percent margin of error. Even if it is assumed that none of the bentonite will ever leave a deposition hole, this design premise requires very stringent quality control in the entire chain from production and handling of the buffer until its placement in the deposition hole (7).

- Remaining uncertainties: The Council's State-of-the-Art Report 2011 discussed in great detail remaining uncertainties regarding the function of the canister and the buffer (8). They further underscore both the necessity and the difficulty of satisfying the density requirement for the buffer. Regarding the risk of buffer erosion, SKB claims that the lower limit of 1950 kg/m^3 allows ample margin for erosion (3). But the minimum requirement to eliminate microorganisms is 1900 kg/m^3, so the margin is 2.5 percent. SKB observes somewhat hopefully: "However, it is possible that a better understanding of the process would allow neglect of buffer erosion in future assessments" (3).
- Operational design premises: A building code should be verifiable. This means that the design premises should be operational in the sense that it is possible by means of reasonable measurement efforts in connection with the various work steps to check that the premises are met. It is the Council's considered opinion that some of the proposals in SKB's report (TR-09-22) (3) are not operational in their current versions. For example, the total water inflow to the deposition holes must not exceed 150 m^3, from initial inflow until the buffer is water-saturated. This criterion is interesting in a safety assessment, but in its current form it is unusable in a building code. In order to provide guidance to the project organization, it must be broken down into operational components.
- Lock-ins: The feedbacks in Figure 2.2 show that both system analysis and development of the building code are iterative processes. Feedback lends stability and efficiency to the process, but in its 2007 RD&D review the Council also pointed out the risks of lock-in. The Council observed that the system receiving feedback can be "transformed into a resource-demanding system for effectively learning more about what is already known. The system discourages innovation and meets new threats with more of the same measures." (1). It is the Council's considered opinion that the question of lock-in effects is important, and that SKB should give an account of what mechanisms exist for e.g. restarting technology development if the canister-buffer-rock interplay does not function as expected.

- Interpretation of "best available technology": SKB offers a complicated argument regarding SSM's risk criterion and the best available technology (BAT) (3). The argument could be interpreted as implying that if the quantitative risk criterion extended after 100,000 years cannot be satisfied, then the argument about applying the best available technology for the period after 100,000 years is sufficient. It is the Council's considered opinion that the principle of best available technology should be clarified, for example by defining the concepts of necessary and sufficient conditions. A necessary condition in order for a final repository to be judged safe after 100,000 years is that the applicant can show that the best available technology has been used with a reasonable input of resources. However, this may not be sufficient in order for the final repository to be judged safe. Requirements can be made on development of additional methods and technology.

2.4 From building code to initial state

The safety assessment is supposed to guarantee that a reasonably safe final repository can be built, and the building code is supposed to translate the results of the safety assessment into operational design premises. Realizing the building code in an initial state that agrees with the premises of the safety assessment is a task for project management and project organization.

As a building project, the final repository can be said to be unique. It is a small project compared with many Swedish mines, which have been built out over a longer period than that projected for the repository. The building code is based on four decades of research and development but mainly specifies known construction methods. The cathedral builders of the Middle Ages took greater risks than the repository's project management. The repository will be built to be closed and sealed, like the pyramids of Egypt.

What, then, is so unique about this project that project control is addressed in a separate section in a state-of-the-art report? The answer relates to Figure 2.1. The repository will be built to ensure safety not just for the foreseeable future, but above all for the unforeseeable future. None of today's or tomorrow's decision-makers and builders will be able to verify that the repository fulfils its purpose. Verification of goal fulfilment is based entirely on computer simulations, i.e. the safety assessment. The question arises: what does this mean for project control and for the ability of the project organization to handle the safety assessment? For example, how is the dynamic safety assessment–building code–project control handled when the rock, research and development or human error require modifications to the repository and/or a new safety assessment? How is the safety assessment integrated in the procurement of contracts and in the day-to-day activities? Do the long time spans in the safety assessment create a moral risk? How do you check whether a contractor starts to take "short cuts," intentionally or unintentionally, when the effect of any wrong-doing won't become apparent for another 50,000 years?

It is the Council's considered opinion that matters related to safety assessment and project control are of such importance that they should be systematically studied, for example with the aid of tools from organization theory.

The studies of safety assessment and project control should be based on a broad approach. In his classical work "Images of Organization," Morgan (1986) underscores the need for multiple perspectives in the analysis of an organization. An organization designed to achieve specified goals can, according to Morgan, be described at the same time as:

> …a species of organization that is able to survive in certain environments but not in others; an information-processing system that is skilled in certain kinds of learning but not in others; a cultural milieu characterized by distinctive values, beliefs and social practices; a political system where people jostle to further their own ends; an arena where various subconscious or ideological struggles take place; an artefact and manifestation of a deeper process of social change; an instrument used by one group of people to exploit and dominate others; and so on. (9).

Figure 2.3 **SKB's illustration of the two main processes and their goals during the construction phase. Dashed boxes indicate activities that are not executed during this phase. The illustration is taken from SKB's application, appendix VU, "Activity, management and control – Construction of the final repository, page 20"**

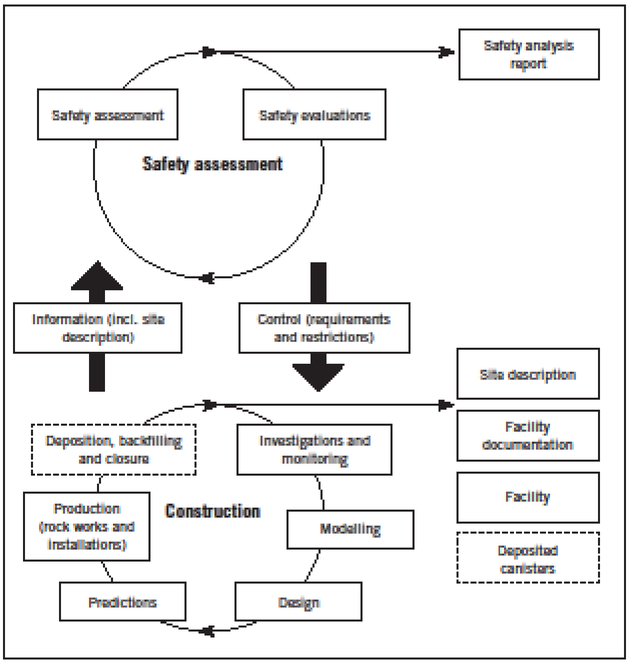


Figure 2.3 shows SKB's own illustration of the relationships between safety assessment and the work of designing, building and commissioning the final repository. SKB observes:

> In the ongoing planning for construction and operation of the Spent Fuel Repository, the activities have been divided into two main processes. Between these processes and sub-processes are important relationships in the form of control, information and feedback. The goal of the project plan and other parts of the management system is that these relationships should function efficiently (10).

SKB's view conforms to one of the perspectives described by Morgan. In this perspective, an organization is seen as a social system for information processing, learning, decision-making and execution. In the organization literature, many references are made in this perspective to how our own brain works (11). Very briefly, it could be expressed in the words of Luhmann, a sociologist who sees organizations as social systems for making and communicating decisions (12). Finding an effective and reliable means of controlling the final repository project requires analysis from many perspectives, but the information-communication-decision perspective appears to be a reasonable starting point.

The illustration of the organization in Figure 2.3 is very general, and SKB has not defined what efficient and reliable relationships between main processes and sub-processes for control, information and feedback should look like. Results from previous studies can be used here to reflect on SKB's approach and to begin to identify critical steps in the organization's handling of the safety assessment's requirements.

Examples of studies of the organization for management of nuclear waste can be found in projects initiated in the late 1990s and early 2000s by the Swedish Nuclear Power Inspectorate (SKI) together with the Swedish Radiation Protection Authority (SSI). The studies were done partly under the auspices of SKI/SSI and partly as EU projects and covered the organization in Sweden, the UK and France (13), (14), (15). An internationally well known model – the Viable System Model, VSM (11) – was used for the organization. The studies did not focus on the role of the safety assessment, but the perspective included Figure 2.3. If we apply the results of these studies to today's situation, we are immediately faced with the question of the status of the two main processes. Should they be organized as two independent processes with their own objectives, as suggested by Figure 2.3, or as two processes with separate functions and with a completely different status in the organization? How are the two main processes related to each other?

Based on the previous studies, several areas can be distinguished where organizational studies are interesting:

- The dialogue between "Construction" and "Safety assessment". This dialogue is marked in Figure 2.3 by the two vertical arrows labelled "Information" and "Control". Efficient communication between the processes is a prerequisite for realistic and operational design premises that are correctly realized in the initial state. The necessity of this type of dialogue was noted in SKB's RD&D programme 2007 and repeated in SKB's RD&D Programme

2010. The Swedish National Council for Nuclear Waste observed in its review of SKB's RD&D Programme 2007: "Within the main process 'Construction and operation', 'Safety assessment and site modelling' is supposed to contribute to coordinating ongoing activities and serve as a conversation partner in a dialogue about measures within 'Construction and operation' in order to handle deviations from premises and assumptions in the safety assessment" (1). The forms and content of this dialogue are important to study, along with the relationships between the parties in the dialogue.

- Differences and relationships. The dialogue does not occur between equal parties. It is the process "Construction" that builds the final repository and is then succeeded by the operating phase. The process "Safety assessment" produces safety reports and control instruments. The main process "Construction" can be divided into a number of independent sub-processes with their own goals and management, for example rock construction, buffer production, deposition and backfilling. The results of the previous organization studies show that similar attempts to divide the main process "Safety assessment" into a number of independent sub-processes would make the whole organization dysfunctional. "Safety assessment" must be available as a dialogue partner within all sub-processes in "Construction" – not as independent units, but as a member and part of the management of the particular sub-process for the purpose of processing information and developing tools to control the sub-process. This means, among other things, interpreting and defining those parts of the building code that are relevant for the sub-process. Two areas stand out as being of interest for further studies.
- Coordination and building code. Coordination requires a detailed protocol or a rule book for the relationships between the sub-processes in "Construction", for example how a produced buffer should be handed over to the deposition team for placement in the deposition hole. The protocol should be based on the building code. Thus, coordination is strongly linked to the quality assurance that is supposed to guarantee adherence to the building code, both within each sub-process, but also in the transfer between sub-processes. There is reason to consider the possibility of moral risks, especially in the transition between different sub-processes.

- Levels and sub-processes. In the preceding two points we have emphasized the necessity of bringing out the safety assessment and the building code to all sub-processes and levels in the project so that safety-mindedness permeates every nook and cranny of the project. The question should be asked how the subdivision is to be done. It is normally done so that production will be as efficient as possible. That which is to be produced in the final repository is long-term safety. This means that the project should not be organized for the most efficient rock construction, but to provide optimal conditions for verification of compliance with the building code and thereby for achievement of the desired initial state.

The above discussion makes use of a special organizational model from previous studies in order to illustrate some organizational questions relevant to the construction of a final repository. The results should be regarded as examples and do not advocate the use of a particular analysis model.

The Council would, however, like to underscore the need for systematic studies of what the organization should look like in order to guarantee compliance with the building code and achievement of the initial state under the special conditions that prevail for the execution of a final repository. The Council believes that such studies should commence as soon as possible so that the knowledge is available prior to a decision on the permissibility of a KBS-3 repository in Forsmark.

2.5 Summary

The Swedish National Council for Nuclear Waste draws the following conclusions regarding safety assessment, building code and organization for construction, operation and closure of the final repository for spent nuclear fuel:

- The licensing process and a permissibility decision for an encapsulation plant in Oskarshamn and a final repository in Forsmark will increase the demands on the safety assessment. In addition to its function as a guarantor that it will be possible to build a reasonably safe final repository, the safety assessment will serve as a basis for the formulation of design premises and for project control to realize the initial state. The design premises will serve as a building code for the repository. The Swedish National Council for Nuclear Waste regards it as an important task to follow the development of a building code and the build-up of a project organization.

- SKB has begun the process of formulating design premises. The results clarify remaining uncertainties regarding canister and buffer function. They also demonstrate the importance of far-reaching quality control in each work step and a building code with measurable design premises. SKB's work also raises the question of defining the criterion "best available technology" in SSM's recommendations. Showing that the best available technology is used should be regarded as a necessary but not a sufficient condition for judging a final repository to be reasonably safe after 100,000 years.
- Buildout and deposition will continue in the final repository over five decades with the goal of producing long-term safety, which is verified by computer simulations. Organization and control of such a project raises special questions regarding handling of unplanned events, procurement of contracts and daily quality control. The fact that the effects of human error or deliberate cheating only become evident after tens of thousands of years could create a new type of moral risk. It is the Council's considered opinion that matters related to organization and project control are of such importance that they should be systematically studied, for example with the aid of tools from organization theory. Such studies should get started as soon as possible so that the knowledge will be available prior to a decision on the permissibility of a KBS-3 repository in Forsmark.

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3 From initial state to target state in the final repository for spent nuclear fuel

3.1 The final repository in a time perspective

The final repository will be operational for an extremely long time – more than 100,000 years. Man evolved from Homo Neanderthalis to Homo Sapiens over the same span of time in the past, and no one can predict what will happen during the same span of time in the future.

The climate has also varied, and many changes on the Earth's surface can be explained by this. The last ice age ended about 10,000 years ago, and if we go 20,000 years back in time the climate was very cold. A detailed description of the influence of the continental ice sheet on the landscape is provided in an in-depth supplement to a previous report from the Swedish National Council for Nuclear Waste and is dealt with only summarily here (1).

The formation and advance of the ice sheet led to great changes in rock, soil and water, both beneath and outside the ice sheet. The groundwater froze to ice, leading to the widening of fractures and pores in the rock, and when the pressure from the ever-thickening ice sheet increased, its base began to melt. Some meltwater from the surface found its way down into crevasses in the ice. The landscape outside the ice sheet was characterized by permanently frozen ground (permafrost) and tundra. The permafrost beneath the glacier had formed over a long period of time during different phases, and therefore to great depth (several hundred metres). The ice sheet and the high water pressure also led to increased vertical rock stresses.

