The Government

The Ministry of the Environment

(submitted to the Swedish Radiation Safety Authority)

APPLICATION FOR LICENCE UNDER THE NUCLEAR ACTIVITIES ACT

Applicant:	The Swedish Nuclear Fuel and Waste Management Company (Svensk Kärnbränslehantering AB), corp. ID no. 556175-2014, Box 250, SE-101 24 Stockholm, Sweden
Matter:	Application for licence under the Nuclear Activities Act for construction, ownership and operation of a nuclear facility for the final disposal of spent nuclear fuel and nuclear waste.

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PETITIONS

Svensk Kärnbränslehantering AB (SKB) applies for a licence under the Act (1984:3) on Nuclear Activities

1. to construct, own and operate a facility for final disposal of nuclear material, consisting primarily of spent nuclear fuel, as well as nuclear waste[1] from the Swedish nuclear power programme, in Forsmark in Östhammar Municipality. The nuclear material and waste are specified in section 1.2 below.

2. to manage, handle, transport, dispose of and otherwise deal with the material specified in point 1 within the facility.

SKB further requests

(i) that the prepared environmental impact statement (EIS) be approved, and

(ii) that the Government stipulate the following conditions for the licence:

   1. The facility for final disposal of nuclear material according to point 1 above shall be constructed, owned and operated in essential conformity with what is stated in the application documents.

   2. Prior to construction of the final repository, SKB shall submit a report to the Swedish Radiation Safety Authority (SSM) explaining how safety and radiation protection matters will be taken into account during construction. The report shall be approved by SSM before construction may commence.

   3. The Swedish Radiation Safety Authority (SSM) may approve changes in the described reference design, for example changes in the choice of materials and the dimensions of constituent

[1] Construction material in the fuel assemblies

components, as well as the emplacement of the canisters in the rock.

PRESENTATION OF THE LICENCE APPLICATION

1. Background and orientation regarding the matter at hand

1.1 SKB's task

SKB is owned by the companies that own nuclear power plants in Sweden. SKB's owners are Vattenfall AB, E.ON Kärnkraft Sverige AB, Forsmarks Kraftgrupp AB and OKG Aktiebolag. On their behalf, SKB is responsible for the management and final disposal of Sweden's nuclear waste and spent nuclear fuel in the safe manner required by society.

The energy industry in Sweden has been producing electricity in nuclear power plants for nearly 40 years. Since Barsebäck was shut down, there are three nuclear power plants in operation in Sweden: Forsmark, Oskarshamn and Ringhals. They have altogether ten reactors that produce some 60 TWh per year, which is equivalent to nearly half of Sweden's total electricity production.

The operation of the nuclear power plants produces not only high-level spent nuclear fuel, but also other types of radioactive waste, categorised as short- or long-lived and low- or intermediate-level waste. Taking care of this waste so that human health and the environment are protected, both now and in the future, is also part of SKB's task. This task is vital in achieving the national environmental objective of a safe radiation environment. Today, SKB has a functioning system for taking care of spent nuclear fuel and nuclear waste. Since the mid-1980s there are both a final repository for short-lived radioactive waste (SFR at Forsmark) and a central interim storage facility for spent nuclear fuel (Clab at Simpevarp). Safe transport of the radioactive waste from the nuclear power plants to the storage facilities is included in SKB's system for radioactive waste management. Over long distances, the waste is transported by sea.

1.2 Fuel quantities and types

This application regards the nuclear material, consisting primarily of spent nuclear fuel, which is stored today at Clab. The application also regards the additional spent nuclear fuel and nuclear material from activities in Studsvik and from the operation of the ten nuclear power reactors that have operating licences today. The nuclear waste covered by the application mainly consist of the construction material in the fuel assemblies that the nuclear material form part of.

Almost all spent nuclear fuel to be finally disposed of comes from the reactors at Forsmark, Oskarshamn and Ringhals that are in operation and from Barsebäck, which is closed down. The estimate of the quantity of fuel on which the safety report is based assumes that the reactors at Forsmark and Ringhals are operated for 50 years and the reactors in Oskarshamn for 60 years.

The total quantity[2] of spent nuclear fuel from the reactors in Barsebäck, Forsmark, Ringhals and Oskarshamn is today estimated to be about 12,000 tonnes.

A small quantity of fuel from Oskarshamn has been reprocessed, and the plutonium resulting from the reprocessing will be used to fabricate MOX fuel (Mixed Oxide Fuel), which will be used in one of the reactors in Oskarshamn. The spent MOX fuel is included in the estimated quantity of spent nuclear fuel. The spent fuel from the R1 research reactor that was operated at KTH (*translators remark:* Swedish Royal Institute of Technology) between 1954 and 1970 has been sent for reprocessing, and the plutonium from the reprocessing is included in the MOX fuel to be used in Oskarshamn. A small fraction of the R1 fuel is not suitable for reprocessing but will be finally disposed of together with nuclear material (mainly fuel residues) from activities in Studsvik. The total quantity of nuclear material from Studsvik is about three tonnes.

At an early stage of the Swedish nuclear power programme, some fuel from Barsebäck and Ringhals was reprocessed. In 1986, this fuel was exchanged for spent MOX fuel of

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[2] The weights refer to the quantity of uranium, and for MOX fuel plutonium as well, in the unirradiated nuclear fuel.

German origin, often called “swap MOX”. It is being stored in Clab, and the quantity is just over 20 tonnes. This fuel will be finally disposed of.

Between 1963 and 1974, a nuclear reactor was operated in Ågesta south of Stockholm, and there are about 20 tonnes of spent fuel from there to be finally disposed of.

Altogether, SKB is applying for a licence to emplace approximately 12,000 tonnes of spent nuclear fuel in the final repository. To this must be added nuclear waste, mainly in the form of construction material in the fuel assemblies. This is hereinafter referred to collectively as “spent nuclear fuel”.

1.3 The purpose of the applied for activity

The purpose of the applied for activity is to finally dispose of the spent nuclear fuel in order to protect human health and the environment from the harmful effects of ionising radiation from the spent nuclear fuel, both now and in the future.

The fundamental conditions for the final repository system is that the nuclear fuel from the Swedish reactors shall be finally disposed of within Sweden’s borders with the consent of the concerned municipalities. The final repository facility shall be built and operated with a focus on safety, radiation protection and environmental consideration. The facility shall be designed so that illicit handling of nuclear fuel is prevented. The post-closure safety of the final repository shall be based on a system of passive barriers and be designed so that the final repository remains safe even without future maintenance or monitoring after closure. The final repository shall be established by the generations that have derived benefit from Swedish nuclear power.

SKB’s current and planned facilities and activities have been developed to take care of both the existing spent nuclear fuel and the additional fuel from the continued operation of the current Swedish nuclear power plants. Safety is always in focus in the design and operation of Clab, the encapsulation facility, the transportation system and the final repository. The method of achieving final disposal of the spent nuclear fuel is called the KBS-3 method.

1.4 Statutory requirements

The requirement on final disposal of the nuclear waste from Swedish nuclear power plants is found in the **Nuclear Activities Act,** which also contains provisions regarding all handling of nuclear materials or nuclear waste. Under the Nuclear Activities Act, the holder of a licence for nuclear activities is responsible for "*adopting whatever measures are needed to finally dispose of [the] nuclear waste [...] in a safe [...] manner*."[3]

Provisions regarding precautions and protective measures for preventing damage or detriment to human health or the environment are found in **The Environmental Code** (SFS 1998:808). Construction and operation of Clab, the encapsulation facility and the final repository also require permits under the Environmental Code. The environmental court examines the permit application, but the Government has to make a special decision regarding the permissibility of the activity.

The principal purpose of **the Radiation Protection Act** (SFS 1988:220) is to protect people, animals and the environment against the harmful effects of both ionizing and non-ionizing radiation. The Act also provides that the operator is responsible for ensuring that radioactive waste arising from the activity is managed and, when necessary, finally disposed of in a manner that is satisfactory from the viewpoint of radiation protection[4]. Licensing review under the Nuclear Activities Act also includes the provisions of the Radiation Protection Act.

SSM's regulations contain detailed provisions regarding the design required for safety.[5] Under SSM's general guidelines for the regulations, safety is "*the ability of a final repository to prevent the dispersion of radioactive substances*". Under the regulations, this shall be done by a system of engineered and natural barriers which shall contain, prevent or at least retard the dispersion of radioactive substances. The geological formation at the site of a final repository can, under the general recommendations for the regulations, constitute a natural barrier which can both isolate the nuclear waste from the environment on the ground surface and hinder human intrusion. The site of a repository

[3] Sec. 10, para. 1, clauses 2 and 3.
[4] Sec. 13 of the Radiation Protection Act
[5] SSMFS 2008:1 and 2008:21

should be chosen so that the geological formation provides sufficiently stable and favourable conditions to ensure that the final repository barriers perform as intended over a sufficiently long period of time.

