Strål säkerhets myndigheten
Swedish Radiation Safety Authority

Report

Kingdom of Sweden ARTEMIS Self-assessment Report 2023

The IAEA Integrated Review Service for Radioactive Waste and Spent Fuel Management, Decommissioning and Remediation (ARTEMIS) Mission to Sweden in April 2023.

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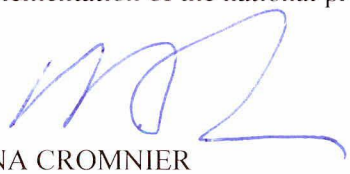
Foreword

In January 2018, the Swedish Radiation Safety Authority, SSM, submitted a request to the IAEA on behalf of the Swedish Government for international peer reviews to be conducted of the Swedish national frameworks for nuclear safety regulation (IRRS) and the safe management of spent fuel and radioactive waste (ARTEMIS). In dialogue with the IAEA, and in support of the then Swedish Ministry of the Environment, it was agreed that the IRRS review would be conducted 13-25 November 2022 "back-to-back" with the ARTEMIS review 16-27 April 2023.

The EU Radioactive Waste and Spent Fuel Management Directive (2011/70/Euratom) stipulates that EU Member States shall periodically, and at least every ten years, arrange for self-assessments and invite international peer reviews of their national framework, competent regulatory authority and implementation of the national programme for the management of radioactive waste and spent nuclear fuel. There has been no previous international peer review of the national framework for safe management spent fuel and radioactive waste in Sweden, which means that the ARTEMIS mission in April 2023 will be the first such review in accordance with the Directive.

A preparatory meeting was held with IAEA representatives and the nominated chairperson for the ARTEMIS mission on 14 October 2022. Organisational elements of the ARTEMIS mission were discussed and some of the detailed expectations of the IAEA with respect to the conduct of the review were clarified.

This report summarises the results of Sweden's self-assessment in preparation for the ARTEMIS mission. The report has been produced in accordance with the review questionnaire provided by the IAEA. The report is published on behalf of Government of Sweden by the Swedish Radiation Safety Authority, but has been compiled with the support of a range of public and private actors responsible for the development and implementation of the national programme.



NINA CROMNIER
Director General

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List of abbreviations

AKL	Active metal laboratory (Studsvik Nuclear AB)
AM	Rock cavern storage facility for low and intermediate waste (AB Svafo)
AU / AUA	Storage buildings for low and intermediate waste (AB Svafo)
BFA	Rock cavern storage facility for waste (Oskarshamn site)
BKAB	Barsebäck Kraft AB
BLA	Waste vault for low level waste (part of the SFR facility)
BMA	Waste vault for intermediate level waste (part of the SFR facility)
BTF	Waste vault for concrete tanks (part of the SFR facility)
BWR	Boiling Water Reactor
Clab	Central interim storage facility for spent nuclear fuel (SKB)
Clink	Integrated central interim storage facility and encapsulation plant
CRA	Credit Risk Amount
EIA	Environmental Impact Assessment
ESS	European Spallation Source ERIC
EU	European Union
FA	Storage facility for highly active material (Studsvik Nuclear AB)
FKA	Forsmarks Kraftgrupp (Licence holder for the Forsmark nuclear power plant)
FR0-A	Treatment facility for non-nuclear radioactive waste (Cyclife Sweden AB)
HA	Incineration and pyrolysis facility (Cyclife Sweden AB)
HCL	Hot Cell Laboratory (Studsvik Nuclear AB)
HM	Treatment facility for intermediate level solid and liquid wastes (AB Svafo)
HRL	Hard Rock Laboratory
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IGD-TP	Implementing Geological Disposal of Radioactive Waste – Technology Platform
IRRS	Integrated Regulatory Review Service
KBS-3	SKB's planned method for disposal of spent nuclear fuel
LILW	Low and intermediate level waste
LLW	Low level waste
MOX	Mixed oxide fuel
NEA	Nuclear Energy Agency within the OECD
NGO	Non-governmental Organisation
NORM	Naturally Occurring Radioactive Materials
NPP	Nuclear power plant (including all nuclear power units at one site)
OECD	Organisation for Economic Cooperation and Development
OKG	Operating company and licence holder for the Oskarshamn nuclear power plant
PHWR	Pressurised Heavy Water Reactor
PSAR	Preliminary Safety Analysis Report
PWR	Pressurised Water Reactor
R0-A	Treatment facility for non-nuclear radioactive waste (Cyclife Sweden AB)
RAB	Ringhals AB (Licence holder for the Ringhals nuclear power plant)
RD&D	Programme for Research, Development and Demonstration
RM	Risk margin
SAR	Safety Analysis Report
SEK	Swedish crown (krona)
SFL	Disposal facility for long-lived low and intermediate level waste
SFR	Disposal facility for short-lived low and intermediate level waste (SKB)
SKB	Swedish Nuclear Fuel and Waste Management Company