Our current knowledge of future events has also been described in the above-mentioned report from the Swedish National Council for Nuclear Waste, where Professor Bert Bolin gave an account of the state of knowledge concerning the future evolution of the climate on three different time scales (1). During the next 1,000 years, the climate will be affected by the great disturbances caused by, for example, the fact that an increasing concentration of carbon dioxide and other greenhouse gases in the atmosphere will prevent or impede the radiation of heat from the Earth's surface out into space. A rising temperature in turn gives rise to a number of undesirable effects (melting of the ice, sea level rise, etc.).

The final repository is expected to function for 100,000 years under these varying conditions, isolating the spent fuel nuclear from the surrounding environment.

It is naturally a great challenge to design and build such a repository. It is thereby necessary to use the best technology available today and make realistic calculations and projections of the future during this long period of time. It is not possible in this context to provide complete guarantees that nothing unexpected will happen or that no parameter has been overlooked or underestimated in SKB's safety assessment.

It will not be possible to determine certain conditions until during the actual underground work, for example the size of the rock stresses, which were large and difficult to determine during the site investigations (2). The magnitude and variation of the water flow in different sections can also be difficult to predict.

3.2 About the role of the initial state in the safety assessment

The safety assessment is the instrument SKB uses to describe possible scenarios for the evolution of the final repository and calculate the probabilities of different outcomes. The safety assessment is a "living" document that is constantly changing as new knowledge and research results become available of relevance to processes in the repository. The so-called initial state is used as a starting point for the calculations.

The initial state corresponds to the state of fuel, canisters, buffer, backfill and closure immediately after deposition. In the case of the geosphere and the biosphere, the initial state refers to the natural conditions that prevail before rock excavation is commenced. The description is based on the reference design (3) of the KBS-3 repository using the described methods for execution and inspection, a descriptive model of the site for the final repository and a site-specific design of the repository. The concept of initial state also includes the variation in properties that can be expected, given the methods for execution and inspection that are employed.

The initial state of the canister thus describes the properties which the canisters are expected to have when they are placed in the deposition holes and will not be handled anymore in the final repository. The requirements and design premises that relate to the canister's barrier function are described in previous reports from SKB (3).

The properties of the technical barriers when they have been finally put into place in the final repository are described by the initial values of a number of variables (4). The initial state of the buffer and backfill is the result of the reference design, fabrication and installation chosen on the basis of the design premises. The expected initial state of other variables depends on how buffer and backfill evolve after installation, and this is determined by means of analyses.

Initial state of the buffer is the state when the deposition equipment has been removed and all buffer components are installed in the deposition hole. The initial state will depend on the composition of the buffer material, the size and density of the installed buffer components and the dimensions of the deposition hole (5).

3.3 From initial state to target state

When all canisters and buffer have been deposited, a number of natural processes will be initiated which will eventually result in the consumption of the oxygen molecules present in the bentonite in the form of entrapped portions of air and water, and the buffer swells due to sorption of groundwater. At best, these processes lead to a target state characterized by the fact that the density of the water-saturated buffer (6) lies in the range 1,950–2,050 kg/m^3 and that the oxygen has been consumed. In this way the environment becomes reducing, i.e. oxygen-free, which reduces the risk for corrosion of the copper canister. It is in fact this desirable target state that serves as a basis for the long-term evolution of the repository.

An important question in this context is how it can be verified if and when the repository as a whole has achieved its target state after closure, since no follow-up measurements are planned to verify this. What does it mean for long-term safety if it takes several hundred years for certain parameters in the target state to be achieved in some deposition holes? An uneven distribution of sorbed groundwater through the bentonite buffer and contact with the copper canister (the most important barrier) can, for example, create conditions for undesirable corrosion reactions on the canister, deterioration of buffer properties due to cementation and erosion of buffer and backfill.

3.3.1 Initial state of the copper canister

The copper canister is the most important barrier in the KBS-3 system, since it contains the spent nuclear fuel and prevents radionuclides from escaping. The canister also attenuates ionizing radiation and prevents further uranium fission (criticality). It must therefore be fabricated and sealed with high reliability.

SKB has chosen reference methods for fabrication of the canister's components and for welding and sealing. The copper tube has a wall thickness of 50 millimetres and is fabricated by extrusion (the metal is shaped by being squeezed through a die). Copper lid and copper bottoms are forged, and the loadbearing iron insert is cast. Welding of the copper bottom and the lid seal is done by means of friction stir welding (FSW).

The canister's barrier function in the repository is dependent on the ability of metallic copper to resist corrosion and lend high strength to the canister. The canister must withstand an isostatic load of 45 MPa, which is about 450 times the normal barometric pressure. The stress in this case is the sum of the swelling pressure in the buffer, the groundwater pressure and the hydrostatic pressure during a glaciation.

The Swedish National Council for Nuclear Waste has in previous reports and review statements offered viewpoints on fabrication processes, criteria for material structure, material properties and defects in both the copper shell and the cast iron insert, and the underlying requirements for nondestructive testing (1), (7). For details on acceptance criteria and inspection of the copper shell and the insert, see the above references.

The fact is that all the requirements that have to be made on fabrication, testing and inspection of the canister's components, as well as of the whole system, have not yet been finally determined. SKB has continued to develop the design premises for the canister, and a compilation of the canister's strength and damage tolerance (design analysis) has recently been published (8). Acceptance criteria for the system and its operation have not yet been established, and the work of specifying these criteria is under way.

Creep properties (slow plastic deformation) of the copper canister cannot be determined on the basis of the results obtained from creep testing of a homogeneous parent metal of copper; the creep properties of the heterogeneous microstructure in the friction stir weld are also needed for modelling and analysis. Creep strain in the weld is a complicated process due to e.g. varying microstructure, residual stresses and degree of cold working, as well as the very long period of time. Not enough studies have been done of creep in welds, and in future the creep properties of friction stir welds and geometric discontinuities that show the greatest strains in design analysis (8) must be studied much more thoroughly.

The equally important creep properties of copper have been investigated, but a validated creep model is still lacking.

Copper corrosion has been discussed a great deal during the past few years. The Swedish National Council for Nuclear Waste has in previous state-of-the-art reports (9), (10) described the differences of opinion that exist in this area, and has given its view on the matter in a special statement to the Environment Minister (11). The most important discussion concerns possible copper corrosion in the environment that will eventually dominate in the repository, when the oxygen has been consumed. Copper corrosion in that environment always results in hydrogen gas evolution, and the hydrogen gas pressure is therefore an important parameter. When the pressure reaches a certain level the corrosion ceases, and the question is at what pressure this occurs and whether the critical pressure can be maintained indefinitely near the canister. The Council's overall assessment of the current state of knowledge leads to the conclusion that the integrity of the copper canister can be preserved for the foreseeable future, as long as the buffer's barrier function is maintained and continuous transport of corrosive ions from the groundwater to the canister can be prevented. However, the copper canister is of such crucial importance for the long-term safety of the repository that there must be no doubt.

The Council therefore takes a very positive view on the continued research on copper corrosion being funded by SKB and SSM and conducted at independent universities and research institutes.

3.3.2 Processes on the copper canister

The copper canisters will thus contain the spent fuel from the nuclear reactors and subsequently be deposited in the final repository, when they meet the acceptance criteria made on fabrication and testing. Theoretically, the initial state should exist when the canisters have been emplaced in the deposition holes and are surrounded by the compacted bentonite blocks, but reality is not quite that simple.

The copper canisters have a relatively high temperature (about 100 °C), and they have been transported from the encapsulation plant in Oskarshamn to the planned repository in Forsmark with more or less free air access. As a result, the surfaces will have a coating of chemical products that have been formed after reactions with oxygen molecules and carbon dioxide in the air. The copper canisters with these corrosion products, for example copper oxides and copper carbonate (Cu_2O, CuO and $Cu_2(OH)_2CO_3$ on the surfaces, will thus be deposited in the repository in this condition and thereby comprise the real initial state.

This condition also comprises a starting point for a number of desirable and undesirable processes on the canister and in the surrounding buffer before conditions have stabilized, and they will at best correspond to the target state which will then exist for the duration of the life of the repository.

This part of the state-of-the-art report 2012 aims to describe and problematize some of the processes that lead to a transition from an initial state to a target state for the different components in the repository.

When the canisters with their coating of copper oxides come into contact with the moist bentonite, the copper hydroxides will be hydrated (react with the water) so that different types of copper hydroxides are formed on the surface. ($2{\equiv}Cu_2O + H_2O \Leftrightarrow 2{\equiv}CuOH$ and ${\equiv}CuO + H_2O \Leftrightarrow {\equiv}Cu(OH)_2$, where ≡ designates the canister surface).

Similar reactions have been published previously (12), and it can be expected that the speciation (composition) on the canister surfaces will persist for a very long time, i.e. even after the free oxygen in the buffer has been consumed. The coating of copper oxide/hydroxide on the surface will probably protect the canister to some extent from further oxidation, since oxygen is in short supply in the buffer. When the environment becomes reducing (the oxygen has been consumed) and groundwater containing sulphide ions (HS^-) reaches the canister, the surface coating is transformed from copper oxides to copper sulphide ($\equiv Cu_2S$).

The copper sulphide coating will then probably also be hydrated (react with the groundwater), producing one or more layers of reaction products ($\equiv CuSH + \equiv CuOH$). The surface of the canister, which is thus both oxidized and hydrated, can be described as a parameter in the establishment of the copper canister's target state.

After continued contact with groundwater transported through the bentonite buffer, the copper canisters may adsorb hydrogen sulphide (HS) ions from the groundwater, as suggested by previously published results for lead sulphide and zinc sulphide (PbS and ZnS) (13). These reactions on the copper canister will only occur under oxygen-free conditions, since an oxidizing environment leads to oxidation of sulphide ions in solution and on the surface. Long contact with groundwater containing hydrogen sulphide (HS^-) may lead to corrosion of the copper canister (through the reaction $\equiv Cu + 2HS^- \Leftrightarrow \equiv CuS_2 + H_2$), and the canister must therefore be protected by the buffer. In this case, long-term safety is dependent on whether a sufficiently high hydrogen pressure can be sustained to slow and stop the reaction.

Chloride ions in the groundwater are not expected to pose any real threat of corrosion, since copper chloride (CuCl) does not form in any great quantities if the pH is higher than 4.

The target state in the deposition hole is also characterized by the fact that the bentonite buffer is water-saturated and that all oxygen in air and water has been consumed. These processes are described in greater detail in the next section. The time between initial state and target state can have an adverse effect on the copper canister if sorption of water in the buffer occurs locally and very unevenly. The pressure caused by the swelling of the buffer on different parts of the canister will then vary, which can in turn initiate undesirable processes on the surface (for example stress corrosion cracking) before the pressure differences have been equalized.

The relatively high temperature on the canister surface (about 100 °C) results in a high vapour pressure of the water in the wet bentonite (even if the water doesn't boil) before the buffer has become water-saturated, which affects water transport out from the canister and further accentuates the moisture gradient in the buffer.

3.3.3 Processes in the buffer

Before the buffer in the form of compacted blocks and pellets is emplaced in the deposition holes, the natural bentonite has undergone a series of processes (including grinding to achieve a homogeneous blend of minerals) at the same time as the mineral surfaces are activated before the bentonite is compacted to blocks and pellets. Water is added prior to compacting so that the water content increases from about 10 percent to about 17 percent.

Compaction, which involves compression of the bentonite under high pressure with an increase in density, also causes portions of air (about 21 percent $O_2(g)$) to be entrapped in the blocks. The incoming water also contains dissolved oxygen gas, $O_2(aq)$, theoretically about 8 mg/dm^3. Since blocks and pellets are lowered down into the deposition holes after compaction, this comprises the bentonite buffer's initial state. Compaction causes voids and pores in the bentonite to be compressed, especially those containing atmospheric oxygen, and the internal pressure in the pores increases radically.

The literature contains different figures on the total volume occupied by these interparticulate pores and how they will behave during the bentonite's sorption of groundwater and water saturation. A recently published doctoral dissertation (14) proposes that this pore volume is less than 3 percent at a bentonite density equal to or greater than 1.4 kg/dm^3. This is a much lower figure than that previously published (15), and it is important to have a realistic estimate of the pore volume in order to be able to assess possible transport pathways for ions and colloids through the buffer.

After compaction, the molecular oxygen will be consumed by bacteria activity and reactions with impurities in the bentonite, while oxidation of the surfaces of the copper canister will hardly consume significantly more oxygen, since it is already oxidized in its initial state.

How fast the molecular oxygen is consumed is now an interesting question in this context. New (unpublished) results from Posiva indicate that this could take only ten days, while earlier results (15) from SKB indicate a much longer time – tens to hundreds of years.

One explanation for the differing results could be that different things are being measured. The oxygen molecules in the entrapped air under high pressure will probably be consumed relatively quickly, while consumption of the oxygen in the interparticulate pore water and the laminar water in the montmorillonite takes much longer.

It is known from environmental research that the transport rate of oxygen in soil pores is 6,000–10,000 times higher than in water. The redox potential, which describes how reducing the environment has become, will vary depending on the quantity of different forms of oxygen. It is only when all oxygen has been consumed, including that dissolved in the water, that the buffer will have achieved its target state with respect to the oxygen level in the buffer.