SSM's regulations also contain provisions regarding what protective capability the final repository should have.[6] An important requirement is the authority's risk criterion. It entails that the annual risk of cancer or hereditary defects from radiation doses caused by releases from the final repository may not exceed one in a million for those individuals who are exposed to the greatest risks.[7] In simplified terms, this corresponds to saying that people in the vicinity of the repository may not be exposed to radiation doses that exceed approximately one-hundredth of the natural background radiation in Sweden.

SSM's regulations stipulate the limits on radiation doses to personnel and the general public that shall apply to activities with ionizing radiation[8]. The permissible concentration of naturally occurring radon in the final repository is limited by the rules in the Swedish Work Environment Authority's code of statutes.[9]

Certain provisions in the Environmental Code, including the general rules of consideration, shall be applied when examining applications under the Nuclear Activities Act.[10] One of these – the principle of best available technology/technique[11] – is also found in SSM's regulations.[12] Under SSM's general guidelines, the principle of best available technology in connection with final disposal entails that "*the siting, design, construction and operation of the final repository and appurtenant system components should be chosen so as to prevent, limit and delay releases from both engineered and geological barriers as far as is reasonably achievable. In considering different measures,*

[6] Cf. SSMFS 2008:1 and 2008:37
[7] Cf. Sec. 5 of SSMFS 2008:37
[8] Cf. 2008 SSMFS 51
[9] AFS 2003:2 [4]
[10] Chap. 2 of the Environmental Code
[11] Chap. 2, Sec. 3 of the Environmental Code
[12] Cf. SSMFS 2008:21, Sec. 6

an overall assessment should be made of their impact on the protective capability of the final repository."[13]

Aside from the requirement on best available technology, optimization is an important requirement on the final repository's design and activity, under the regulations.[14] Optimization can be described as an application of the ALARA principle.[15] Under SSM's regulations, optimization is a limitation of radiation doses to humans to a level "*as low as reasonably achievable with regard to economic and societal factors*".[16]

One of the requirements under SSM's regulations and general guidelines is risk reporting for different periods of time after closure of the final repository. Two time periods are defined in the regulations: the period up to a thousand years after closure and the time thereafter.[17] It follows from the general guidelines that "*the risk analysis should at least include approximately one hundred thousand years or the length of a glacial cycle to illustrate reasonably predictable external stresses on the final repository. The risk analysis should thereafter be extended in time as long as it provides important information about the possibility of improving the protective capability of the final repository, but no longer than for a time span of up to one million years*".[18]

1.5 Reports on SKB's activities to the Government

The KBS-3 method served as a basis for applications in 1983 for permits under the Stipulations Act to put the nuclear power reactors Oskarshamn 3 and Forsmark 3 into operation. In a decision in June 1984 – based on the provisions of the then-new Nuclear Activities Act – the Government observed that the KBS-3 method *"in its entirety has been found essentially acceptable with regard to safety and radiation protection".* The Government therefore decided to grant fuelling permits for the two reactors.

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[13] Cf. the guidelines to SSMFS 2008:37
[14] SSMFS 2008:26, Secs. 4-5
[15] The ionizing radiation to which human beings risk being exposed shall not only be less than a given prescribed limit value; it shall be "As Low As Reasonably Achievable".
[16] SSMFS 2008:26, Sec. 4
[17] SSMFS 2008:37, Secs. 9-12
[18] SSMFS 2008:37, Guidelines page 6 (English version)

Under Section 12 of the Nuclear Activities Act, the reactor owners shall prepare a programme for the comprehensive research and development work that is needed "*for ensuring the safe management and final disposal of nuclear waste arising in the activities or nuclear material arising therein that is not reused*". The programme shall be prepared every three years, cover a period of six years and be submitted to SSM (previously SKI, the Swedish Nuclear Power Inspectorate).The reactor owners have assigned SKB the task of preparing this programme, called an RD&D programme, where RD&D stands for research, development and demonstration.

The Government has stipulated requirements on that accounts should be provided of alternative methods and sites. As a result of the RD&D process, the Government decided in 1995 that feasibility studies should be conducted on five to ten sites and site investigations on at least two sites. In 2001, the Government also declared that the KBS-3 method would be the planning premise for the continued site investigations – based on the evaluation of alternatives presented by SKB in the supplement to RD&D programme 98, known as RD&D-K (Fud-K).

The RD&D programmes presented so far have been reviewed and circulated to a number of organisations for comment. At the same time, the Swedish National Council for Nuclear Waste has also reviewed SKB's programmes. Based on these comments, the Government has then decided that the programmes meet the requirements of the Nuclear Activities Act. SKB submitted the most recent RD&D programme to SSM in September 2010.

1.6 The scope of the review

The licensing review under the Nuclear Activities Act entails an initial assessment of whether the activities can be conducted in such a manner that the prescribed safety and radiation protection requirements can be met.

At the same time as the review under the Nuclear Activities Act, the facilities in the final repository system will be reviewed under the Environmental Code. Under Chap. 9, Sec. 1 of the Environmental Code, "environmentally hazardous" shall be understood to mean any use of land, buildings or structures that may cause a detriment to the *surroundings* due to noise, vibration, light, ionizing or non-ionizing radiation or similar impact.

The Government will review the final repository under the terms of both the Nuclear Activities Act and the Environmental Code. The licensing review under the Nuclear Activities Act is comprehensive as regards ionizing and non-ionizing radiation, but does not include any other impact on the surroundings. The licence application according to Sec. 5 of the Nuclear Activities Act shall include an EIS, which shall be approved by the Government. SKB assumes that SSM will prepare the matter based on nuclear safety and radiation protection and leave the assessment of other impacts on the surroundings to the environmental court.

1.7 The contents of the application

In addition to this document, the application consists of appendices intended to support the licensing review of whether the activity complies with the provisions of the Nuclear Activities Act, the Radiation Protection Act and the Environmental Code, with applicable ordinances.

The appendices are (abbreviation in parentheses):

- Safety report for final disposal of spent nuclear fuel (SR)
- Safety report for operation of the final repository facility for spent nuclear fuel (SR-Operation)
- Long-term safety for the final repository for spent nuclear fuel at Forsmark (SR-Site)
- Preliminary plan for decommissioning (AV)
- Operation, organization, management and control – site investigation for final repository (VP)
- Operation, management and control – construction of the final repository facility (VU)
- Site selection – siting of the final repository for spent nuclear fuel (PV)
- Choice of method – evaluation of strategies and systems to manage spent nuclear fuel (MV)
- Environmental Impact Statement (EIS)
- Operations and the general rules of consideration (AH)

2. SKB and the nuclear fuel programme

In the early days of nuclear power in the 1950s, the focus was on developing and building nuclear power reactors. It was not until the 1970s that the question of management of the radioactive waste came to the fore in the political debate. The result of this political involvement was a statutory requirement passed in 1977 – the so called Stipulations Act, under which the spent fuel should either be reprocessed or finally disposed of in an "absolutely safe" manner. In 1984 the Stipulations Act was superseded by the Nuclear Activities Act (1984:3).

In response to the Stipulations Act, the nuclear power producers assigned their company SKBF (now SKB) the task of working out a general proposal on how to take care of the spent fuel. The first proposals were presented in two reports: KBS-1 in 1977 and KBS-2 in 1978, where KBS stands for Kärnbränslesäkerhet (Nuclear Fuel Safety). The proposals in the reports were based on the two alternatives offered by the Stipulations Act: final disposal after reprocessing, and final disposal without reprocessing. The report "*Final storage of spent nuclear fuel – KBS-3*" was presented in May 1983. The concept presented in that report, the present KBS-3 method, has since then been further developed and now has the design described in this application.

Most countries that work with the nuclear waste issue have come to focus on geological final disposal, which is based on a system of multiple barriers as the main alternative. This is true regardless of whether they have chosen direct disposal as a method or plan to dispose of high-level waste after reprocessing of the fuel. The concepts look different depending on the geological conditions in the different countries.

2.1 Safety – the superordinate goal

Since the work with the Swedish final repository project commenced in the late 1970s, SKB has established a number of principles for the design of a final repository for spent nuclear fuel. These principles constitute the safety strategy behind the KBS-3 method.