SMA	Metals treatment facility (Cyclife Sweden AB)
SNAB	Studsvik Nuclear AB
SR-Site	Long-term safety assessment in support of licensing of the spent fuel repository
SSM	Strålsäkerhetsmyndigheten (Swedish Radiation Safety Authority)
SSMFS	SSM's Regulatory Code
VLLW	Very low level waste
WAC	Waste acceptance criteria
WSE	Westinghouse Electric Sweden AB
WTD	Waste type description

Introduction

IAEA has established the ARTEMIS Integrated Review Service for Radioactive Waste and Spent Nuclear Fuel Management, Decommissioning and Remediation. The objective of the ARTEMIS Peer Review Service is to provide independent expert opinion and advice on radioactive waste and spent nuclear fuel management, management of residues arising from uranium production, environmental remediation, and decommissioning, based upon the IAEA safety standards and technical guidance, as well as international good practice.

The purpose of the ARTEMIS review mission to Sweden is to provide an independent international evaluation of the National Programme for Radioactive Waste Management in Sweden, which has been requested on behalf of the Government of Sweden in relation to obligations under the Council Directive 2011/70/EURATOM. The ARTEMIS review shall assess the overall programme for the management of all types of radioactive waste and spent fuel in Sweden against the relevant IAEA Safety Standards and proven international practice and experiences.

A key component in preparing for ARTEMIS peer review is the self-assessment to be performed by the Member State in advance of the peer review (this report). The IAEA has developed a suite of questionnaires covering all the topics relevant to a review of the national framework for radioactive waste and spent fuel management, to assist the self-assessment process. These questionnaires have been used in preparing the current report. The material presented in the report follows the general structure of the questionnaires, but is designed to read and understood as a description of the national framework, rather than a simple Q&A document. The report, which has been produced specifically for the purposes of the ARTEMIS peer review, is supported by a series of existing published documents (some of which are unofficial translations of material originally published in Swedish) that constitute so-called Advance Reference Material (ARM) for the peer review team. The majority of the ARM documents provided to the IAEA ahead of the ARTEMIS mission are either detailed supporting references for this report or have otherwise been used as inspiration in preparing the material herein.

The Swedish Radiation Safety Authority (SSM) is the National Counterpart for the ARTEMIS mission and has been responsible for co-ordinating the production of this self-assessment report. The contents of the report have, however, been written not only by staff from SSM but with the support of a range of other public and private organisations that play important roles in the Swedish national programme for safe management of radioactive waste and spent nuclear fuel. These include:

- The Swedish National Debt Office
- The Swedish Nuclear Fuel and Waste Management Company (SKB)
- AB Svafo
- Cyclife Sweden AB
- Studsvik Nuclear AB
- Barsebäck Kraft AB
- Forsmarks Kraftgrupp AB
- OKG AB
- Ringhals AB
- European Spallation Source ERIC
- Vattenfall AB – Business Unit Nuclear Decomissioning

In accordance with the Terms of Reference for ARTEMIS Review of Sweden's National Programme on Radioactive Waste and Spent Fuel Management it has been agreed that the outcomes from the November 2022 IRRS mission to Sweden should be taken into account, where relevant and appropriate. The aim is to avoid unnecessary duplication of effort in situations ("back-to-back") when an ARTEMIS mission is hosted subsequent to and within six months of an IRRS mission.

According to guidance on back-to-back missions that has been developed by the IAEA, it is not expected that detailed information should be provided on regulations and regulatory controls as part of the background material prepared ahead of the ARTEMIS mission. Some information on relevant legislation and regulatory issues is nevertheless included in this self-assessment report in order to provide necessary context for descriptions of different aspects of the national programme. Additional background material, for example in relation to major installations and activities responsible for generating radioactive waste and spent fuel, has been included in the report at relevant locations, even though this is not necessarily specifically requested by the IAEA questionnaires.