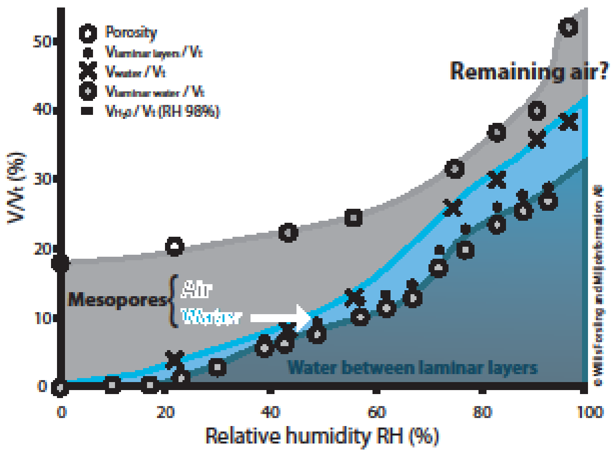
When the buffer comes into contact with groundwater in the surrounding rock, it will theoretically take up (sorb) water, causing the buffer to swell and fill out the space in the deposition hole, whereby its density will increase to about 2 kg/dm^3. This will take more or less time depending on how dry the surrounding rock is, and the process will occur as previously described under conditions determined by large temperature gradients, dissolution and transport of impurities in the bentonite, consumption of dissolved oxygen by oxidation of sulphides and organic compounds, plus bacteria activity etc.

It might be asked why the density of the buffer increases from about 1.6 kg/dm^3 to 2.0 kg/dm^3) when it absorbs more water, since water has a density of 1 kg/dm^3, i.e. much lower than the solid material – for example the montmorillonite, with a density of 2.7 kg/dm^3. The only reasonable explanation is that the groundwater is absorbed between the layers in the bentonite, i.e. laminarly, that the pore volume between the mineral particles decreases, and that the entrapped air is forced out. In this way the density increases, but this also means that the original pore volume after compaction of the buffer may be far too small. In other words, there must be enough entrapped air volume to enable the density to increase when the buffer becomes water-saturated.

Figure 3.1 below illustrates an example of what the quantitative balance may look like with respect to the distribution of air and water in different types of pores in MX-80 bentonite (sodium bentonite) that gradually becomes water-saturated (16).

It is obvious that the quantity of water between the laminar layers in the montmorillonite increases, while the quantity of mesopores (sized 2–50 nanometres) with air decreases. (1 nanometre is equal to one millionth of a millimetre). The figure illustrates what happens if the bentonite is allowed to swell freely, but if swelling takes place under constrained conditions (such as in the deposition holes), the differences between different types of pores will be even more accentuated.

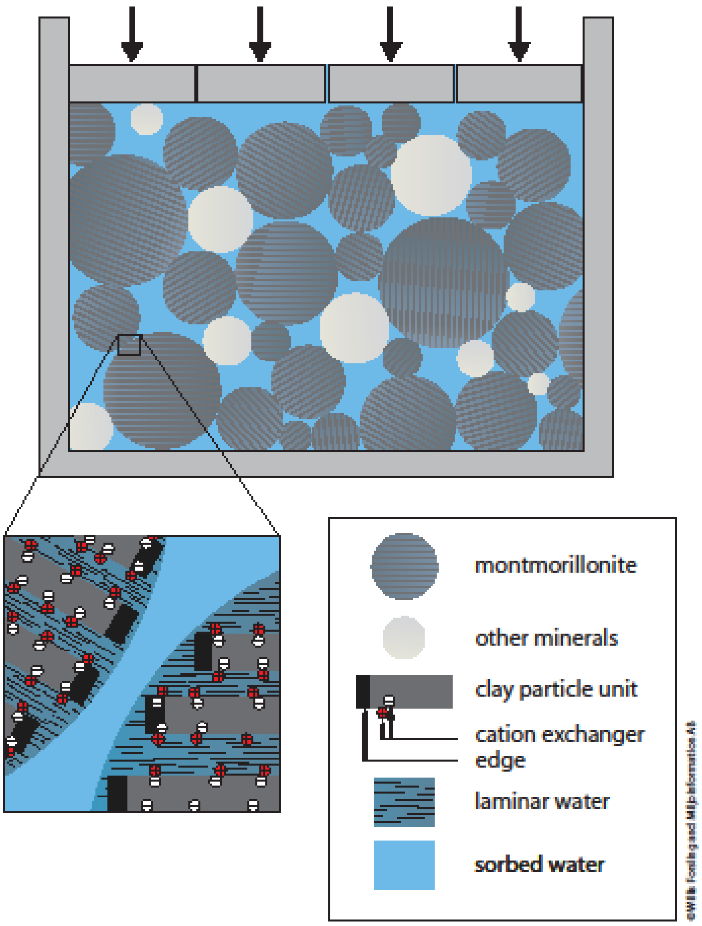
Figure 3.1 **The figure shows a quantitative distribution between air and water in MX-80 bentonite (sodium bentonite) as a function of type of pores and degree of saturation.**
Modified from D Pret, E. Ferrage et al. 2011; Ref. 16



A similar study of the pore distribution in compacted MX-80 bentonite, which is more similar to conditions in the final repository, shows a larger fraction of macropores (size greater than 50 nanometres) between aggregates of particles, at the expense of mesopores occurring between particles in the above figure (see also Figure 3.2 below). When the relative water saturation exceeds 91 percent, the size of the aggregates of swelling minerals grows, causing the networks of macropores to close partially or collapse completely (16). The swelling of the bentonite as it absorbs water appears to affect the mesopores between the particles to a high degree before the macropores close. In other words, the macropores are preserved for a longer time.

Quantification of macropores with the aid of a microscope (for example by synchrotron radiation) is difficult, since the contrast between pores and surrounding aggregates is weak. The water in highly compacted montmorillonite is almost exclusively located between the layers or near the surface, and it is thereby obvious that water transport through the buffer will be greatly limited in a direction perpendicular to the layers. This situation can be regarded as the buffer's target state.

Figure 3.2 Sketch of the microstructure of the bentonite after compaction and water saturation.
Modified from Wersin, 2003; Ref. 17



The figure illustrates that when the bentonite swells and has a density of 1.7 kg/dm^3, the quantity of water in interparticulate pores (i.e. between the particles) decreases from 38 percent to 5 percent. Instead, the quantity of water between the layers in the montmorillonite, i.e. what is called laminar water in the figure, increases (17).

A number of problems can occur during the period between installation and water saturation of the buffer due to fracturing with associated water flows from walls and floors in the deposition holes.

Furthermore, the bentonite in the buffer blocks and the groundwater with which the bentonite is being saturated is not pure, but contains a number of impurities that affect the environment in the buffer in different ways. Certain minerals in the bentonite, for example pyrite (FeS_2) and siderite ($FeCO_3$), consume oxygen, while other minerals, for example calcite ($CaCO_3$) and gypsum ($CaSO_4$), have relatively high solubility and can be transported with the water flowing towards the copper canister and be precipitated there.

The outward transport of heated water from the canister will occur in part in the form of water vapour, involving other transport pathways. The consequences of these processes have been described in previous reports from the Swedish National Council for Nuclear Waste (9), (10) and will not be repeated here.

The groundwater also contains quite a few ions that affect the environment in the buffer and must be prevented from coming into contact with the canister in excessive quantities. The most important are sulphides (e.g. HS^-) and other sulphur anions (e.g. HSO_4^-), chlorides (Cl^-), carbonate ions (e.g. HCO_3^-) and sodium (Na^+) and calcium ions (Ca^{2+}).

The sulphide ions consume oxygen, and under reducing conditions they can cause corrosion on the copper canister. Sulphate ions are food for certain types of bacteria, producing sulphide ions, which are harmful to the copper canister.

Thus, before the buffer has been completely saturated by groundwater, a number of processes have occurred affecting the state in the deposition hole. This state of the buffer is the starting point for the long-term evolution of the repository.

3.3.4 Processes in the backfill

SKB's RD&D programme 2010 states that "the most important functions of the backfill are to make the mass transport capacity comparable with that of the surrounding rock and to minimize the upward expansion of the buffer". This state must be regarded as the backfill's target state and does not correspond to the properties of the backfill immediately after closure, which by definition can be designated the backfill's initial state.

There are a number of differences between conditions in the deposition tunnels (where the backfill is placed) and in the deposition holes where buffer and canister are located.

The deposition holes are bored, which means that they will have relatively smooth walls. Moreover, they are individually inspected and approved with respect to fractures with inflowing water before the buffer is emplaced. The same exacting requirements cannot be made on the deposition tunnels; here you have to take what you get.

Furthermore, the tunnels are blasted instead of drilled, which means that walls and roofs are much rougher and there is a greater risk of rock breakout. In other words, it can be expected that there will be water-bearing fractures in roofs and walls that must somehow be sealed or minimized (for example with silica sol) so that the backfill (blocks and pellets) will not be eroded and washed away. In fact, the water flow needs to be kept very low (18) so as not to cause damage to the backfill via erosion before blocks and pellets have become water-saturated.

All sub-processes involved in water saturation of the buffer, which are dealt with above, also apply for the backfill – with the exception of the fact that the temperature gradient from the canister to the rock that exists in the deposition holes does not exist in the backfill.

A complication in connection with the backfill is, however, the difficulty of sustaining the density when the bentonite swells. The deposition tunnels are relatively large and do not have the same constraints in volume as the deposition holes. This means that water absorption in the bentonite causes it to swell more freely, which can result in an overly soft consistency. This increases the risk of erosion and does not result in as low values for diffusion of water and possible radionuclides from a damaged canister.

The backfilling concept entails that compacted bentonite blocks will be stacked on top of one another to a quantity corresponding to approximately 60 percent of the volume, and that bentonite pellets will fill out the voids nearest the walls and roof (equivalent to nearly 40 percent of the volume). The requirements on the bentonite in the backfill are lower than the equivalent requirements on the buffer with respect to content of swelling mineral, montmorillonite. The large fraction of pellets in the backfill means that the water saturation process in the backfill involves many more uncertainty factors than in the buffer in the deposition holes.

The installation of barriers and the subsequent water saturation process in deposition holes and transport tunnels can be divided into three different periods: installation, water filling and water saturation (19). The first period includes the work of filling the tunnel with blocks and pellets, and fitting plugs to limit the volume and reduce the flow of water. The second period includes the inflow of water to deposition holes and tunnel until the installation of bentonite pellets is water-filled. The third period refers to the wetting of bentonite blocks in deposition holes and tunnels until they have become completely water-saturated.

If the initial state of the backfill matches the state at closure and the target state matches the requirements stipulated by SKB, there are many unclear points and thereby many research questions surrounding the processes that lead from the one state to the other.

3.4 Summary

All barriers in the final repository (copper canister, bentonite buffer, backfill) are characterized by both an initial state and a target state. The transition from one state to the other is dependent on a number of processes that start at deposition and conclude at different times after closure.

In the case of the copper canister, the heated surface reacts with air and water before the surrounding buffer has become water-saturated and thereafter with different components in the groundwater. The target state entails that the buffer is free from oxygen and exerts an even pressure over the entire canister.

At deposition, the buffer contains different forms of molecular oxygen (O_2) in air and water and is not completely water-saturated. The target state entails that the buffer is homogeneous and water-saturated with a density in the range 1.95–2.05 kg/dm^3. The buffer is impermeable, and transport of gases, water and different kinds of ions can only take place by diffusion. The concentration of molecular oxygen is negligible.

The initial state of the backfill is far from the desired target state. The target state entails that the buffer's mass transport capacity is comparable to that of the surrounding rock and its mechanical stability is great enough to resist the buffer's upward expansion in the deposition holes. Conditions in deposition tunnels and shafts are for natural reasons much less well defined than in the deposition holes, and it will be a great challenge to satisfy the long-term requirements on the backfill.

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4 From Chalk River to Fukushima – accidents that have influenced the nuclear power legislation

The legislation in the nuclear power countries has often been influenced by accidents and other incidents in nuclear power reactors. Furthermore, the safety work at the facilities has benefited from the lessons learned from the accidents.

The earlier events that have had a particularly great impact are the accidents at Chalk River in Canada and Windscale (Sellafield) in England in the 1950s, which led to the passage of a new Swedish law (the Atomic Accident Act), the accident at Three Mile Island in the USA in the 1970s, which led to the Swedish referendum on nuclear power, and the Chernobyl accident in Ukraine in the 1980s, which gave rise to several joint international initiatives and conventions.

More recently, the nuclear power accident in Fukushima Daiichi, Japan, in 2011 had a great impact on energy policies in Italy, Switzerland and Germany. After the accident, the nuclear power countries, acting on the initiative of the EU Council of Ministers, decided to carry out stress tests in their nuclear power reactors in order to analyze the safety of the reactors in the event of a disaster.

This chapter provides a brief account of the previous accidents in Canada, the UK, the USA and Ukraine, and the impact they have had on the nuclear power legislation, particularly in Sweden. A brief description is then given of the nuclear reactor disaster in Fukushima and the impact the accident has had on energy policy in Italy, Switzerland and Germany.

4.1 Overview of accidents in nuclear power plants

4.1.1 The 1950s: Chalk River and Windscale

Chalk River in Canada was the site of two reactor accidents in the 1950s. The first occurred in 1952, when a power failure and a partial loss of coolant in the reactor led to extensive core damage. The fuel rods were overheated, resulting in a meltdown, and large quantities of radioactivity were dumped in ditches near the Ottawa River. The second accident occurred in 1958, when a fire broke out in the reactor building. The valves in the ventilation system were opened, and a large area outside the building was contaminated. Both accidents required a major cleanup effort involving both civilian and military personnel.

In Windscale, or Sellafield, a large nuclear facility in Cumbria, England, a fire occurred in a reactor on 10 October 1957. Substantial amounts of radionuclides were released during the fire and contaminated the environs, including iodine-131 (which may lead to cancer of the thyroid).

The reactor accidents in Chalk River and Windscale led to the adoption of the Act (1960:331) on protective measures in the event of accidents in atomic facilities (the Atomic Accident Act) in Sweden on 3 June 1960 (1).

The Act can be considered an emergency planning law, where responsibility for protective measures outside the facility in the event of a reactor disaster was imposed on the County Administrative Board in the concerned county. The law was supplanted in 1987 by the Rescue Services Act, which was in turn supplanted by the Civil Protection Act (2003:778) in 2004.