- The final repository will be located deep down in a long-term stable geological environment to isolate the waste from man and the environment. This reduces the risk that the repository will be impacted by possible societal changes or long-term climatic changes.

- The final repository will be located at a site where the host rock can be assumed to be of little economic interest for future generations, reducing the risk of human intrusion.

- The spent nuclear fuel will be surrounded by multiple safety barriers – engineered and natural.

- The primary safety function of the barriers will be to contain the fuel in the canister.

- If the containment should be breached, the secondary safety function of the barriers will be to retard any release from the repository.

- Engineered barriers will consist of naturally occurring materials that are stable in the long-term in the repository environment.

- The repository will be designed so that the radiation from the spent fuel does not have significant detrimental effects on the properties of the engineered barriers or rock.

- The repository will be designed so that high temperatures, which could have significant detrimental effects on the properties of the barriers, are avoided.

- The barriers will be passive, i.e. function without human intervention and without active input of materials or energy.

Together with other aspects – such as the premises defined by Sweden's geological environment and the requirement that the final repository's facilities must be technically feasible to build and operate safely – these principles have led to the choice of the KBS-3 method for final disposal of spent nuclear fuel.

2.2 The KBS-3 method

The KBS-3 method can be summarized as follows:

- The spent nuclear fuel is placed in copper canisters with high resistance to corrosion in the repository environment. The approximately five metre long canisters have an insert of nodular iron that increases their stability.

- The canisters are surrounded by a buffer of bentonite clay – a naturally occurring material that swells in water. The buffer protects the canister in the event of minor rock movements and also shields it from groundwater movements. This limits the amount of corrodants in the groundwater that can reach the canister. The buffer also absorbs radioactive substances that could be released if the canisters should be damaged.
- The canisters with surrounding bentonite clay are placed at a depth of about 500 metres in crystalline bedrock with long-term stable conditions.
- If any canister should be damaged, the nuclear fuel and the chemical properties of the radioactive materials, for example their low solubility in water, severely limit the transport of radionuclides from the repository to the ground surface.

Based on these principles, the extensive development work and several safety assessments, a reference design for the final repository and its activities has been worked out. The analysis on which the application is based shows that the design and production as it is planned for Forsmark will provide a final repository that meets the requirements on safety and radiation protection.

The KBS-3 method allows for some variation in its implementation. This applies to both the choice of material quality in the barriers and the dimensions and placement of canisters and openings in the rock. The licence application regards vertical deposition (KBS-3V), which is available technology and satisfies the safety requirements. By vertical deposition, the canisters are emplaced one by one, upright in deposition holes in the floors of rock tunnels. A variant of the KBS-3 method is KBS-3H, where the canisters are placed lying down in a row in horizontal tunnels. The two variants could be possible to combine within the final repository. The development work on horizontal deposition shows that the method is interesting and promising, but not yet sufficiently developed to be available. More research and development is required to determine whether it can be used. Only when and if a safety assessment shows that KBS-3H offers equivalent or improved safety will a switch to horizontal deposition be considered. Work is continuing on development of the technology for horizontal deposition.

2.3 The KBS-3 system

The KBS-3 system consists of the facilities which SKB plans to build, own and operate for final disposal of the spent nuclear fuel according to the KBS-3 method. The whole system will consist of the existing interim storage facility for the spent fuel **Clab,** which will be built together with an encapsulation facility to form an integrated facility called **Clink**, a **transportation system** for transportation of the encapsulated fuel and a **final repository facility**.

The facilities that will be built currently have the reference design that is specified in the application documents. The work of developing details regarding the different barriers, the execution of deposition and the design of the facility will continue. Possible changes in technology or material quality will be examined by SSM, after notification by SKB.

2.3.1 Clab – central interim storage facility for spent nuclear fuel

Clab is a nuclear facility that was put into operation in 1985. In Clab, the spent nuclear fuel is received and stored in pools in rock caverns approximately 30 metres underground. Fuel from nearly 40 years of operation of the Swedish nuclear power plants is stored there. Clab was expanded in the early 2000s with a new facility section that was put into operation in 2008.

Today there are around 5,000 tonnes of spent nuclear fuel and core components in Clab, which is licensed to store 8,000 tonnes of spent fuel. During the period of about 30 years for which the spent nuclear fuel is stored, its radioactivity and heat output decline, which facilitates further handling.

2.3.2 Interim storage facility and encapsulation facility – Clink

After interim storage in Clab, the spent nuclear fuel, in the form of fuel assemblies, will be encapsulated in copper canisters. An encapsulation facility is planned for this purpose, to be built adjacent to Clab. The two facilities will be operated as a single integrated facility. Existing functions and systems in Clab will be co-utilized wherever possible. A licence application under the Nuclear Activities Act for construction, ownership and operation of the encapsulation facility was submitted to the Swedish Radiation Safety Authority (then SKI) in 2006 and was supplemented in 2009 with a preliminary safety report for the integrated facility.

2.3.3 Transportation

Shipments of spent nuclear fuel from the nuclear power plants at Forsmark and Ringhals to the port of Simpevarp go by sea today. From the industrial port of Simpevarp and from the Oskarshamn Nuclear Power Plant, the fuel is transported by a specially built terminal vehicle to Clab in dry, air-cooled transport casks that provide radiation protection and protection against external damage.

After encapsulation, the copper canisters completely shield off the alpha and beta radiation, but the gamma and neutron radiation is high even outside the canister. Filled canisters will be shipped in transport casks approved for the purpose. Such casks will be available prior to the commissioning of the encapsulation facility and the final repository facility.

The encapsulated fuel will be shipped by sea between the industrial ports of Simpevarp and Forsmark. A specially built terminal vehicle will be used for transporting canisters from Clink to the industrial port of Simpevarp, and from the industrial port of Forsmark to the final repository. It will be similar to the one that is used today for transport of spent nuclear fuel from the industrial port of Simpevarp to Clab.

SKB will subsequently apply for the licences required for the future shipments. How future applications for transport licences will take place is described in section 9.3. The transportation system is described in greater detail in the appendix SR-Operation with associated references.

2.3.4 The final repository facility

The siting of, design of and activities at the final repository facility are described in Chapters 3 and 4 below.

3. The site of the final repository facility

3.1 Site selection

A big challenge for SKB has been selecting a site for final disposal. The Environmental Code states that "*in the case of an activity or measure for whose purposes a land or water area is used, a site shall be chosen that is suitable in order to achieve the purpose with a minimum of damage and detriment to human health and the environment"* (Chap. 2, Sec. 6). Section 5 of the Nuclear Activities Act also refers to Chap. 2, Sec. 6 of the Environmental Code.

The prospects for achieving the purpose of final disposal are dependent on the properties of the bedrock. The fundamental requirement on the site that is chosen is therefore that there is rock at the site that can satisfy the safety requirements. In order for the site to be available and the project to be feasible, there must also be acceptance in the concerned municipality and among nearby residents. These basic requirements have guided SKB's siting work.

In order to find the most suitable site, SKB has conducted **general siting studies** (general and regional compilations and analyses), **feasibility studies** (comprehensive compilations and analyses of siting prospects at the municipal level) and **site investigations** (comprehensive investigations of bedrock and biosphere on selected sites).

In various RD&D decisions, the Government has made declarations on the need for background material for site selection. In a decision in May of 1995, the Government stated that future applications for a licence to build a final repository should contain material that shows that site-specific feasibility studies have been conducted at between 5 and 10 sites in the country and that site investigations have been conducted at at least two sites. The statement has been repeated with partly varying formulations in several Government decisions concerning SKB's RD&D programmes.

SKB conducted feasibility studies in eight municipalities between 1993 and 2000: Storuman, Malå, Östhammar, Nyköping, Oskarshamn, Tierp, Älvkarleby and Hultsfred.

After municipal referendums in 1995 and 1997, the municipal councils in Storuman and Malå said no to continued investigations in their respective municipalities.

At the end of 2000, SKB presented its conclusions from the feasibility studies of the different sites and a programme for continued site investigations in the report known as RD&D-K (SKB TR-01-03). Both geological and industrial prospects as well as environmental and societal aspects were evaluated. Eight siting alternatives were judged to be sufficiently promising to warrant further studies.