4.1.2 The 1970s: Three Mile Island

The accident on 28 March 1979 in the Three Mile Island plant near Harrisburg in Pennsylvania, USA, led to a meltdown in a pressurized water reactor. Radioactive gases and iodine-131 were released. It took more than five years to clean up after the accident, and it sparked a debate in many countries concerning the safety of nuclear power. The official investigation concluded that the accident had been caused by a number of human errors made in connection with ongoing maintenance work in the reactor. The question of the importance of the operators' process knowledge and safety-mindedness as well as operator training therefore received particular attention. The accident also led to an increased interest in safety assessments.

As a result of this accident, Sweden decided to hold a national referendum on nuclear power in 1980. The referendum included three alternatives (lines 1, 2 and 3) for the phase-out of nuclear power at different speeds.

Line 2 received 39.1 percent of the votes. The alternative was worded as follows:

> Nuclear power shall be phased out at all possible speed, taking into account the need for electric power to sustain employment and welfare. In order to reduce the country's dependency on oil, and pending the availability of renewable energy sources, not more than 12 reactors will be used of those currently in operation, finished or under construction. No further nuclear power plants may be built. The order in which the reactors will be taken out of service shall be determined by safety considerations.

The text on the reverse of the ballot read:

> Society shall bear principal responsibility for the production and distribution of electric power. Nuclear power plants and other future facilities for the production of significant volumes of electric power shall be owned by the state and the municipalities. Excessive profits from hydroelectric power generation shall be reduced by taxation.

Line 1 had the same text on the front side as line 2, but no text on the reverse side. Line 1 received 18.9 percent of the votes. Line 3 formulated a no to the further expansion of nuclear power, and the nuclear power reactors that were in operation were to be shut down within ten years at the most. This alternative received 38.7 percent of the votes.

After the referendum had been held, a new Bill on certain energy matters was introduced in the Riksdag (2). The Riksdag's decision (3) included a statement that there should be no further expansion of nuclear power beyond the twelve reactors currently in operation, finished or under construction. Furthermore, the Riksdag mandated that nuclear power should be phased out with all possible speed, taking into consideration the need for electric power to sustain employment and welfare, and that safety considerations should determine the order in which the reactors will be taken out of service. The Bill estimated the service life of the reactors to be 25 years. The Riksdag therefore stated that the last reactor in Sweden should be shut down by not later than 2010. Finally, the

Riksdag stated that provisions concerning the number of reactors and the length of the phase-out period should be introduced in nuclear power legislation.

In the travaux préparatoires to the Nuclear Activities Act, however, the Government emphasized that a statutory regulation of the number of reactors was unnecessary and that a stipulation of the length of the phase-out period should wait until all matters that should be regulated in connection with a phase-out have been clarified[i].

The safety work of both the Swedish Nuclear Power Inspectorate (SKI) and the nuclear power plants was also affected. SKI accorded great importance to experience feedback in its supervisory work. In particular, a strong link was striven for between facility-specific probability-based safety assessments, incident reporting, incident analysis and experience feedback.

Based on the growing body of experience from nuclear power reactor operation, the Government said that the regulatory authority, SKI, should establish a programme aimed at ensuring that every Swedish nuclear power reactor should, if possible, undergo at least three complete safety reviews during its service life. Such a review should be done every eight to ten years. The completed review should also be presented to the Government, who could issue "necessary regulations"[ii].

After the accident in Three Mile Island, systems have been incorporated in all Swedish reactors that contain pressure relief and filters to mitigate releases in connection with serious core accidents. The Barsebäck plant was the first with its Filtra system, which was finished in 1983.

In the Bill for the Nuclear Activities Act, which entered into force on 1 January 1984 (4), further attention was given to those issues that had been particularly underscored in connection with the accident investigation after Three Mile Island, namely the relationship between man, technology and organization (the so-called MTO issues)[iii].

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[i] See Gov. Bill 1983/84, p. 59, as well as Gov. Bill 1986/87:24, p. 4.
[ii] See Gov. Bill 1980/81:90, Appendix l, Ministry of Industry, p. 313.
[iii] See Gov. Bill 1983/84:60, pp. 38 and 82.

4.1.3 The 1980s, Chernobyl

The Chernobyl disaster occurred on 26 April 1986 in the Chernobyl nuclear power plant north of Kiev in Ukraine. During the night between 25 and 26 April 1986, reactor no. 4 was to be closed for routine maintenance. At the same time, the operators wanted to conduct an experiment to test whether the rotational energy in the power plant's own turbines was sufficient to supply the cooling water pumps with power if there should be an interruption in the external power supply to the plant at the same time as an accident occurred.

In order to conduct the experiment the reactor's power level had to be reduced to 25 percent. The operators received an order to regulate the reactor manually. To do this, they disabled the automatic safety system, in contravention of the safety regulations. The control rods were pulled out too far. The cooling water flow was reduced, and within just 35 seconds there was a power surge in the reactor. Since the automatic scram system was disconnected, the reactor began to spike out of control. The operators tried to reduce the power level by inserting the control rods again, but the reactor was so hot by then that the control rods melted and got stuck. At this point, the runaway reactor was running at about 100 times its full rated power. The nuclear fuel was largely vaporized and the graphite moderator caught fire.

At 01:24 hrs local time on 26 April 1986, the reactor exploded. The roof and other parts of the reactor building collapsed or were blown away. Radionuclides, mainly cesium (Cs-137) and iodine (I-131), were released and spread over large parts of Europe.

One of the causes of the accident was that the special type of nuclear reactor (RBMK, Reaktor Bolshoy Moshchnosti Kanalniy) involved has an inherent instability due to a so-called positive void coefficient. If the temperature increases in the reactor, the reactor's power level therefore tends to increase. Since the reactor was not enclosed by a pressure-tight containment building, the release of radionuclides could not be prevented.

The Chernobyl disaster is classified as a level 7 event on the International Nuclear Event Scale (INES), which is the maximum level. As a consequence of the accident, several initiatives were undertaken to strengthen international cooperation in the nuclear safety field.

Within the framework of the IAEA, the Convention on the Early Notification of a Nuclear Accident (Early Notification Convention) (5) was ratified in 1987. The convention contains requirements governing reporting of nuclear or radiological accidents of such a scope that they have resulted or may result in transboundary releases. Another convention that was ratified within the framework of the IAEA is the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (Assistance Convention) from 1987. It contains a framework for cooperation between parties to the convention and the IAEA in order to facilitate prompt assistance and support.

Sweden and other Member States in the EU have an obligation to maintain preparedness in the event of a nuclear energy accident for notification and exchange of information with other EU Member States. This exchange of information is coordinated via the European Commission. Euratom has written a manual containing detailed and precise information on how the conventions should be applied in practice[iv].

In addition to the two international conventions, Sweden has concluded bilateral agreements on notification and information exchange with the Nordic countries, Germany, Russia and Ukraine.

4.1.4 2011, Fukushima Daiichi (6), (7)

The nuclear power plant in Fukushima Daiichi is located on the east coast of Japan and consists of 6 boiling water reactors. On 11 March 2011, reactors 1, 2 and 3 were in normal operation while reactors 4, 5 and 6 were shut down for maintenance. All nuclear fuel in reactor 4 had been moved to the fuel pool in the reactor building.

At 14:46 hrs in the afternoon, Japan was struck by a violent earthquake of magnitude 9.0 on the Richter scale. Approximately 40 minutes after the earthquake, 10 metre high tsunami saves rolled in over Japan's northwest coast, laying waste large areas containing towns and villages. The devastation was catastrophic and the number of dead is estimated at 15,749 with 3,962 people missing. It was

[iv] Euratom has acceded to both conventions for formal legal reasons, even though the Community early had a coordinating role in this context. The instrument of Euratom's accession to these two conventions was deposited with the IAEA on 14 November 2006 and entered into force on 14 December 2006. See the Commission's decisions 2005/844/Euratom and 2005/845/Euratom.

under these catastrophic circumstances that the nuclear power accident in Fukushima Daiichi occurred.

First the earthquake knocked out the power supply to the nuclear power plant, after which the reactors that were in operation were scrammed, at the same time as the emergency diesel generators started in all six reactors.

At 15:42 hrs, Fukushima was hit by a 14 metre high tsunami wave. The wave broke over the nearly six-metre-high wall built as a protection against tsunami waves, partially flooding the nuclear power plant. All emergency diesel generators were disabled, except the one in reactor six. Furthermore, all sea water pumps, which were supposed to supply the reactors with cooling water, were destroyed, causing a loss of cooling to the reactor cores, whereby the temperature in the reactors rose and water began to boil off.

The rescue work took place under extremely difficult conditions, without electricity, with inadequate equipment for measuring radiation doses and poor communications. The work was initially focused on preventing explosions in the reactors caused by the high pressures that began to build up, and on providing emergency cooling so that the reactor cores could be kept cooled. A further risk of explosion existed due to the possibility that hydrogen can form when a reactor core is exposed. At 17:00 hrs, parts of the reactor core in reactor 1 had been exposed.

During the days following 11 March, explosions occurred in reactors 1 and 3 as well as in reactor 4, the latter probably due to the fact that hydrogen that had formed in a nearby reactor had leaked over to reactor I.E. meltdown occurred in reactors 1, 2 and 3, and reactor 4 suffered great damage to its nuclear fuel pool.

Infobox 4.1 Evacuation

Following is a summary of decisions and recommendations on evacuation up to 22 April.

- 11 March: recommendations to evacuate a zone with a two kilometre radius around the nuclear power plant were issued in the evening. A half hour later the radius was increased to three kilometres and residents within a distance of between three and 10 kilometres of the nuclear power plant were advised to remain indoors.
- 12 March: evacuation out to 10 kilometres from the nuclear power plant was recommended early in the morning, and at midday this distance was increased to 20 kilometres.
- 15 March: residents within a distance of 20 to 30 kilometres of the nuclear power plant were advised to remain indoors.
- 25 March: voluntary evacuation was recommended within a radius of between 20 and 30 kilometres of the plant.
- 22 April: people were banned within a radius of 20 kilometres of the plant, at the same time as the advice to remain indoors between 20 and 30 kilometres of the plant was rescinded. At this point another new zone was also created, called the "Evacuation Prepared Area", replacing the advice to remain indoors and voluntary evacuation between 20 and 30 kilometres.

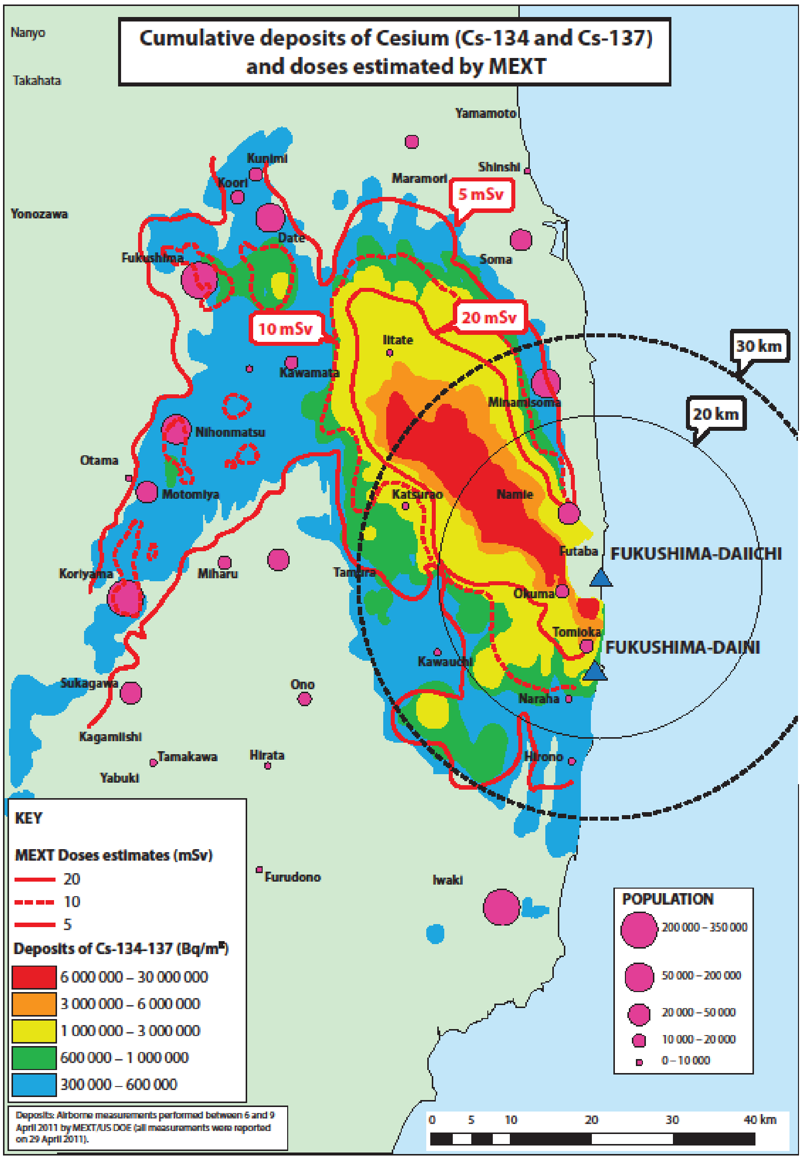
Radiation releases

During the period 12–15 March, extensive airborne releases of iodine 131, cesium 137 and cesium 134 occurred. The biggest releases probably occurred in connection with explosions on 15 March, and altogether the releases are estimated to have been equivalent to 10–19 percent of the radioactivity released in conjunction with the nuclear power disaster in Chernobyl.

The scope of the releases was initially underestimated, since a number of monitoring stations in this part of Japan were out of order due to power failures. One reason for this was that the monitoring stations had been disabled. Another reason could be that available personnel were busy with the rescue work after the earthquake and the tsunami. A third reason was that the local command centre could not be used since it was located within the evacuated area and relocation to Fukushima City was difficult under the prevailing circumstances.