In RD&D-K, SKB also drew the conclusion that the KBS-3 method was well-developed and ready to move into an implementation phase. The Government's decision on RD&D-K in November 2001 was unequivocal: "*The Government judges that the company should use the KBS-3 method as a planning premise for the upcoming site investigations.*"

SKB made a selection and wanted to conduct site investigations in three areas situated in the municipalities of Östhammar, Oskarshamn and Tierp. SKB also wanted to conduct additional evaluations of an area in Nyköping Municipality, but the municipal council in Nyköping decided in May 2001 not to participate any longer in SKB's siting process. Tierp Municipality withdrew in 2002 and was thereby no longer a candidate site.

In Östhammar and Oskarshamn, clear majorities of each municipal council spoke in favour of the proposed site investigations. In 2002, after the decisions and agreements with these two municipalities, SKB commenced site investigations in the Forsmark area in Östhammar Municipality and in an area in Oskarshamn Municipality that included the Simpevarp Peninsula and the Laxemar area, see also Appendix PV. The investigations could gradually be concentrated on a smaller area in Forsmark and on the Laxemar area west of Simpevarp.

In the field investigations SKB has conducted in these areas, great resources have been devoted to collecting the data on the properties of the bedrock, the soil layers and the ecosystems that are needed to analyse the prospects for a safe final repository. Obtaining the necessary knowledge of the properties of the rock has required drilling boreholes to and below repository depth on a large scale. In June 2009, with the support of these investigations, SKB made its selection of a site for a future final repository: Forsmark in Östhammar Municipality.

The site was selected after a systematic evaluation and comparison of the two final alternatives, Forsmark and Laxemar. The prospects for post-closure repository safety were paramount in the evaluations. The advantages of Forsmark in relation to Laxemar when it comes to the prospects of achieving a repository that satisfies the safety requirements are clear. The main reason is that there are few water-conducting fractures in the rock at repository depth, which means that the groundwater flow through the repository is greatly limited. This provides great advantages for the long-term performance of the copper canister and the bentonite clay. The dry and fracture-poor rock at repository level in Forsmark also offers advantages for construction and operation.

The EIS shows that the activity in the final repository will not give rise to unacceptable damage and detriment for human health and the environment. This means that the siting at Forsmark satisfies the requirements in Chap. 2, Sec. 6 of the Environmental Code.

A more detailed account of SKB's efforts to find a suitable site and its reasons for choosing Forsmark is given in Appendix PV.

3.2 Site characteristics

The surface parts of the final repository facility will be located in an area of approximately ten hectares on industrial land near the Forsmark Nuclear Power Plant in Östhammar Municipality. At a depth of about 500 metres in the rock, the repository will, when fully expanded, occupy an area of nearly four square kilometres. There are approximately 700 households within a radius of ten kilometres. SKB's final repository for short-lived radioactive waste, SFR, is also located in Forsmark.

More detailed descriptions of the characteristics of the site are provided in the appendices PV, EIS, SR-Operation and SR-Site with associated supporting documents. A statement of assessed environmental impacts is presented in EIS.

3.3 National interests

In 2004, with authority from Chap. 3, Sec. 8 of the Environmental Code, SKI decided that the area in Forsmark being considered for all parts of the final repository is of national interest for the final disposal of spent nuclear fuel and nuclear waste. A large part of the area is also of national interest for energy production, and part of the area is of national interest for nature conservation. The whole area is of national interest under the special provisions concerning management in highly developed stretches of coast in Chap. 4, Secs. 1 and 4 of the Environmental Code.

4. The activity in the final repository facility

4.1 The phases of the final repository facility

The time required for construction, operation and closure of the facility is estimated at about 70 years, based on the currently planned operating times of the nuclear power plants. According to the current timetable, the facility will be ready to receive the first canister by the mid-2020s and the last canister about 50 years later. After that, the repository will be backfilled and closed, which could take another ten to twenty years.

During this time the final repository will undergo three phases:

Construction: No radioactive material is handled during construction. The phase commences when the licences, permit and conditions required to begin construction have been issued. Ground works and construction of certain buildings are done first, then shafts and ramp are excavated to repository level. The central area in the facility and parts of the first deposition area are then excavated at repository level. Systems and equipment for deposition are installed, and remaining buildings are erected on the ground surface. The rock heap for the excavated rock spoil begins to take shape.

Operation: This phase is divided into two stages: *trial operation and routine operation*. Trial operation begins when SSM has approved an updated safety report and issued a licence for trial operation. During trial operation, canisters with spent nuclear fuel are deposited in the repository while new tunnels are excavated. The deposition rate during trial operation gradually increases to approach the rate during routine operation, which can commence once SSM has granted a licence.

Closure and decommissioning: This phase commences when all spent nuclear fuel has been deposited and the last deposition tunnel has been backfilled and plugged. Then the other tunnels are sealed, along with shafts and ramp. The handling of buildings and equipment on the ground surface depends on the premises and preferences that exist at that time. This phase is concluded when the facility has been closed and becomes a passive final repository.

4.2 Management and control during construction, operation and decommissioning

During the gradual expansion of the final repository facility, experience from investigations, analysis and modelling will be utilised to optimise the layout and adapt the repository to existing rock conditions.

Appendix VU and Chapter 4 of Appendix SR-Operation describe SKB's organisation for construction and operation of the final repository facility and the principles of management and control of:

- The activity during construction, including technology development and research
- Operating activity including monitoring
- The maintenance activity
- Management of nuclear material and nuclear waste
- The safety work at the facility
- Quality assurance
- Preparedness for operational disturbances and mishaps

Furthermore, the staffing of the facility and the qualifications of the organisation are described.

In order for the final repository facility to be constructed and operated safely and to achieve a long-term safe final repository, the activity must be supported by a system for leadership and management and by a programme for quality assurance and inspection.

The account is based on current ideas regarding the organization and principles for management and control, but is subject to further development.

4.3 The design of the final repository facility

The facility will be divided into an *outer* and an *inner* operations area. The buildings that do not have any contact with the spent nuclear fuel will be located in the outer area. Spent nuclear fuel will be handled in the inner operations area. This area is a nuclear facility and is therefore subject to the Nuclear Activities Act and the Radiation Protection Act. The area will contain a number of above-ground buildings, as well as an underground part with elevators and supply systems. Means of access to the underground part are only located in the inner operations area. It is therefore a guarded area subject to special requirements on area protection and entry and exit procedures. In addition to the inner and outer operations area, the surface part includes a rock heap and ventilation stations. The ventilation stations are guarded areas, since they are connected to the underground part.

The facility's *underground part* consists of a central area and a repository area with connections to the surface part in the form of shafts for elevators and ventilation and a ramp for vehicle transport. The central area consists of a series of parallel halls with different functions. The halls are interconnected by tunnels that serve as transport pathways in the central area. Tunnels emanate from the central area for transport to the repository area, where final deposition of the canisters with spent nuclear fuel will take place. Buffer and backfill are transported out to the repository area, from which excavated rock spoil is hauled back. Rock excavation works and deposition are conducted in special areas separated from each other.

All areas in the facility where spent nuclear fuel is handled are controlled and classified with regard to predicted radiation levels.

4.4 Deposition of canisters

A deposition sequence is initiated when a special vehicle with a canister filled with spent fuel in a transport cask arrives from the industrial port at the final repository facility's terminal building. Here the load is checked and parked until the time comes to transfer it to the transloading hall.

The preparations at the deposition position include cleaning and inspection of the deposition hole and installation of drainage equipment. Then the bottom buffer block and the buffer rings are laid in place in the deposition hole. A radiation shielding hatch is fitted over the hole to shield off radiation from the canister during deposition.

The canister transport cask is transported from the terminal building down to the transloading hall by a specially built vehicle. There the cask is unloaded and the canister is moved to a deposition machine, which transports the radiation-shielded canister from the transloading hall to its deposition position. The deposition machine is positioned above the deposition hole, whose radiation shielding hatch is opened so that the canister can be lowered into the hole and placed on the buffer block on the bottom of the hole. When the canister has been placed in the right position, with the bentonite rings around the canister, the last blocks are put in place above the canister. The sequence is concluded by covering the deposition hole pending backfilling. The deposition machine is driven back to the transloading hall to prepare for the next sequence. All transport takes place at low speed and is monitored from a control room.

4.5 Backfilling of deposition tunnels

The backfill replaces the excavated rock in the deposition tunnels. The upper part of the deposition holes is filled up and the floor is levelled off. In the reference design, blocks of bentonite are put in place in the tunnel and the space between them and the rock is filled with pellets. Temporary installations are removed as backfilling progresses. When the deposition tunnel is completely backfilled, it is sealed by casting a concrete plug in its mouth.

4.6 Closure of the facility

When all spent nuclear fuel has been deposited and SSM has granted a licence, closure of the whole underground part is commenced. Installations and building elements are removed and transported up to the ground surface. Closure includes backfilling and plugging of all other underground openings.

How closure is to be done has not been determined in detail, since it lies so far off in the future, but technology is already available for executing closure in a safe and environmentally sound manner.

4.7 Future decommissioning of the facilities

Decommissioning of the final repository facility for spent nuclear fuel will begin when deposition of canisters with spent nuclear fuel and backfilling ceases, not to be resumed. The decommissioning phase includes dismantling and demolition above and below ground, possible site remediation and closure of the underground part of the final repository facility.

In accordance with the requirements in SSMFS, a preliminary decommissioning plan has been prepared. See Appendix AV.

4.8 Possibility of retrieving canisters

If future generations should wish to retrieve the fuel, this would be resource-consuming but not impossible. There is no formal requirement that it should be possible to retrieve deposited canisters after closure of the facility. Nor is it the intention of final disposal that deposited canisters should be retrieved.

During the operating phase it may be necessary to retrieve an individual canister from its deposition hole if something unforeseen should occur during deposition, since the process is reversible. SKB has demonstrated in tests at the Äspö HRL that it is possible to safely retrieve canisters that have been deposited in accordance with the KBS-3 method. After a deposition tunnel or the whole repository has been closed and sealed, the work required for retrieval increases considerably.

4.9 The post-closure period

The final repository facility is designed so that its safety is not dependent on post-closure monitoring and maintenance. Once the repository has been closed, SKB will have satisfied the statutory requirements on safe final disposal of the spent nuclear fuel. The question of long-term responsibility for the closed repository is being examined in the study (M2008:05) concerning coordinated regulation of nuclear activities and radiation protection.

4.10 Preservation of knowledge for the future

Information on the repository must be preserved for the future so that future generations can make well founded decisions and avoid inadvertent intrusion in the final repository. SKB will, in international cooperation, prepare an action plan for long-term preservation of information on the final repository for radioactive waste. The issue of long-term knowledge preservation should be solved no later than by the time of closure of the repository in about 70 years. Then society can decide which type of information it wants to preserve and how. It is SKB’s ambition to preserve and administer information in accordance with applicable regulations and in such a manner that society has the option of choosing the alternatives for the future that are then considered suitable.

5. Strategies for final disposal of spent nuclear fuel

5.1 General

There are two approaches to the management of spent nuclear fuel. One is to regard the nuclear fuel as a resource, the other to regard it as waste.

Utilising the spent nuclear fuel as a resource affects both waste management and nuclear fuel supply. Extracting fissionable materials from the fuel and reusing them in new fuel reduces the need for new uranium and thereby the need for uranium mining. Radioactive waste always remains anyway and must be disposed of. There are then two possible alternatives:

1. Conventional reprocessing and production of MOX, followed by final disposal of vitrified waste and spent MOX fuel
2. Transformation (transmutation) of the waste after reprocessing.

Alternative 1 entails that uranium and plutonium are separated from the spent nuclear fuel (*translator’s remark:* partitioning), leaving the other radionuclides as high-level waste.

As for Sweden, it is at present not considered economically defensible, or appropriate, to reprocess nuclear fuel in domestic facilities or send spent nuclear fuel abroad for reprocessing. Furthermore, the saving of uranium is moderate: 10–20%, depending on how many times the fuel is reprocessed.

Alternative 2 entails transforming (transmuting) the fuel after reprocessing so that most of the nuclides with half-lives of more than 1,000 years are converted to very short-lived or stable nuclides. This means that new types of reactors and facilities for partitioning need to be developed. Despite heavy research efforts internationally, partitioning and transmutation has not achieved a breakthrough that would permit consideration of the method in the foreseeable future. This alternative also requires final disposal of the waste that is left.

The following strategies have been considered internationally for final disposal of high-level nuclear waste:

1. Final disposal by launching into space.
2. Disposal in inaccessible areas, for example beneath the Antarctic ice sheet or in deep sea sediments.
3. Final disposal of the waste at great depth in the bedrock.
4. Long-term storage of the spent fuel in a monitored repository – possibly pending the further development of other strategic and technical alternatives.

The first two strategies have been dismissed for obvious reasons: they entail unacceptable safety risks and/or violate both the Nuclear Activities Act and international conventions. The fourth strategy entails leaving the disposal of the waste to future generations and is really a variant of the zero alternative described below.

5.2 Methods for final disposal in bedrock

The strategy for nuclear waste management in Sweden has been focused on the third alternative: final disposal at great depth in the bedrock. There is broad agreement among international experts that disposal at great depth in geological formations is the method that is best suited for spent nuclear fuel and other long-lived and high-level waste. This strategy is shared by most countries with a research and development programme for high-level waste or spent nuclear fuel. Over the course of the years, SKB has presented alternative methods for final disposal of spent nuclear fuel in the Swedish bedrock. Besides the chosen KBS-3 method presented above, the following alternatives have been studied but dismissed:

- Long tunnels (VLH) beneath the Baltic Sea: encapsulated fuel is emplaced in a few parallel, roughly five km long tunnels at a depth of 400–700 metres.
- WP-Cave[19]: encapsulated fuel is emplaced densely in a limited rock volume surrounded by a buffer at a depth of 300–500 metres.
- Deep Boreholes: encapsulated fuel is emplaced in very deep boreholes in rock.

Of these alternatives, Deep Boreholes has been examined in the review of SKB’s RD&D programme. The method entails that the waste is emplaced in holes drilled in the rock at a depth of two to five kilometres. The safety of the Deep Boreholes concept is based on the rock as a barrier and a number of assumptions concerning conditions and groundwater movements at great depths which are very difficult, if at all possible, to verify. These conditions must also be shown to persist during the time spans the repository has to continue to function. The biggest technical problem is otherwise considered to be the difficulty of getting the canisters into the right position in a controlled manner. The canisters would be subjected to great stresses during deposition, with the risk of getting stuck and breaking apart during their transport down through the rock. It would also be difficult to correct any problems encountered. Any retrieval of the canister would also be very difficult, if at all possible, from deep boreholes. Another difficulty is the fact that the technology for achieving such deep boreholes with the dimensions in question is undeveloped, and that knowledge of the conditions at such great depths is limited. Nor does the Deep Boreholes method meet the requirements of multiple barriers and being based on available, proven or evaluated technology.

Long Tunnels (*Translators remark:* or Very Long Holes, VLH) was initially considered to be equivalent to a KBS-3 repository in many respects, but is judged to have poorer

[19] After the name of the company that originated the idea

prospects of meeting the safety requirements in the construction and operating phases, including with regard to occupational safety.

With the WP-Cave method, the fuel will be emplaced densely, which leads to high temperatures. This means that cooling will be required in an initial phase of about 100 years. The concept is also technically complicated.

In the case of both Deep Boreholes and WP-Cave, extensive technology and knowledge development is required to demonstrate that the fundamental requirements on radiation protection and safety can be met.

SKB has chosen the KBS-3 method. Appendix MV provides a more detailed description and evaluation of the other strategies and methods studied by SKB and the reasons for SKB's choice.

5.3 The zero alternative

If final disposal of the spent nuclear fuel does not come about, the remaining option is to continue storing it like today, under monitored forms. This can be done either in Clab, where the fuel is stored today, or in the fuel pools at the nuclear power plants, where it is stored awaiting interim storage in Clab. The zero alternative would require an expansion of Clab, and/or of the fuel pools at the nuclear power plants, with a considerably increased storage period. Another possibility would be dry storage, which entails that the fuel is encapsulated in large steel cylinders and cooled by air instead of water, as in Clab. Prolonged monitored storage is not final disposal and therefore does not satisfy the requirements laid down in the legislation on the nuclear power producers.

The zero alternative is described in greater detail in Appendix EIS.

6. Satisfying requirements on nuclear safety for the final repository system

6.1 Safety report and safety assessment

The safety report shows how the safety of the nuclear facility is arranged in order to protect human health and the environment from nuclear accidents. It must contain information on facility site, design rules, radioactive substances, radiation protection, facility operation and analysis of operating conditions[20]. A description of the facility and functions must be included, along with references and drawings. For the final repository, the report must also contain information on post-closure safety.[21]

The safety report that is being submitted with this application is a *preparatory* preliminary safety report (Appendix SR). It contains two safety assessments: one presents an assessment of safety during operation (SR-Operation, Chap. 8) while the other concerns the post-closure safety of the repository (SR-Site). Prior to construction of the facility, the safety report will be supplemented to become a preliminary safety report (PSAR), and prior to operation an updated analysis report (SAR) will be submitted to the Swedish Radiation Safety Authority.