However, extensive airborne surveys have yielded good information on deposits, and areas with high radioactivity have been pinpointed. This is evident from Figure 4.1, which also shows zones of calculated annual dose. The estimated annual dose in areas with the highest deposits (red) exceeds 100 millisieverts (mSv), to be compared with 1–4 mSv, which is the normal annual dose from natural background radiation in Sweden.

Figure 4.1 Map showing deposits of cesium 137 and 134 (MBq/m2) and the estimated annual dose for the first year (mSv) (6)



Leakage and intentional releases have resulted in extensive releases to the sea. Between 4 and 10 April, intentional releases of low-level water were done to provide room for high-level water. Due to the great dilution effect, the level of radioactivity in the sea off

Fukushima has declined rapidly, but elevated radioactivity can persist for a long time in bottom sediments in near-coastal areas.

Human exposure to radioactivity

Since there was a shortage of dosimeters during the initial period after the accident, it isn't known exactly how high doses the rescue personnel were exposed to. However, calculations during the month of March show that 6 persons have been exposed to more than 250 mSv (the highest dose was 670 mSv). On 14 March, the dose limit (effective dose) for personnel who participated in the rescue work was increased from 100 to 250 mSv. 16 persons were in the range 150–250 mSv, 384 in the range 50–150 mSv, 847 in the range 20–50 mSv and 947 in the range 10–20 mSv. The exposure level fell during April, and three persons are reported to have received doses in the range 50–150 mSv, while 86 were in the range 20–50 and 310 were in the range 10–20.

Public exposure to radiation is being determined by means of questionnaires and may also include whole-body measurements and other analyses. This survey includes all two million residents in the Fukushima prefecture.

Large national resources have been set aside for dose reconstruction, health examinations and long-term follow-up, and cooperation has been initiated with different international organizations. This work has great potential for adding to the body of knowledge regarding health effects of low doses and dose rates.

Cleanup

The cleanup work has begun and goals have been defined that will pose great challenges, both technically and economically. In general, they can be summarized as follows: In areas with dose rates higher than 20 mSv/year, the goal is to reduce the dose rate to less than 20 mSv. In areas where the dose rate is lower than 20 mSv, the goal is to come as close to 1 mSv as possible, and areas with children are to be given clear priority. The large areas with dose rates above 20 mSv per year (Figure 4.1) provide some indication of the challenges inherent in the above goals.

The situation in December 2011

Of Japan's 54 nuclear power reactors, six are in operation. All six reactors in Fukushima Daiichi are shut down due to damage caused by the tsunami. All 4 reactors in the nuclear power plant Fukushima Daiichi just south of Fukushima Daiichi are shut down, also as a consequence of the tsunami. Due to ongoing inspections and stress tests, 31 nuclear power plants are not producing electricity, while two reactors are shut down for other reasons.

The current situation for the three damaged reactors in Fukushima Daiichi can be summarized by saying that the reactors now have a temperature below 100 degrees and a functioning system for cooling water purification. In this situation, the risk of further releases is judged to have decreased, which has also led to a relaxation of preparedness for evacuation. The scope of the damage in reactors 1–3 is not known, while the damage to the fuel pool in reactor 4 is described as moderate.

The accident in Fukushima has had a significant impact on energy policy in Italy, Germany, and Switzerland. In other nuclear power countries, the safety margins for the nuclear power reactors have been analyzed by stress tests. These tests were carried out in a coordinated manner within the EU and via the International Atomic Energy Agency, IAEA, see below.

4.2 Changes in national legislation as a result of the accident in Fukushima-Dai

4.2.1 Italy – referendum rejected nuclear power

Italy was one of the first countries to invest in the development of nuclear energy technology for electricity production. The country has previously had four nuclear power reactors in operation. The two oldest reactors were closed in 1987 and 1982, and after a referendum in 1987 (following the accident in Chernobyl), the two remaining reactors were shut down in July 1990. In a national referendum in 1987, the Italian parliament decided not to permit nuclear power.

In 2004, however, a new energy act was passed which made it possible for Italian companies to import electricity from nuclear power reactors in association with foreign nuclear power companies.

The next step towards a more nuclear-friendly national policy was that the Italian Government declared in May 2008 that it would be possible within five years to build new nuclear power reactors in Italy in order to reduce the country's heavy dependence on oil, gas and imported power. The Government encouraged the development of new nuclear power, with the goal that one-quarter of the country's power supply should come from nuclear power by not later than 2030.

In January 2011, the Italian constitutional court ruled that Italy could hold a referendum on the planned reintroduction of nuclear power in the country. The referendum was held on 13 June 2011, three months after Fukushima. The result of the referendum was that Italy rejected all proposals to introduce new nuclear power in Italy.

4.2.2 Switzerland – new nuclear power policy

Switzerland has 5 nuclear power reactors in operation[v], with licences that are unlimited in time. The five the nuclear power plants have a total capacity of 3.2 GW, and the average annual percentage of electricity produced by nuclear power in Switzerland is 39 percent (up to 45 percent in the winter), which is above the European average of 33 percent.

In March 2011, two new nuclear power reactors were planned and had received the necessary licences to begin construction. An additional three reactors in Verbois, Inwil and Rüthi were in the planning stage.

However, the events at Fukushima on 11 March 2011 led to a reversal in Switzerland's nuclear power policy. Three days after Fukushima, the Swiss Federal Council decided to stop the licensing of the planned reactors. On 23 March 2011, the Federal Department of the Environment, Transport, Energy and Communications (DETEC) was instructed to prepare a proposal for a revised energy policy. On 25 May 2011, the Federal Council decided, as a result of the investigation, that existing nuclear power reactors should be decommissioned at the end of their operating life and not be replaced by new ones[vi]. In practical terms, the decision entails that

[v] Information obtained from the Swiss Federal Office of Energy.
[vi] Information obtained from the Swiss Federal Office of Energy.

the last reactor in Switzerland will go offline in 2034, assuming an operating life of 50 years.

4.2.3 Germany – fluctuating public opinion turned again

Immediately after the accident at the Fukushima Daiichi nuclear power plant, the Christian Democrat/Liberal Government declared a three-month moratorium on nuclear power. Nuclear safety evaluations will be carried out and the country's nuclear power policy will be reconsidered.

On 6 June 2011, the German Government decided to review its previously agreed-on phase-out plan for nuclear power, and at the end of June the Bundestag voted to approve an amendment to the Atomic Energy Act entailing that all nuclear power reactors must be shut down by 2022. The resolution was passed by a vote of 513 to 79, and the amendment entered into force on 31 July 2011.

The right to operate reactors for production of electricity will cease to exist by the date stipulated in Section 7 of the Atomic Energy Act:

- 6 August 2011 for Biblis A, Neckarwestheim 1, Biblis B, Brunsbüttel, Isar 1, Unterweser, Philippsburg 1 and Krümmel
- 31 December 2015 for Grafenrheinfeld
- 31 December 2017 for Gundremmingen B
- 31 December 2019 for Philippsburg 2
- 31 December 2021 for Grohnde, Gundremmingen C and Brokdorf
- 31 December 2022 for Isar 2, Emsland and Neckarwestheim 2.

The reactors stipulated in the first point can thus be regarded as permanently closed and cannot be connected to the grid again.

The mandated German phase-out can be viewed against the background of fluctuations in German public opinion over four decades.

Infobox 4.2 The administrative structure in Germany

General about the administrative structure

The Federal Republic of Germany consists of 16 states (Länder) with considerable autonomy. Responsibility for nuclear safety and radiation protection is divided between the governments of the states and the federal government in accordance with general principles in the German constitution.

In simple terms, the federal government – via the Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) – is responsible for the federal legislation, while the state ministries are responsible for licensing and supervision.

Federal expert bodies

BMU oversees that the states act in accordance with the regulatory framework. Thus, BMU has authority to give the state governments guidance and in certain cases binding directives for the purpose of achieving a uniform application of the regulatory framework.

Both in its development of the regulatory framework and in its supervisory and advisory functions towards the states, BMU utilizes two federal expert bodies: GRS (Gesellschaft für Anlagen- und Reaktorsicherheit) and BfS (Bundesamt für Strahlenschutz = Federal Office for Radiation Protection).

GRS is in principle a consulting firm with a special position as an independent review and advisory body. GRS is owned principally by the federal government and by German inspection and testing bodies (regional Technische Überwachungsverine, TÜVs or Technical Inspection Associations, and Germanische Lloyd). Its main clients are different federal and state bodies and the European Commission.

BfS is the Federal Office for Radiation Protection. Besides its role as an expert body for all types of radiation protection, BfS is charged with the task of realizing a federal final repository for spent nuclear fuel and radioactive waste – under its own auspices or under contract.

Oversight of safety and radiation protection
Oversight of both safety and radiation protection is exercised by the concerned state ministry in its capacity as regulatory authority under the Atomic Energy Act. The state ministry engages various expert bodies, both the federal bodies and the regional ones mentioned below (for example regional Technische Überwachungsverine, TÜVs). These expert bodies can be engaged both for inspections at the facilities and for review of different reports, such as safety analysis reports. The state ministry is, however, not bound to comply with the expert statements.

Sanctions
The state ministry has the authority to issue injunctions to the licensees for infractions of rules and licence conditions revealed by reviews and inspections. This includes the authority to stop operation if warranted for safety reasons.

BMU oversees that the state ministries' regulatory decisions comply with federal regulations. In the event of non-compliance, BMU can refer the matter back to the state for reconsideration.

Infractions of rules, regulations and licence conditions can result in the imposition of administrative fines of up to 50,000 euros on the person responsible for the infraction and an order barring the person from holding positions with responsibility for safety or radiation protection.

Very serious infractions can lead to criminal prosecution and imprisonment.

Ever since 1949, the power to govern West Germany, and subsequently the Federal Republic of Germany, has rested with the Social Democrats or the Christian Democrats (and sometimes with both in coalition). Both parties strongly supported nuclear power at first, especially after the 1974 energy crisis, when OPEC more than quadrupled the price of oil.

But opposition to nuclear power began to grow in Germany in the 1970s, and in 1980 the Greens was formed as a pro-environmental and anti-nuclear party. After the Chernobyl nuclear disaster the Social Democrats withdrew their previous support for nuclear power, and in August 1986 the Social Democratic Party adopted a resolution to phase out nuclear power within ten years. In 1998 the German Social Democrats formed a coalition government with the Greens, and this government decided to commence a phase-out of nuclear power. However, this could not be done without amending the legislation, since the licences for the nuclear power reactors (which were unlimited in time) had strong support in the law.

Long drawn-out "consensus talks" began with the owners of the nuclear reactors with the aim of establishing a timetable for the phase-out of nuclear power. The Government threatened to impose certain curtailments of the licences without compensation if agreement was not reached.

In 2000, a compromise was agreed between the red-green coalition government and the four biggest energy utilities. The agreement set an absolute "ceiling" for the electricity which nuclear power would be allowed to produce, corresponding to an average plant lifetime of 32 years.

The compromise entered into force in June 2001. The agreement entailed that the companies undertook to limit the operating time of the nuclear power reactors, at the same time as the state agreed to respect the rights of the licensees to operate the existing reactors, and to guarantee the operation of the reactors and the management of the waste would be protected from any "politically motivated interference".

Since nuclear power had accounted for approximately one-quarter of Germany's electricity production, the compromise agreement led to an extensive debate concerning whether Germany could live up to its climate commitments, especially with regard to reduction of carbon dioxide emissions. (Coal has accounted for about two-thirds of electricity production, gas for 13 percent and wind power for six percent.)

A new coalition government was elected in 2009 consisting of the Christian Democrats (CDU) and the Liberal Democrats (FDP).This government was committed to rescinding the phase-out policy and began new negotiations with the power companies.

An agreement was reached in September 2010 between the Government and the power companies extending the licences to operate the nuclear power reactors by 8 years for reactors built before 1980 and by 14 years for ones built later. At the end of October 2010, the Bundestag passed amendments in the Atomic Energy Act which confirmed the new agreement between the Government and the power utilities.

After Fukushima, domestic opinion against nuclear power grew, and eight months after the extension agreement with the power industry had been confirmed in the Atomic Energy Act, the Bundestag resolved to phase out German nuclear power within 12 years.

Infobox 4.3 The German legislation

General
The fundamental law is the Atomic Energy Act (Gesetz über die friedliche Verwendung der Kernenergie und den Schutz gegen ihre Gefahren [Atomgesetz]).It is complemented by various ordinances promulgated by BMU, including a radiation protection ordinance and various ordinances concerning licensing.

The introductory section states that the purpose of the Act is:

1. to phase out the use of nuclear energy for the commercial generation of electricity in a controlled manner, and to ensure orderly operation up until the date of termination,
2. to protect life, health and real assets against the hazards of nuclear energy and the harmful effects of ionizing radiation and to provide compensation for damage and injuries caused by nuclear energy or ionizing radiation,
3. to prevent danger to the internal or external security of the Federal Republic of Germany from the application or release of nuclear energy or ionising radiation,
4. to enable the Federal Republic of Germany to meet its international obligations in the field of nuclear energy and radiation protection.

The Atomic Energy Act requires periodic safety review every ten years based on up-to-date knowledge in science and technology.

The fundamental safety requirements for nuclear activity are described in the guidelines issued by an advisory Reactor Safety Commission (RSK) as well as in the more detailed standards issued by the Nuclear Safety Standards Commission (Kerntechnischer Ausschuß – KTA). Both of these advisory bodies are tied to BMU, along with an advisory Commission on Radiological Protection (SSK).These guidelines and standards are not legally binding, but are in practice normative for licensing and supervision.

Licensing process
Licences in principle to build and operate a nuclear facility are issued by the concerned state government after an extensive and transparent review and consultation process in several steps, in which BMU and the above-mentioned federal committees, as well as various federal expert bodies (see below), participate. The process also includes review under other laws, such as the Environment Act.

The following detailed licences for different steps in the construction process and for the operation of a nuclear installation are also issued at the state level by the competent state ministry.