6.2 SR-Operation safety assessment

SR-Operation deals with the operating phase but not the decommissioning phase or the time thereafter. The safety assessment in Chapter 8 describes how events that could occur during operation could affect the safety of the facility. The purpose of the assessment is to verify that the facility satisfies all safety requirements and design premises for possible anticipated events (disturbances) and non-anticipated, improbable events (mishaps). SR-Operation also analyses events during operation which could affect the final repository's barriers if no measures are taken. Several preventive measures are therefore also described, and the reversible process that can be executed so that the requirements on post-closure safety can be met.

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[20] Cf. SSMFS 2008:1, Chap. 4, Sec. 2
[21] Cf. 2008 SSMFS 21, Sec. 9

6.3 SR-Site safety assessment

The purpose of the SR-Site safety assessment is to investigate whether the KBS-3 method can fulfil SSM's risk criterion (see section 7.1) at the selected site at Forsmark and to serve as a basis for further development of the repository's design. SR-Site should also deal with a number of other regulatory requirements. These include the design of a repository with multiple barriers and selection of a site with good characteristics for long-term safety. According to the requirements, the contents of the safety analysis report should include, for example, scenarios and handling of uncertainties. The analysis in SR-Site is based on the reference design of the repository and on the site descriptive model. It describes the rock's geology, rock mechanics, thermal properties, hydrogeology and geochemistry and the transport properties of the radionuclides. It also describes conditions on and near the ground surface.

7. Post-closure safety and radiation protection

Safety is evaluated for a time period of a million years. The primary safety function of the final repository is the containment of the spent nuclear fuel in copper canisters. If a canister should be damaged, the secondary safety function is retardation of any releases from the canister so that they do not cause unacceptable consequences.

The repository system – consisting of the deposited spent nuclear fuel, the barriers, the surrounding rock and the biosphere adjacent to the final repository – will evolve with time. The future state of the system will depend on:

- the initial state,
- internal processes that act in the repository system over time, and
- external processes acting on the system.

The initial state includes the state of the engineered barriers after deposition, for example the thickness of the copper of the deposited canisters, the quantity of buffer material in the deposition holes, or the shape of the deposition holes. Conditions in the rock at the time of construction are also included in the initial state.

Internal processes include e.g. decay of radioactive material, which causes heating of the fuel, the barriers and the rock. Groundwater movements and chemical processes that affect the barriers and the composition of the groundwater are other examples.

External processes include e.g. the future climate, earthquakes and human actions that can affect the repository.

SKB's safety assessments apply to the reference design described in the application. Detailed solutions may be modified in time, due to new knowledge and improved technology during construction and operation.

Calculations of how the repository system will evolve are presented in SR-Site.

7.1 The risk criterion

It follows from SSM's regulations that nuclear accidents shall be prevented by a facility-specific design for each nuclear facility which shall incorporate multiple barriers, as well as a facility-specific defence-in-depth system.[22]

In its regulation SSMFS 2008:37, SSM has specified a risk criterion stating that the annual risk of harmful effects after closure may not exceed 10^{-6} (one in a million) for a representative individual in the group exposed to the greatest risk. By "harmful effects" is meant cancer and hereditary defects. Under the regulation, the risk limit is equivalent to a dose of about one percent of the natural background radiation
(1.4×10^{-2} millisievert per year). SKB has to show that the final repository will meet the risk criterion in the long term.

The general guidelines on SSMFS 2008:37 state that the time scale for a safety assessment for a final repository for spent nuclear fuel should preferably cover a period of one million years after closure. A detailed risk analysis is required for the first 1,000 years after closure. The general guidelines also state that the risk criterion is applicable up to and including 100,000 years after closure. For the period after 100,000 years, calculated risks can be used to discuss the repository's protective capability. After about 100,000

[22] SSMFS 2008:1, Chap. 2, Sec. 1

years, the radiotoxicity of the spent nuclear fuel is comparable to that of the natural uranium ore used to produce the fuel.

7.2 Construction and design of the final repository's barriers

The KBS-3 method's barriers consist of *the copper canister*, which contains the spent fuel for a very long time, *the bentonite buffer*, which prevents flowing groundwater from coming into contact with the canister or, in the event of canister failure, with the spent nuclear fuel, and finally *the rock* surrounding the final repository.

7.2.1 The fuel

The spent nuclear fuel is not regarded as a barrier, but does have properties that prevent leakage – much of it is poorly soluble in water. The radioactive decay of the spent fuel liberates energy that generates heat. It is important to know the magnitude of this heat output, since elevated temperatures speed up chemical and other processes in the final repository. The fuel causes elevated temperature for a few thousand years, which is a relatively short time in relation to the assessment period of a million years.

7.2.2 The canister

The canister's primary task is to completely contain the spent fuel for a long time to prevent the release of radionuclides to the groundwater. The material of which the canister is made and its wall thickness are decisive for how long the canister remains intact. Canister failure can occur either due to corrosion (by substances in the groundwater) or due to mechanical stresses (caused by ice ages or earthquakes).

SKB has developed a canister that consists of a nodular iron insert and an outer shell of copper. The nodular iron insert provides mechanical stability while the copper shell protects against corrosion in the repository environment. The copper shell in the reference design is five centimetres thick and the cylindrical canister is approximately five metres in length with a diameter of about one metre. The insert has channels in which the fuel assemblies are placed and comes in two versions: one for assemblies from boiling water reactors and one for assemblies from pressurised water reactors. One canister holds about two tonnes of fuel, and the filled canisters weigh 25 and 27 tonnes, respectively.

SKB has tested different methods for fabricating the copper canister. The reference canister is a seamless tube. Lid and bottom are machined to the desired dimensions from hot forged blanks. The canister bottom is put in place at the canister factory, which is not a nuclear facility. The fuel is placed in the canister in the encapsulation facility and the insert is sealed with a lid and fixed with a bolt. The copper tube's lid is welded on the canister and inspected by nondestructive testing.

The reasons for the choice of copper and the thickness of the copper canister are explained in Appendix MV and Appendix AH.

7.2.3 The buffer

The function of the bentonite buffer is to be a mechanical and chemical protective zone around the canister and to limit the transport of corrosive substances from the groundwater to the canister surface. The buffer material should also limit releases of radionuclides from a damaged canister to the surrounding rock.

Bentonite is a naturally occurring clay material that consists mainly of a mineral that swells in contact with water. This gives the bentonite a self-sealing capability. Transport of various substances through the buffer can only take place by diffusion.

The buffer is placed in the form of blocks on top of and beneath the canister and in the form of rings around the canister. The gap between the blocks and the walls of the deposition hole is filled with bentonite pellets.

Different grades of bentonite have been examined and proved to have good properties.

7.2.4 The rock

The canisters of spent fuel will be emplaced at a depth of about 500 metres in crystalline rock. At this depth the environment is mechanically and chemically stable and the impact of possible glaciations, earthquakes and major societal changes is limited. The transport of most radioactive substances is greatly retarded in the rock by chemical processes between the minerals and the radioactive substances. A large portion of the radioactivity will have decayed during any transport that may occur through the rock to the biosphere.

The rock at Forsmark has good properties for post-closure safety. It has few water-conducting fractures, low groundwater flow and suitable groundwater chemistry. The low groundwater flow provides great advantages for the safe long-term function of the copper canister and the bentonite clay.

The dry and fracture-poor rock at repository level at Forsmark also offers advantages in construction and operation of the final repository. The rock at Forsmark also has high thermal conductivity, which enables the heat from the canisters to be dissipated more efficiently. This means that the canisters can be emplaced more densely than in rock with poorer thermal conductivity.

By orienting the deposition tunnels in the same direction as the maximum horizontal stress and by giving them a certain geometric shape, the stresses on the tunnel walls can be greatly reduced.

7.3 Reference evolution and scenarios

A reference evolution that covers the entire assessment period of a million years is being studied for the repository in order to understand what happens and provide a basis for the choice of scenarios and scenario analyses. The objective is to describe a reasonable evolution of the repository over time. Two cases of the reference evolution have been analyzed. The first is a base case, where it is assumed that the external conditions during the first glacial cycle in 120,000 years are similar to those that prevailed during the last ice age. After that it is assumed that seven repetitions of the same glacial cycle cover the entire assessment period of a million years. The second line of evolution is a greenhouse variant where it is assumed that the future climate will at first be strongly influenced by anthropogenic emissions of greenhouse gases.

The reference evolution serves as a basis for a main scenario that is expected to provide a reasonable picture of how the repository might evolve. The main scenario is nearly identical to the reference evolution. A number of critical questions pertaining to the safety of the repository are analyzed in a series of additional scenarios. Can the buffer freeze or disappear? Can it be transformed in an unfavourable way? Can the canister corrode so that containment is breached or be damaged by pressure from bentonite and groundwater? Can it be damaged by earthquakes?

Each of these questions is being studied in separate scenarios to determine whether conditions can become less favourable than in the main scenario and what the consequences might then be. The choice of scenarios is based on a systematic review of the safety functions that the repository should fulfil during the assessment period.

7.4 Handling of uncertainties

Claims and assumptions in safety assessments must be supported by scientific and technical arguments in order to lend confidence to the calculated results, but all the processes that might affect the final repository during a period of a million years can never be fully described and understood. Therefore, handling of uncertainties plays a central role in a safety assessment. This entails that uncertainties are classified, described and analysed in order to provide a possible picture of the evolution of the final repository.

Analyses in SR-Site lead to conclusions about the fulfilment of requirements in SSM's regulations. The conclusions are based on the results of the thorough and systematic evaluation of the evolution of the barriers during the next million years that is done in the assessment. This evaluation is in turn based on the results of completed site investigations at Forsmark, a reference design with specified and practically feasible production and inspection methods and the scientific understanding of issues of importance for long-term safety.

7.5 Conclusions

The scenario analyses show that a canister failure during the first 1,000 years can be ruled out, with the exception of a minimal probability of damage due to earthquakes. The probability of such a canister failure is calculated pessimistically to be one in 40,000. This means that only one canister failure due to earthquakes would occur in a thousand-year period in 40,000 final repositories, each with 6,000 canisters.

During the period up to a million years after closure, canister failure could occur due to either copper corrosion caused by sulphide in the groundwater, if the protective buffer has eroded, or earthquakes. With pessimistic assumptions concerning buffer erosion, copper corrosion and radionuclide transport, the radiological risk from releases from canisters damaged by erosion or corrosion is judged to be non-existent for tens of thousands of years after closure. The radiological risk for 100,000 years is at most a hundredth of the risk criterion and for a million years about a tenth of the risk criterion. The radiological risk from canister failure due to earthquakes is less than one-hundredth of the risk criterion for a period of 100,000 years and less than one-tenth of the risk criterion for a million years.

The total risk for a final repository in Forsmark with the described reference design and production and inspection methods is well below SSM's risk criterion, even over a period of a million years. The conclusion in SR-Site is therefore that a long-term safe KBS-3 repository can be built at Forsmark.

8. Safety and radiation protection during operation

8.1 Design of radiation protection

As far as the final repository facility is concerned, under no circumstances will free radioactivity from the spent fuel be present in the facility, and therefore not outside the facility either. The reason is that the spent nuclear fuel is enclosed in copper canisters that are free of radioactivity on the surface and leakproof both in normal operation and in the event of incidents or mishaps. This means that there cannot be any radiation dose to man or the environment outside the facility due to activities inside the facility.

Regarding dose to personnel, the ALARA principle underlies all work with radiation protection in the final repository. In order to demonstrate that the facility and the working methods comply with the ALARA principle, target values will be set for individual and collective doses. The target value for the doses will be lower than the limit value stipulated in SSM's regulations.[23]

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[23] SSMFS 2008:51

The repository's safety during construction and operation is dependent on technical, organisational and administrative measures to prevent the canister from being damaged. According to SR-Operation, analysis of design-basis events shows that no event is so serious that it leads to criticality[24] or failure of the copper canister, and thereby the risk of radionuclide release.[25] It is therefore not necessary to describe or report any release of radioactivity in the facility from the fuel contained in a canister. The final repository is a unique nuclear facility since there is only direct radiation there and no radioactive particles released from the fuel. The risk of an elevated radiation level therefore only exists in spaces where canisters in transport casks are stored, or where a canister is handled outside the transport cask.

The predominant naturally occurring radioactive substance in the final repository is radon and its decay products. It is difficult to estimate in advance the concentration of radon in connection with rock excavation works. As at other large hard rock facilities, the ventilation system at the final repository will be designed to keep the concentration of radon to levels below the limit values in force.[26]

The expected dose load to personnel is far below the limit values laid down by SSM, even when it is calculated pessimistically and includes natural background radiation. The Appendix SR-Operation describes the radiation safety requirements (Chapter 3) and how they are applied to the final repository facility's radiation protection and radiation shielding (Chapter 7).

8.2 Physical protection

The inner operations area, the underground part and the ventilation stations are included in the nuclear portion of the final repository facility. This portion comprises the guarded area that is surrounded by the kind of physical protection referred to in SSM's regulation 2008:12. The peripheral protection is designed so that unauthorised intrusion is made

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[24] The state that can lead to a chain reaction of nuclear fissions
[25] This is verified by analyses of various load cases.
[26] Cf. the Swedish Work Environment Authority's regulations AFS 2003:2

difficult and delayed and access is controlled and registered. The description of the physical protection is confidential information.

8.3 Safeguards

Spent nuclear fuel contains substances that can be used to manufacture nuclear weapons. Therefore, there are international agreements about preventing and safeguarding against the diversion of nuclear material and nuclear waste for possible use in weapons manufacture. The Nuclear Activities Act requires that Sweden should fulfil its obligations under these agreements. The Act states that licensees of nuclear facilities are obligated to allow access to their facilities by the authority designated to exercise safeguards, in other words SSM, Euratom and the International Atomic Energy Agency, IAEA. The international control is exercised by Euratom, since the Euratom Treaty applies in Sweden due to the country's membership in the EU.

A more detailed account is given in SR-Operation.

9. Licensing under the Nuclear Activities Act and permissibility under the Environmental Code

9.1 Applications under the Nuclear Activities Act for encapsulation facility (Clink) and final repository

A licence has been applied for under the Nuclear Activities Act for construction, ownership and operation of an encapsulation facility, located adjacent to Clab at the nuclear power plant in Oskarshamn. The application was submitted to the Swedish Nuclear Power Inspectorate (SKI) in 2006. After initial review, SKI submitted viewpoints with a request that the application be supplemented by SKB. A description of the co-siting of the facility with the existing Clab and an update of the physical protection and safeguards have therefore been done. These accounts, along with a preliminary safety report for routine operation of the integrated facility, Clink, was submitted to SSM in October 2009. As objects of supervision, Clab and the encapsulation facility – Clink – will be regarded as one nuclear facility. Documents showing that the facility meets the requirements of the Nuclear Activities Act and the Radiation Protection Act with ordinances and regulations are included in the application.

This application supplements the application for the encapsulation facility with an updated EIS and a new appendix concerning the activity and the general rules of consideration which, like the EIS, now covers the entire KBS-3 system.

9.2 Applications under the Environmental Code for Clab, Clink and the final repository

SKB is applying (simultaneously with this application under the Nuclear Activities Act for the final repository) for permissibility and permits under the Environmental Code for the facilities and activities in the KBS-3 system that require a permit. This includes both existing activities in Clab and planned activities at the encapsulation facility, as well as pre- and post-closure activities at the final repository.

Permissibility under the Environmental Code for the final repository system will be decided by the Government. This means that three matters will be decided by the Government:

1) licence under the Nuclear Activities Act for Clink

2) licence under the Nuclear Activities Act for the final repository

3) permissibility under the Environmental Code for the whole final repository system

According to the travaux préparatoires for the Environmental Code, licensing under the Nuclear Activities Act and examination of permissibility under the Environmental Code should be coordinated. Both the environmental court and the concerned municipality should have access to SSM’s review statement before they submit their own review statements in the permit matter. The Government’s final preparation and decisions under the two laws should also be coordinated[27].

[27] Gov. Bill 1997/98:90

Under the provisions of the Environmental Code, the Government may not grant permissibility for the activity without the municipal council in the concerned municipality having approved the activity, except under certain specified circumstances.

When the Government has heard the concerned municipalities, a permissibility assessment is performed under the Environmental Code. Licensing under the Nuclear Activities Act is focused on safety and radiation protection issues, while permissibility assessment under the Environmental Code entails an overall assessment of the impact of the siting and the activity on human health and the environment.

When the Government has declared the activity permissible, the case is sent back to the environmental court for issuance of a permit and conditions.