Licences are required for erection, operation or alteration of a stationary installation for production, enrichment, processing or fission of nuclear fuel or for reprocessing of irradiated nuclear fuel (Section 7 of the Atomic Energy Act), as well as for interim storage of nuclear fuel in a non-federal facility (Section 6). A licence is also required for exports and imports of nuclear fuel (Section 3) as well as for carriage of nuclear fuel (Section 4). A special licence is required for treatment, processing and other utilization of nuclear fuel outside installations requiring a licence (Section 9).

Since 1 July 2005 it is illegal to deliver spent nuclear fuel to a reprocessing plant.

Licences may not be granted for erection and operation of nuclear power plants
Further licences may not be issued for construction and operation of installations for fission of nuclear fuel for commercial generation of electricity or of facilities for the reprocessing of irradiated nuclear fuel. This does not, however, apply to essential modifications of these installations or the operation thereof (Section 7).

Nuclear power must be phased out before 31 December 2022
The authorization to operate an installation for the fission of nuclear fuel for the commercial generation of electricity shall expire once a certain quantity of electricity, as stipulated in the Act, has been produced in the installation. Production of electricity at each nuclear power plant shall be measured and monitored under rules carefully specified in the Act. The quantities of electricity specified in the Act may be wholly or partially transferred from one installation to another.

4.3 Stress tests

Following the nuclear accident in Japan in March 2011, the EU Council of Ministers agreed at an extra meeting convened at the end of March that all EU Member States must conduct an overall risk and safety evaluation of their nuclear power plants, called stress tests.

In addition to the EU requirements, the Swedish Government has decided that the central interim storage facility for spent nuclear fuel (CLAB) should also be stress-tested.

The nuclear power industry will conduct the stress tests, while a national authority (in Sweden the Swedish Radiation Safety Authority, SSM), will review its analyses and compile a national report. SSM will report the results to the Government, as well as to the European Nuclear Safety Regulators Group (ENSREG). The stress tests for CLAB will, however, only be reported to the Government. When all countries have submitted their reports, a team of international experts will review the countries' reports. Stress tests are also being conducted in Japan at all the country's nuclear power reactors. According to the Japanese Government, the stress tests will be similar to those conducted by the EU.

In a communication dated 20 October 2011 to the International Nuclear Energy Agency, IAEA, the International Nuclear Regulators Association, INRA, urges the organization to ensure that stress tests are carried out in all IAEA Member States with nuclear power plants and that the results are shared among all concerned parties[vii].

4.4 Reflections

The nuclear disaster in Fukushima has had a great impact on the nuclear safety debate in Europe, but it is only in Switzerland, Italy and Germany that the debate has led to extensive changes in national energy policy.

The national nuclear safety authorities in France, Finland and the USA were instructed to conduct an evaluation of how their nuclear power plants would cope with extreme events, and in the UK a special investigator was appointed to review safety in the

[vii] The INRA consists of the heads of the nuclear regulatory authorities in Canada, France, Germany, Japan, South Korea, Spain, the USA, the UK and Sweden.

British NPPs[viii]. The Chinese government also decided to conduct an extensive safety evaluation of the country's reactors, including reactors under construction. However, the evaluations have not led to any policy changes with regard to the expansion of nuclear power in these countries[ix].

In Sweden, on 12 May 2011 the Government instructed the Swedish Radiation Safety Authority, SSM, to conduct stress tests on the Swedish NPPs, in accordance with the guidelines established within the EU. SSM has furthermore received a number of Government commissions to improve the safety work at the Swedish nuclear power facilities.

Ongoing and planned safety-enhancing measures will be evaluated in the light of the events (8), and SSM will analyze and evaluate which measures have the highest priority for producing optimal safety in the short and long term. The Authority will describe measures at Swedish nuclear facilities in response to the events at the nuclear power plant in Fukushima, review the physical protection of nuclear facilities against acts of terrorism, give an account of its view of ageing NPPs and conduct a review of the Swedish regulatory model. The results of these commissions will then also become a part of the safety work.

The events in Fukushima have not had any direct effects on the debate about nuclear waste in Sweden. SKB submitted its applications to the Swedish Radiation Safety Authority and the Land and Environment Court on 16 March 2011, as planned. According to SSM, the spent nuclear fuel already exists and must be managed and disposed of in a safe manner, and the events in Japan do not alter the perspectives for SSM's evaluation of SKB's applications (9).

[viii] Mike Weightman, chief inspector of nuclear installations.
[ix] In France, the possibility of imposing a moratorium on the development of new reactors was discussed. China is considering a slowdown in the pace of development.

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5 The Nuclear Waste Directive – new European framework for management of nuclear waste

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 (1). The directive entered into force on 22 August 2011. The Member States shall report to the Commission for the first time not later than 23 August 2015, and after that every three years.

The Directive shall be applied to all stages in the management of spent nuclear fuel and radioactive waste from civilian activities. It is thus not applicable to military activities.

Nor is the Directive applicable to waste from the extractive industries which may be radioactive and falls within the scope of Directive 2006/21/EC (2). Nor is the Directive applicable to authorized releases or in conjunction with the repatriation of disused sealed sources to a supplier or manufacturer. Shipments of spent fuel from research reactors to a country where research reactor fuels are supplied or manufactured are also exempted from the area of application of the Directive.

Sweden, Austria and Luxembourg abstained for certain reasons from voting on the adoption of the Directive – see below. The Directive is nevertheless applicable in Sweden and shall be incorporated in the Swedish legislation.

5.1 General principles

The Directive is based on a number of general principles that shall apply to the management of spent nuclear fuel and radioactive waste, including the following:

- that it is an ethical obligation for all Member States to avoid any undue burden on future generations
- that the Member States bear the ultimate responsibility for the safety of spent fuel and radioactive waste management, while the prime responsibility for the safety of spent fuel and radioactive waste management rests with the licence holder under the supervision of its competent regulatory authority
- that the generation of radioactive waste shall be kept to the minimum which is reasonably practicable, in terms of both activity and volume
- that transparency in the management of spent fuel and radioactive waste is guaranteed by ensuring effective public information and opportunities for all stakeholders concerned, including local authorities and the public, to participate in the decision-making process
- that the Member States should ensure that adequate funding is available for the management of spent fuel and radioactive waste.

Where radioactive waste or spent fuel is shipped for processing or reprocessing to a Member State or a third country, the ultimate responsibility for the safe and responsible disposal of those materials, including any waste as a by-product, shall remain with the Member State or third country from which the radioactive material was shipped.

The purpose of the Directive can be said to be to ensure that these general principles are followed by means of appropriate national arrangements by the Member States[i].

5.1.1 The principle that radioactive waste shall be disposed of in the Member State in which it was generated

As a general principle and prime rule in the Directive, radioactive waste shall be disposed of in the Member State in which it was generated. There is, however, an exception to this principle which was particularly discussed when the Directive was adopted.

Providing that a Member State has entered into a special agreement with another Member State or a third country, it is possible

[i] Cf. Article 1 and Article 4 in the Directive.

to use a facility in one of these countries for disposal of the radioactive waste. This agreement must comply with the criteria established by the Commission[ii]. In the case of a third country, there are certain additional requirements, for example that the country is a party to the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

The possibility of exemption from the principle prompted abstentions by Sweden, Austria and Luxembourg from voting on adoption of the Directive. The countries recognize the value of several important provisions in the Directive, but regret that the Community has not been able to accept full responsibility for managing its own spent fuel and radioactive waste, given that the Community accepts the possibilities of exports of waste for disposal in a third country.

5.2 A national framework

The Member States shall establish and maintain a national legislative, regulatory and organizational framework ("national framework") for spent fuel and radioactive waste management that allocates responsibility and provides for coordination between relevant competent bodies. The Directive gives a general account of what this framework should include[iii].

The framework shall include a national programme for national plans of action with regard to the management of spent nuclear fuel and radioactive waste – see below. Furthermore, the national framework shall include a system for licensing, allocation of responsibility between different bodies, inspection and supervision, enforcement actions and national requirements for public information and participation. As far as allocation of responsibility is concerned, the Directive states that the national framework shall give primary responsibility for the spent fuel and radioactive waste to those who generate it or, under specific circumstances, to the licence holder to whom this responsibility has been entrusted by competent bodies. The framework shall also include a financing scheme for spent fuel and radioactive waste management.

[ii] Cf. Article 16.2 in Directive 2006/117/Euratom on the supervision and control of shipments of radioactive waste and spent fuel.
[iii] Cf. Article 5 in the Directive.

The legislation in force in the field of nuclear waste in Sweden – the Nuclear Activities Act (3), the Radiation Protection Act (4), the Environmental Code (5) and the Financing Act (6) – would appear to comply with the requirements made by the Directive on the national framework.

5.3 National programmes

According to the Directive, the national framework shall include a national programme for the implementation of spent fuel and radioactive waste management policy. The programme shall cover all types of spent fuel and radioactive waste under each Member State's jurisdiction and all stages of spent fuel and radioactive waste management from generation to disposal[iv].

The programme shall be regularly reviewed and updated "taking into account technical and scientific progress as appropriate as well as recommendations, lessons learned and good practices from peer reviews". Furthermore, the Directive contains relatively detailed requirements on the content of the programme[v]. The national programme and subsequent significant changes shall be reported to the Commission[vi].

In the opinion of the Swedish National Council for Nuclear Waste, it is unclear to what extent and in what way the requirements on a national programme can be said to be matched by the provisions of current legislation in Sweden. It could be argued that they are matched by the requirements of the Nuclear Activities Act that the reactor owners shall prepare a comprehensive research and development programme for management and disposal of the nuclear waste[vii]. Moreover, the Financing Act contains provisions entailing that license holders who manage spent nuclear fuel and radioactive waste shall prepare cost calculations for the measures they intend to adopt for management and disposal of the waste[viii].

The Directive's requirements on a national programme could also be matched by the requirements in the Swedish Radiation Safety Authority's regulations concerning management of radioactive

[iv] Cf. Article 11 in the Directive.
[v] Cf. Article 12 in the Directive.
[vi] Cf. Article 14 in the Directive.
[vii] Cf. Section 12 of the Nuclear Activities Act.
[viii] Cf. Section 18 of the Act (2006:647) on Financial Measures for the Management of Waste Products from Nuclear Activities.

waste and nuclear waste at nuclear facilities (7). The regulations provide that the activity operators shall prepare waste plans describing the radioactive waste that is produced, radioactive releases and final disposal of the waste. The plans shall be kept updated and be available from the activity operator.

Thus, various Swedish statutes contain provisions which in different ways deal with the preparation and presentation of plans for management and disposal of spent nuclear fuel and radioactive waste. But there is scarcely any coherent national programme to speak of.

In its statement of comment on the Commission's draft of the current Directive, the Swedish National Council for Nuclear Waste endorsed the idea of a national programme as a point of departure for assumption of national responsibility for the management and disposal of spent nuclear fuel and radioactive waste (8). It is the Council's considered opinion that a national programme could contribute to transparency and quality assurance of radioactive waste in Sweden.

5.4 Competent regulatory authority

Each Member State shall "establish and maintain a competent regulatory authority in the field of safety of spent fuel and radioactive waste management"[ix].

The authority shall be functionally separate from any other body or organization active in the area. This includes organizations active in electricity production and radioisotope applications. The authority shall be given the legal powers and the human and financial resources necessary to fulfil its obligations in accordance with "the national framework".

The Swedish Radiation Safety Authority and its activities meet the Directive's requirements.

5.5 Licence holders

The Nuclear Waste Directive requires that the Member States ensure that the prime responsibility for the safety of spent fuel and radio-

[ix] Cf. Article 6 in the Directive.

active waste management rests with the licence holder. According to the Directive, this responsibility cannot be delegated[x].

Safety must be regularly assessed, verified and continuously improved, as far as is reasonably achievable. As part of the licensing procedure, the safety demonstration shall cover the closure of a disposal facility as well as the post-closure phase. The Member States shall also ensure the licence holders establish and implement integrated management systems, including quality assurance, which give due priority to safety in the overall management of spent fuel and radioactive waste. Further, the licence holders shall have adequate financial and human resources to fulfil their obligations with respect to safety.

The requirements of the Directive in these respects are matched by the Nuclear Activities Act and the Swedish Radiation Safety Authority's Regulations concerning Safety in Nuclear Facilities[xi].

[x] Cf. Article 7 in the Directive.
[xi] Sections 10 and 13 of the Nuclear Activities Act and Sections 7–10 of the Swedish Radiation Safety Authority's regulations (SSMFS 2008:1).

References

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6 Final disposal in other countries – Current situation in Finland, France, Germany, Switzerland and USA

6.1 Finland

6.1.1 Introduction

Finland is one of the three countries in the world that has come the farthest in the process of establishing a final repository for high-level spent nuclear fuel (1). However, Finland has no national programme for management of spent nuclear fuel; rather, it is the responsibility of the nuclear power producers to develop a final disposal method for spent nuclear fuel generated by the nuclear power producers' reactors (2).

The nuclear power companies Teollisuuden Voima Oyj (TVO) and Fortum Power & Heat Oy have two reactors each. They are joint owners of Posiva Oy (Posiva), which is responsible for developing a safe final disposal method for the spent nuclear fuel.

Posiva has chosen the Swedish KBS-3 method, which entails that the spent nuclear fuel will be placed in copper canisters and deposited approximately 500 metres down in the bedrock, embedded in bentonite clay. Posiva and the Swedish Nuclear Fuel and Waste Management Co (SKB) are cooperating closely in research on this method.

Posiva is planning to build a final repository for spent nuclear fuel on the Olkiluoto peninsula in the municipality of Eurajoki in western Finland. Posiva is building a research tunnel near Olkiluoto in the bedrock of Onkalo, which, according to plans, will be a part of Finland's final repository for spent nuclear fuel. Posiva's purpose with the research facility is to investigate whether the site is suitable for a final repository for spent nuclear fuel and to find out more about the bedrock in Olkiluoto before the company applies for a building permit in 2012.