9.3 Future applications and licences/permits

Application for ground works permits and building permits under the Planning and Building Act

SKB must also apply for building permits for its facilities. The detailed development plans for Forsmark allow construction of the facilities for the final repository, while the detailed development plan for Simpevarp allows the activity at Clab and construction of the encapsulation facility.

Application for transport licence and licensing of canister transport cask

SKB will apply to SSM for a licence to transport canisters of spent nuclear fuel in a manner similar to that in which spent fuel transports take place today. The transport casks required for the encapsulated nuclear fuel will undergo extensive testing before they are approved (licensed), and this will be done before SKB applies for the necessary transport licences.

Approval before construction, trial operation and routine operation

Before a facility may be built, and before any major rebuilds or alterations of an existing facility may be done, a preliminary safety report (PSAR), along with a project plan, must be compiled and submitted to SSM for approval. Trial operation entails that nuclear material is brought into the facility and handled there. Before trial operation of a facility may commence, the safety report (SAR) must be updated so that it reflects the built facility. SKB will submit applications for permission to commence trial operation to SSM when systems and processes have been tested and work as intended.

After trial operation, before the facilities may be put into routine operation, the safety report must be supplemented taking into account experience gained from trial operation.

Both the preliminary safety report and the updated and supplemented safety report shall at every stage be safety-reviewed according to special provisions and be examined and approved by SSM.[28]

Under the Nuclear Activities Act, an overall assessment is required every ten years, entailing a relatively extensive periodic examination of the activity.

Applications for decommissioning and dismantling

When the last canister has been deposited, the facility is to be closed. Prior to closure, a final safety report must be approved by SSM.[29]

10. Discussion of conditions

The Swedish Radiation Safety Authority's Regulations concerning Safety in Nuclear Facilities (SSMFS 2008:1) requires that a preliminary safety report (PSAR) be prepared before a facility is built.[30] The report shall show how the safety of the facility is arranged in order to protect human health and the environment from nuclear accidents. Prior to trial operation, the report shall be updated so that it reflects the facility as built, analysed and verified and shows how the requirements on its design, function, organisation and activities are met.

The regulations do not contain any requirements on description and approval of the actual construction process. From SKB's viewpoint, it is desirable that SSM should approve a report on how safety-related issues are handled during construction. SKB therefore

[28] SSMFS 2008:1, Chap. 4
[29] See SSMFS 2008:21
[30] Chap. 4, Sec. 2, para. 2

undertakes to prepare such a report and requests that the Government stipulate as a condition that SSM should approve the report.

11. Environmental requirements in particular

11.1 Environmental impact statement and consultations

An environmental impact statement (EIS) must be submitted together with applications for permissibility and permits under the Environmental Code and licences under the Nuclear Activities Act for new nuclear facilities. The EIS that has been prepared by SKB is included in the applications for continued operation of Clab in Simpevarp in Oskarshamn Municipality as well as for construction and operation of an encapsulation facility adjacent to Clab (Clink) and final disposal of spent nuclear fuel in Forsmark in Östhammar Municipality.

SKB has conducted extensive consultations in accordance with Chap. 6 of the Environmental Code. The views expressed in the consultations have been taken into account in the preparation of this application with appendices. Further information on the consultations is provided in the EIS and in the the consultation report included as an appendix to the EIS.

SKB has also carried out, via the Swedish Environmental Protection Agency, the first part of the written consultations with the countries around the Baltic Sea concerning possible transboundary environmental impact, in accordance with the Espoo Convention. When SKB's applications have been submitted, a second and concluding portion of the consultations will be carried out with relevant parts of the application documents, with e.g. safety analysis reports and the EIS as supporting documents.

11.2 Permissibility under Chap. 2 of the Environmental Code – Operations and the general rules of consideration

How SKB satisfies the general rules of consideration in Chap. 2 of the Environmental Code, which will also be applied in the licensing under the Nuclear Activities Act, is described in greater detail in Appendix AH. A summary of the most important parts is provided below.

The knowledge requirement

The principles of nuclear safety and radiation protection have guided the choice of technology and design of the final repository facility and the activity that is the subject of this application. SKB has complied with the requirement in SSMFS 2008:1 that available, proven or evaluated technology shall be used. SKB has therefore built the Canister Laboratory to develop and demonstrate the copper canisters that will contain the spent nuclear fuel. Technology and methods for the buffer that will protect the canisters are being developed in the Bentonite Laboratory. SKB is conducting full-scale research and development of deposition at the Äspö Hard Rock Laboratory in preparation for the construction and operation of the final repository facility.

The precautionary principle and the principle of best available technology

The special laws and regulations on nuclear safety and radiation protection contain detailed nuclear safety and radiation protection requirements governing the design and operation of the final repository.

Spent nuclear fuel has been managed and stored in pools of desalinated water that cools the fuel and shields its radiation at Clab for more than 20 years, with good results. The same technology is also used in the nuclear power plants and complies with the principle of tried and tested technology in SSMFS 2008:1. The spent fuel will be transferred from Clab to the encapsulation facility in storage canisters via water-filled pools. SKB has developed technology for sealing and nondestructive testing of canisters and tested it on a full scale in the Canister Laboratory. The method for transferring the canisters has also been tried out and evaluated there.

A fundamental requirement on a final repository is that it must be based on a system of passive barriers. Together, these barriers must contain, prevent and retard the escape of radioactive substances. SKB has developed the KBS-3 method because it enables the spent fuel to be kept isolated from the biosphere in an effective manner for such long periods of time that SSM's requirements on safety and radiation protection are met. Releases of radionuclides can only occur if the copper canisters are breached. The safety assessment shows that the probability of canister breaches is non-existent during operation and very small after closure of the repository, in a million-year perspective.

The safety assessment confirms that the design of the copper canister with a nodular iron insert is the best available technology. Erosion of the buffer after a long time cannot be ruled out under certain conditions, but the safety analysis report shows that the radiological risk resulting from this is very small.

Every facility in the final repository system is optimised with respect to safety and radiation protection. Since the facilities are dependent on each other for the whole system to work, the interaction between the facilities is also adapted so that the whole system will satisfy the requirements on safety and radiation protection.

The site selection principle

The choice of the site for the final repository is the result of 30 years of investigations. To find the most suitable site, SKB has conducted regional general siting studies, local feasibility studies and site investigations on selected sites. (See also Chap. 3 for a summary account of site selection).

12. Miscellaneous

12.1 Financial security for compensation in the event of nuclear accidents

Matters pertaining to liability for nuclear accidents and related insurance matters are currently regulated in the Nuclear Liability Act (1968:45). However, the Riksdag (Swedish parliament) has ratified the 2004 protocols to amend the Paris Convention and the Supplementary Convention on Third Party Liability in the Field of Nuclear Energy.

The Convention contains rules regarding extended liability for damage caused by nuclear accidents. In order to comply with the obligations that follow from the new international rules, the Riksdag has passed the Act (2010:950) on Liability and Compensation for Nuclear Damage. It will enter into force on a date determined by the Government and will then supersede the Nuclear Liability Act.

SKB currently has insurance that complies with the requirements in the Nuclear Liability Act. When the new act enters into effect, SKB will take out insurance on its facilities and transportation system in accordance with the new requirements.

12.2 Security in accordance with to Chap. 16, Sec. 3 of the Environmental Code

Chap. 16, Sec. 3 of the Environmental Code states that the party that is liable for paying a fee or pledging a guarantee under the Act (2006:647) on Financial Measures for the Management of Residual Products from Nuclear Activities (the Financing Act) does not have to pledge a guarantee for measures covered by such fees and guarantees.

The Swedish nuclear power companies are subject to the Financing Act and therefore pay fees to the state Nuclear Waste Fund in accordance with the Financing Act. SKB's owners finance the activities for which SKB is now applying for permits and licences with money taken from the Nuclear Waste Fund.

13. Formalities

13.1 Contact person at SKB

SKB's contact person in technical matters is Olle Olsson, who can be reached at olle.olsson@skb.se.

13.2 Article 37 of the Euratom Treaty

According to Article 37 of the Euratom Treaty, each Member State must provide the European Commission with information on the disposal of radioactive waste. SKB assumes that SSM will handle this reporting, but SKB can on request provide the authority with data on the activities covered by this application. This obligation, as well as matters pertaining to the 1976 agreement on the exchange of notes between the Nordic countries regarding guidelines for contact in security matters, is not given special treatment in this application.

Stockholm, 16 March 2011
Svensk Kärnbränslehantering AB

Claes Thegerström
President