The research facility is intended to become Finland's final repository for spent nuclear fuel, provided the licensing process goes as Posiva has planned.

The new energy company Fennovoima Oy plans to build a nuclear power plant in the town of Pyhäjoki. According to the Finnish Government, Fennovoima is obliged to produce an agreement showing that the spent nuclear fuel from Fennovoima's new nuclear power plant can be disposed of in Posiva's final repository in Olkiluoto. Alternatively, Fennovoima must present an environmental impact statement for its own final repository (2).

A more detailed description of the decision process surrounding Finland's programme for final disposal of spent nuclear fuel follows below, along with a brief presentation of the Finnish State Nuclear Waste Management Fund.

6.1.2 The Finnish decision process

The Finnish decision process around the construction of a final repository consists of three decisions made by the Finnish Government: a decision in principle, a construction licence and an operating licence (3). The first decision in the licensing process was taken in 2001, when the Finnish Government made a decision in principle to approve the erection of a final repository for spent nuclear fuel in the municipality of Eurajoki in Finland.

Posiva will apply for a construction licence for its planned final repository in 2012. After that, an operating licence must be obtained from the Finnish Government in order for Posiva to begin operation of a final repository.

6.1.3 Decision in principle

In order to build a nuclear facility of major public importance, the Finnish Nuclear Energy Act requires a so-called decision in principle establishing that the facility is in the best overall interests of society (3).

An application for a decision in principle is prepared by the Ministry of Employment and the Economy, which must consult the Finnish Radiation and Nuclear Safety Authority (STUK), the Ministry of the Environment and Eurajoki Municipality, where the facility will be erected. The Ministry of Employment and the Economy must also give the inhabitants and the municipalities in the immediate environment of the facility, as well as local authorities, an opportunity to express their viewpoints on the planned facility in writing. Viewpoints expressed at the meeting must come to knowledge of the Finnish Government. The Ministry must also hold a public meeting in the town where the company plans to build the final repository.

Once the Government has made its decision in principle, the decision should be presented to the parliament for review without delay. The parliament may nullify the decision in its entirety or decide that it can enter into force without changes. As mentioned, the decision in principle was made by the Finnish Government in 2001 and has been adopted.

6.1.4 Construction licence

Construction of the final repository cannot commence until the Government has granted a special construction licence. Posiva must submit an application for a licence to build the final repository before the end of 2012. STUK will review the application, which is planned to take about 2 years, and then submit a statement to the Ministry of Employment and the Economy based on a safety evaluation (3).

6.1.5 Operating licence

Before the final repository may be put into operation, the applicant (Posiva) must apply for an operating licence. The application will then be submitted to the Ministry of Employment and the Economy for consideration. The applicant may not commence operation of the facility until STUK has concluded that the final repository meets the safety requirements stipulated for the activity. Posiva expects to be able to conclude closure of the final repository in around 2120.

6.1.6 The Finnish State Nuclear Waste Management Fund

Like Sweden, Finland has a financing system where the nuclear power-producing utilities pay nuclear waste fees to a state fund, the State Nuclear Waste Management Fund. The Fund is a guarantee fund for future costs for managing the spent nuclear fuel and is currently also financing a national research programme for spent nuclear fuel management[i]. The Ministry of Employment and the Economy manages the Finnish Fund[ii], and up until 2010 TVO and Fortum have paid 0.17 eurocents per kilowatt-hour of nuclear-generated electricity to the Fund. The current value of the Finnish State Nuclear Waste Management Fund is about 1.9 billion euros. Posiva's costs are paid directly by TVO and Fortum.

6.2 France

6.2.1 Introduction

France is considered to be one of the three countries that have come the farthest towards finding a solution to the nuclear waste problem. This in spite of the fact that the country suffered a major setback in the 1980s when the process was halted by public opposition. Since then, the principle of voluntary participation has played a central role in the French work.

ANDRA (Agence Nationale pour la Gestion Des Déchets Radioactifs = National Radioactive Waste Management Agency) is charged with the mission of managing France's radioactive waste[iii]. The agency has built a research laboratory in Bure in the Meuse/Haute-Marne district in the northeastern part of France, and has proposed a nearby site as suitable for building a final repository.

In the coming years, ANDRA plans to hold a public debate on licence applications for the erection of a final repository, and the hopes to begin construction of a final repository for high-level waste in Bure in 2017.

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[i] The research programme is called KYT 2014.
[ii] The Ministry of Employment and the Economy's website: http://www.tem.fi/index.phtml?l=en&s=1550
[iii] 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.

This chapter describes milestones in the process, the background of the legislation and those in charge of the French nuclear waste management system.

6.2.2 Site investigations

General geological investigations were begun in the 1980s that identified some 30 possible sites. Four sites were selected from these 30, but public opposition was too great and the investigations were called off. The legislation that entered into force in 1991 stipulated that further efforts must be based on voluntary participation (4).

Geological investigations in Bure

Geological investigations to find a site for an underground research laboratory commenced in 1994. Investigations were conducted at Bure, among other places, and the work was done in consultation with the public and concerned municipalities. The bedrock in the area is dominated by a clay shale, and the purpose of the investigations was to see whether this rock type is suitable for a deep repository for high-level and long-lived nuclear waste with the option of retrieval in accordance with the national strategy. The geological formation consists of stiff clay at a depth of 500 metres. After approval by municipalities and the Government, construction of the research laboratory began in 1999[iv].

ANDRA's report on geological deep repositories

In 2005, ANDRA presented a report to the Minister of Research and Industry on the possibility of disposing of high-level and long-lived radioactive waste in a geological deep repository. The report, which summarized research in the field over the past 15 years, presented

- a feasibility study concerning clay shale based on the work being conducted.

[iv] ANDRA, The Meuse/Haute– Marne Underground Research Laboratory.

- a report on the advantages of granites based on available literature on French granite.

In the 2005 report, ANDRA showed that the geology in a 250 km^2 area around the research laboratory in Bure may be suitable for a final repository. In order to get a clearer picture of where the facility could be sited, the first step was to reduce this area to a zone where more detailed geological investigations would be conducted.

Detailed site investigations

In 2009, discussions were held with local stakeholders regarding a final repository. All involved parties pointed out that long-term safety must have top priority and the local community expressed its expectations with respect to regional development and local integration in the project. At the end of 2009, ANDRA presented to the Government a 30 km^2 area called ZIRA where they wanted to conduct detailed site investigations for the construction of a geological repository called Cigeo that will be able to receive high-level and intermediate-level long-lived waste. The proposal was approved by the National Assessment Board, the licensing authority and ANDRA's scientific council, and in 2010 ANDRA received a licence from the Government to commence detailed geological investigations in the area.

6.2.3 Future plans

During 2012, ANDRA plans to prepare the scientific and technical documentation surrounding its research. During 2012–2013, the agency plans to hold a public debate, and in 2015 to apply for a licence to build a final repository. If all goes according to ANDRA's plans, the work of erecting a final repository will begin in 2017.

French legislation stipulates that the process around a final repository must be reversible (see Infobox 6.1) for at least 100 years. This is so that future generations will have an opportunity to reconsider previous decisions and the freedom to choose another solution. In order to make things easier for future decision-makers, the repository will be monitored with respect to temperature, pressure, deformation and so on[v].

Infobox 6.1 Reversibility

Reversibility refers to the possibility of backing up one or more steps in the planning and development process at every step of the programme. This requires reviewing and, if necessary, a re-evaluating or reconsidering previous decisions, and that the necessary means are available (technical, economic etc.). The term “reversibility” suggests that retreat options are built into the disposal policy and into the technical programme in question.

Reversibility can be facilitated by proceeding in small steps and reviewing the programme frequently. Reversibility can also be facilitated by means of different technical solutions. In the early stages of the programme, it is possible to reconsider a decision on site selection or the choice of a special design solution. Later on in the programme, during construction and operation, it is possible to reconsider one or more components in the repository or, after the waste has been emplaced, even to retrieve waste from the repository (5).

6.2.4 French legislation on research and management of nuclear waste

The general principles for management of spent nuclear fuel and radioactive waste, including financing of future costs, are laid down in the 1991 “Act Concerning Research on Radioactive Waste Management” (6), later modified in the 2006 “Act Concerning the Sustainable Management of Radioactive Materials and Waste” (7) with appurtenant ordinances and regulations promulgated under the French Environmental Code.

The Act formally stipulates a geological deep repository reference as a reference solution for high-level and long-lived radioactive waste, and sets 2015 as the target date for licensing of a final repository and 2025 as the date when deposition of waste should commence. The Act defines three main principles when it comes to radioactive waste and radioactive substances:

[v] www.andra.fr 15 Dec. 2011.

1. reduction of quantity and toxicity,
2. interim storage of radioactive substances and waste for later disposal,
3. final disposal in geological formations.

The principle of reprocessing of spent fuel and use of recycled plutonium and uranium in the form of Mixed Oxide Fuel (MOX fuel) is established "to reduce the quantity and toxicity" of the ultimate waste.

The Act prescribes that a national plan for management of radioactive materials and waste shall be completed prior to 31 December 2006 and subsequently updated every three years.

6.2.5 Responsibility for management of spent nuclear fuel and nuclear waste

According to the legislation, the reactor owners bear primary responsibility for managing and disposing of spent nuclear fuel and nuclear waste in a safe manner in accordance with the national strategy. According to this strategy, spent nuclear fuel shall preferably be reprocessed and extracted fissionable material be reused in the form of MOX fuel. In the long term, an attempt will be made to develop technology for further partitioning and transmutation to reduce the quantity of long-lived radionuclides that need to be emplaced in a geological deep repository.

The nuclear power companies shall regularly calculate future costs for radioactive waste management and, based on these cost calculations, set aside the necessary funds. Research and development is financed via special taxes and charges levied on the nuclear power companies.

Special state commissions oversee the implementation of the national strategy and the financing system.

Licensing and supervision of facilities for management of spent nuclear fuel and nuclear waste are subject to the Nuclear Transparency and Safety Act. This Act regulates the licence holder's responsibilities, licensing procedures, and the position and tasks of the regulatory authority[vi].

[vi] L'Autorité de Sûreté Nucléaire, ASN (Nuclear Safety Authority).

Reprocessing and waste treatment with associated technology development are handled primarily by the nuclear technology group AREVA, which is run as a corporation with the French Atomic Energy Commission (CEA) as the major shareholder. High-level vitrified waste from reprocessing is interim-stored at AREVA's facilities in La Hague.

The final repositories are built and operated by ANDRA. ANDRA's position and tasks are also regulated by the Act Concerning the Sustainable Management of Radioactive Materials and Waste.

Operational waste is placed in concrete cells in a near-surface repository for operational waste in Aube – the district where a final repository for low-level and short-lived radioactive waste in Soulaines is situated, along with a final repository for very low-level waste in Morvilliers (CSTFA). An older repository next to the reprocessing plant in La Hague is now closed but is being monitored.

6.3 Germany

The German Atomic Energy Act with appurtenant ordinances regulates the management of spent nuclear fuel and radioactive waste.

The reactor owners bear full technical and financial responsibility for interim storage of spent nuclear fuel and nuclear waste. However, according to the Atomic Energy Act, final disposal is a federal responsibility, with the Federal Office for Radiation Protection (Bundesamt für Strahlenschutz, BfS) as the executive authority.

The power companies are obligated to pay current and future costs for management of spent fuel and nuclear waste and to make the necessary internal allocations for this purpose, as well as for decommissioning and dismantling of the nuclear energy installations.

A discussion of how spent nuclear fuel and radioactive waste should be managed in Germany and where the waste should be disposed of has been under way for several decades, and has in many aspects not yet been concluded. In July 2009, a decision was made at the federal level on new criteria for final disposal, replacing the earlier rules from 1983. A licence for final disposal of high-level radioactive waste may only be granted if it can be scientifically demonstrated that the waste will remain stable in the repository for a million years. Furthermore, the waste must be retrievable during the time the repository is in operation prior to final closure.

6.3.1 Facilities for storage of radioactive waste

Germany currently has facilities for the disposal of spent nuclear fuel and radioactive waste in Konrad, Asse and Morsleben, Gorleben and Ahaus. The first three are in central Germany between Hannover and Magdeburg, Gorleben is situated 100 kilometres southeast of Hamburg, and Ahaus is located in western Germany.

The facilities that will probably be developed in the future are those in Gorleben and Konrad. Gorleben is being developed for interim storage and final disposal of high-level waste, and Konrad for final disposal of low- and intermediate-level waste.

A licence was granted in January 2008 for the activities in Konrad. The final repository is planned to be ready for operation in 2014. Provided that a licence for a final repository is granted in 2019, a final repository could be put into operation in Gorleben in 2025.

Gorleben

In 1963, the federal Government issued a recommendation to use geological salt domes for final disposal of spent nuclear fuel and radioactive waste. The planning for a national final repository started in 1973[vii], and after an extensive site selection process, the state government in Lower Saxony declared in 1977 that the salt dome in Gorleben would be the site of a national facility for disposal of radioactive waste. A final repository for radioactive waste was to be built deep down in the salt dome, together with a special unit for interim storage of waste. Due to political opposition in the state, however, it has not been possible to realize the original plans, but the work of developing a deep geological repository for high-level radioactive waste is still proceeding. The federal DBE mbH[viii]

[vii] Responsibility for this work was clarified by an amendment to the Atomic Energy Act in 1976 stating that it would be a federal responsibility to develop, build and operate facilities for final disposal of spent nuclear fuel and radioactive waste from nuclear installations. At the same time, the reactor owners were given full responsibility for the management and interim storage of spent nuclear fuel and nuclear waste.

[viii] The German Society for the Construction and Management of Long-Term Waste Storage Units.

operates a pilot plant that is considered possible to develop into a full-scale final repository for high-level radioactive waste.

There are two interim storage facilities for radioactive waste in Gorleben today. Transportbehälterlager Gorleben (the Gorleben transport cask storage unit) is used for interim storage of spent nuclear fuel and vitrified high-level waste from reprocessed fuel. Fuel assemblies and vitrified high-level waste is stored dry in air-cooled casks standing in a hall above ground. A licence has been granted for 420 casks.

Radioactive waste from both German nuclear power plants, as well as from research and industry, is stored in Abfalllager Gorleben (the Gorleben waste storage unit).

Konrad

The abandoned iron ore mine in Konrad has been under development as a final repository for radioactive waste since 1975. In 1982, the predecessor to the current Federal Office for Radiation Protection submitted an application to the Environment Ministry in Lower Saxony for a licence to build a national final repository low- and intermediate-level waste in the iron ore mine. However, the political debate in the state prevented the application from being granted until 2002. The decision to grant the application was appealed, and it was not until January 2008 that a licence to build a final repository could finally be issued. The final repository for low- and intermediate-level waste is planned to be put into operation in 2014.

Konrad will initially be able to receive 300,000 cubic metres of radioactive waste. Eventually, the final repository is planned to hold 650,000 cubic metres of radioactive waste.

Ahaus

In Ahaus there is an interim storage facility for intermediate-level waste, including some fuel assemblies with spent fuel from research reactors. In 2010, the Federal Office for Radiation Protection gave its approval for the shipment of 951 fuel assemblies from the Rossendorf research reactor (shut down in 1991) to Mayak in Russia for reprocessing. The shipment took place in accordance with the Russian Research Reactor Fuel Return Programme.

Asse

The radioactive waste storage facility in the Asse salt mine has been closed. Radioactive waste was deposited in the facility between 1967 and 1978. The facility is in bad shape. Cracks in the old mine allow water to seep in and dissolve the salt in the rock. Brine has to be pumped out of the mine on a daily basis. As a result, the Federal Office for Radiation Protection, BfS, decided in 2010 that the waste, consisting of 126,000 waste drums, had to be moved. A candidate site is the planned final repository for low- and intermediate-level radioactive waste in Konrad. According to plans, the waste has to be removed by 2020 at the latest.

Morsleben

The repository for low- and intermediate-level waste in Morsleben was licensed in 1981 and closed in 1998. The facility is in bad shape and is in the process of being stabilized with concrete at an estimated cost of 2.2 billion euros.

Wiederaufarbeitungsanlage Karlsruhe Betriebsgesellschaft (WAK)

A pilot plant for reprocessing of spent nuclear fuel called WAK was operated in Karlsruhe between 1971 and 1991. Approximately 206 tonnes of spent fuel was processed at the plant.

The separated high-level radioactive waste is stored in liquid form at the plant. The liquid waste is planned to be vitrified by 2012. The vitrified high-level waste will, according to plans, be interim-stored at the closed nuclear power plant in Greifswald awaiting deposition in a geological repository.

The low- intermediate-level radioactive waste generated by the activity in WAK has been deposited in the salt mine in Asse and comprises approximately half of the waste deposited in the salt mine.

6.3.2 Alternative proposals for final disposal of high-level radioactive waste

An alternative proposal for final disposal of high-level radioactive waste than what is planned in Gorleben is to build a final repository in opaline clay, which occurs at a number of different places in Germany.

Reprocessing waste from France

Separated high-level waste from previous reprocessing in France is waiting to be sent back to Germany for final disposal up until 2022. The waste consists of a total of 166 large drums of glass canisters. Of these, 39 are already being interim-stored in Gorleben.

Another roughly 300 drums of packaged radioactive waste from reprocessing are awaiting direct transport to a final repository.

6.4 Switzerland

According to the Swiss Nuclear Energy Act, it is the producers of radioactive waste who are responsible for safe management and final disposal of the waste. The Swiss Confederation is responsible for radioactive waste from medicine, industry and research, while the reactor owners are responsible for spent nuclear fuel (and other radioactive waste from the nuclear power plants).

In 1972, a joint national body (Nagra) was set up between the Swiss Confederation and the reactor owners to ensure that the radioactive waste arising in Switzerland would be managed safely.

In 2002, Nagra submitted a report to the Swiss Confederation showing that it was possible to dispose of spent nuclear fuel, separated high-level waste and long-lived intermediate-level waste in Switzerland. Nagra has therefore been conducting a search for a suitable site for a final repository since 2006. The goal is to put a final repository into operation by 2020.

In Switzerland, the radioactive waste from the nuclear power plants is managed by ZWILAG[ix], which is owned by the four Swiss nuclear power plants. ZWILAG has been operating a central interim

[ix] Zwischenlager Würenlingen AG.

storage facility, ZZL[x], for dry storage of high-level waste in Würenlingen since 2001. ZWILAG also has facilities for incineration, conditioning and storage of low- and intermediate-level radioactive waste.

The Swiss NPPs have previously reprocessed spent nuclear fuel in France for use of MOX fuel. However, tougher rules introduced into the Nuclear Energy Act imposed a moratorium on reprocessing[xi]. This moratorium will be in force for 10 years, starting in mid-2006. Since that time, spent fuel has either been interim-stored at the NPPs or sent as high-level waste to ZZL for interim storage above ground.

Switzerland has a national fund for disposal of radioactive waste plus a fund for decommissioning of nuclear facilities. Each fund is a separate legal entity. The reactor owners are obliged to pay special fees to the two funds[xii].

6.5 USA – from Yucca Mountain to the Blue Ribbon Commission

"America's nuclear waste management program is at an impasse". This is the opening statement in the executive summary of the conclusions of the national Blue Ribbon Commission, presented on 26 January 2012 (8).

The American process for management of commercial spent nuclear fuel suffered a setback in March 2009 when the licence application submitted to the US Nuclear Regulatory Commission (NRC) was withdrawn by the Obama administration. The decision to withdraw the application called into question the work of the past 25 years and necessitated looking at other alternatives.

On 29 January 2010, the independent Blue Ribbon Commission was established on the President's initiative. The Commission was chartered to conduct an exhaustive review of policies for managing the back end of the nuclear fuel cycle and recommend a new strategy for the management of spent nuclear fuel and high-level radioactive waste.

[x] Zentrales Zwischenlager.
[xi] Cf. Art. 9.
[xii] Cf. Chap. 7 and Chap. 8 of the Nuclear Energy Act.

6.5.1 Background

Since 1987, the American plan for disposal of spent nuclear fuel has mainly been based on one concept: a repository in caverns in Yucca Mountain in the state of Nevada. The US Department of Energy (DoE) recommended that the site investigations be limited to Yucca Mountain, after which Congress decided that other site investigations should be called off. This decision was enacted into law in the Nuclear Waste Policy Amendments Act (NWPAA) of 1987.

In 2002, Congress had approved the submission of a licence application to build a final repository for commercial spent fuel, and in 2008 the US Department of Energy submitted its licence application to the Nuclear Regulatory Commission, NRC, which began its review of the application. The US Department of Energy, DoE, is responsible for planning, building and operating interim storage facilities and a final repository for all high-level waste in the country, while the NRC is the principal regulatory authority for high-level waste and has been responsible for reviewing the application[xiii].

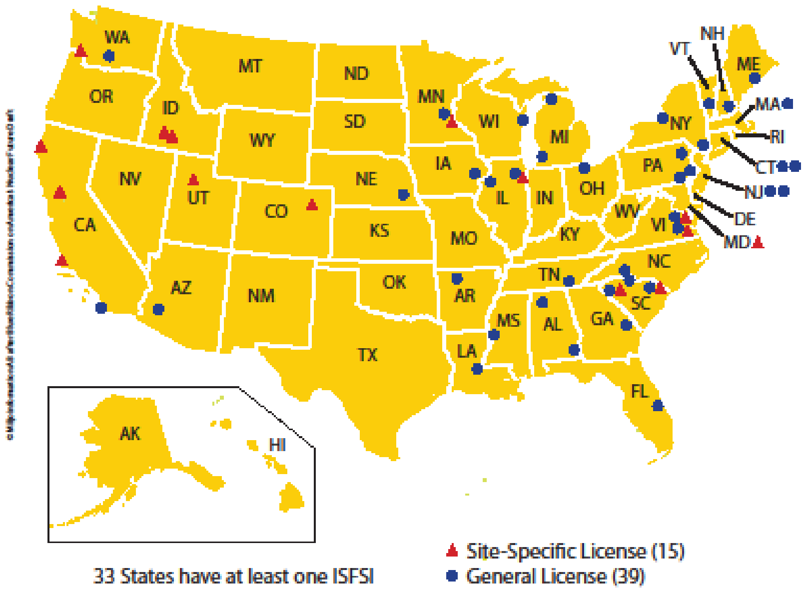
The choice of Yucca Mountain as a site for final disposal of the spent fuel did not win the support of the state of Nevada, and the siting process was plagued by local protests and appeals.

According to the proposal, the repository was to be located at a depth of 300 metres in the rock, above the groundwater level. The fuel was to be contained in canisters consisting of 5 cm thick stainless steel with a 2 cm thick nickel alloy coating[xiv].

At present the spent nuclear fuel is being stored in 39 states at more than 130 sites, both in dry storage and in water pools (see Figure 6.1). The low- and intermediate-level waste is stored at the nuclear power plants.

[xiii] The NRC is headed by five commissioners appointed by the President and confirmed by the Senate for five-year terms. The Commission formulates policies, develops regulations governing nuclear reactor and nuclear material safety, issues orders to licensees, and adjudicates legal matters.
[xiv] Alloy 22.

Figure 6.1 At present there are 54 NRC-licensed Independent Spent Fuel Storage Installations (ISFSIs) for dry storage in 3 states. In addition, there are 14 closed reactors in 9 states with spent fuel in dry or wet storage (8)



6.5.2 Blue Ribbon Commission for America's Nuclear Future

As a result of President Obama's decision to withdraw the DoE's licence application for a final repository in Yucca Mountain, the Secretary of Energy appointed the Blue Ribbon Commission on America's Nuclear Future in February 2010. The Commission – which consists of researchers, politicians and industrialists – was chartered to review current policies for managing spent nuclear fuel and high-level waste and recommend a new strategy for managing the back end of the nuclear fuel cycle. The Commission is responsible to the US Department of Energy.

The Commission consists of three subcommittees that examine different aspects of spent nuclear fuel management: “Reactor and fuel cycle technology”, “Transportation and storage” and “Waste disposal”.

The Commission’s extensive work has entailed exchanging information with a large number of parties, both experts and stakeholders, via discussions and public meetings. Furthermore, the Commission has visited waste management facilities in the United States and abroad, and as a part of this work the Commission visited Sweden in October 2010.

The subcommittees presented their preliminary conclusions in the spring of 2011, the collected preliminary conclusions were presented on 29 July 2011 (9) and the Commission’s conclusions were presented on 26 January 2012 (8).

The report contains recommendations in the following areas:

- approach to siting of future facilities for nuclear waste,
- transport and storage of spent fuel and high-level waste,
- options for waste disposal,
- institutional arrangements for managing spent nuclear fuel and high-level wastes,
- reactor and fuel cycle technologies,
- international considerations.

The Commission does not take positions on the following questions:

- the suitability of Yucca Mountain as a site for the final repository, or whether it was right to withdraw the licence application. It is the Commission’s opinion that a sound strategy is needed, regardless of what happens with Yucca Mountain,
- specific sites for any component of the waste management system,
- the appropriate role of nuclear power in the nation’s (or the world’s) future energy supply mix.

According to the Commission, these are all questions that will engage policy-makers and the public in the years to come. However, none of them alters the urgent need to change and improve the strategy for managing the high-level wastes and spent fuel that already exist and will continue to accumulate so long as nuclear reactors remain in operation.

6.5.3 The Commission's proposed strategy

The proposed strategy presented in the final report contained eight elements for management of the high-level waste and the spent fuel which the Commission regards as necessary:

1. A new, consent-based approach to siting future nuclear waste management facilities
2. A new organization dedicated solely to implementing the waste management program and empowered with the authority and resources to succeed
3. Access to the funds nuclear utility ratepayers are providing for the purpose of nuclear waste management
4. Prompt efforts to develop one or more geologic disposal facilities
5. Prompt efforts to develop one or more consolidated interim storage facilities for spent nuclear fuel
6. Prompt efforts to prepare for the eventual large-scale transport of spent nuclear fuel and high-level waste to consolidated storage and disposal facilities when such facilities become available
7. Support for continued U.S. innovation in nuclear energy technology and for workforce development
8. Active U.S. leadership in international efforts to address safety, waste management, non-proliferation, and security concerns.

The Commission also recommended critical changes needed in the handling of nuclear waste fees and of the American Nuclear Waste Fund.

The majority of these recommendations require immediate action to be taken by the Administration and Congress to enable the American final repository programme to go forward.

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Committee terms of reference

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

Dir. 1992:72

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

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

Dir. 2009:31

Decision at Government meeting of 8 April 2009

Summary of task

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

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

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

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

Task

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

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

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

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

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

Organization

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

Timetable

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

(Ministry of the Environment)

The Swedish National Council for Nuclear Waste (Kärnavfallsrådet) is an independent scientific committee whose mission is to advise the Government on nuclear waste and decommissioning of nuclear facilities. The members of the Council possess expertise in technology, science, ethics and the social sciences.

In the month of February every year, the Swedish National Council for Nuclear Waste publishes its independent assessment of the current state of the art in the nuclear waste field, known as a state-of-the-art report. The purpose of the report is to shed light on issues which the Swedish National Council for Nuclear Waste considers particularly relevant and clarify the Council's viewpoints on these issues.

This year's report "Nuclear Waste State-of-the-Art Report 2012—long-term safety, accidents and global survey" identifies controversial issues that are in need of further elucidation. These issues are: the function of the engineered barriers during the life of the repository, the role of the safety assessment in different phases, the nuclear accident in Fukushima-Dai and the impact of other nuclear accidents on the legislation, different countries' nuclear waste programmes and the Council Directive 2011/70/EURATOM.

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

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