Topic 1: National policy and framework for spent fuel and radioactive waste management

Swedish national policy on the management of spent fuel and radioactive waste

There is no single official document describing Swedish national policy for the management of spent fuel and different classes of radioactive waste. Nevertheless, the rationale for the management of spent fuel and radioactive waste is based on basic principles derived from extensive deliberations surrounding the use of nuclear power that took place in the Riksdag (Swedish parliament), largely during the 1980s, and subsequently became defined in various legal instruments. National policy and strategy for the management system for spent fuel and radioactive waste, as embodied in Swedish legislation, has been developed to encompass the following four basic principles:

1. Expenses for the management of spent nuclear fuel and radioactive waste are to be covered by revenues from the activities that have resulted in these expenses.
2. Licence holders for nuclear activities as well as those that otherwise carry out activities with ionising radiation have an obligation to ensure the safe management and disposal of spent nuclear fuel and nuclear waste from their activities.
3. The state has the ultimate responsibility for the safe management of spent nuclear fuel and nuclear waste generated within the country.
4. Each country is to be responsible for spent nuclear fuel and nuclear waste generated in that country. The disposal of spent nuclear fuel and nuclear waste from nuclear activities in a foreign country is not allowed in Sweden other than in exceptional cases. Disposal of Swedish spent fuel or radioactive waste in another country is also prohibited, unless a number of conditions are fulfilled in line with for example the Council Directive 2011/70/EURATOM and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

Swedish policy for spent fuel and radioactive waste management, for all waste streams, including legacy waste and orphaned sources, is reflected in the legal requirements contained in the Act on Nuclear Activities [1], Radiation Protection Act [2] and Environmental Code [3]. Arrangements relating to financing of the management of residual wastes from nuclear activities (specifically spent nuclear fuel and other nuclear materials not intended for reuse, as well as wastes arising following the permanent closure of nuclear facilities) are reflected in the Act on Financing of the Management of Residual Products from Nuclear Activities [4] (the “Financing Act”). National policy and the principles on which it is based are judged to be in accordance with the European Union’s Council Directive 2011/70/Euratom establishing a Community framework for

the responsible and safe management of spent nuclear fuel and radioactive waste (the Euratom waste directive), which has been formally implemented in Swedish legislation since August 2013.

Reprocessing of spent nuclear fuel is not explicitly prohibited by legislation. However, it has been de facto policy since the 1980s to regard and to manage spent nuclear fuel as a waste ("nuclear material not intended for re-use"), even though it is not legally defined as waste until it has been finally emplaced in a repository.

The four principles listed above were originally developed in relation to the management of wastes from nuclear power production, leading to an emphasis on the obligation of the licence holders for nuclear power plants to develop and implement safe solutions for decommissioning of their facilities and for disposal of the wastes that they produce. The Act on Nuclear Activities encapsulates these provisions and incorporates related obligations on all nuclear licensees, including those without nuclear power reactors, with regard to the safety of their activities as well as responsibilities for safe management of the wastes that they produce and the safe decommissioning of their facilities. There is also a general prohibition within the Act on the disposal of Swedish nuclear waste in other countries, unless specific consent is given.

Furthermore, the Radiation Protection Act underlines that all those who carry out an activity involving ionising radiation are responsible for ensuring the safe management and final disposal of radioactive wastes arising from their activities. The Radiation Protection Act stipulates that implementation of the Polluter Pays principle also applies to non-nuclear generators of radioactive waste (such as industry, research and healthcare), in so far non-public actors also may be obliged as part of licence conditions to provide financial securities regarding the potential future costs of decommissioning and radioactive waste management from their activities.

The legal framework was amended as recently as 2020 with new provisions in the Act on Nuclear Activities (and corresponding changes to the Environmental Code) formalising the State's subsidiary responsibility for nuclear activities and its ultimate responsibility for a closed geological repository and its contents. After a geological repository has been closed in accordance with conditions laid down by the Government, the Act anticipates that a government authority will take over responsibility for and any necessary supervision of the repository.

Other principles constituting national policy on radiation safety and environmental protection are also relevant to spent fuel and radioactive waste management and are included in the legal and regulatory framework. Thus, for example, provisions within the Radiation Protection Act are based on the International Radiation Protection Commission's (ICRP) principles on justification, optimisation and dose limitation. In addition, the overall objective of the Swedish Environmental Code is to promote sustainable development and ensure a healthy environment for current and future generations. The general 'rules of consideration' established in the Chapter 2 of the Environmental Code identify important principles that are applicable to all potentially harmful activities, including nuclear activities and activities involving radiation, e.g. the knowledge principle, the precautionary principle and use of best available technology (BAT), the selection of the most suitable site and the remediation liability.

Sweden's summary report submitted in relation to the IRRS mission that took place in November 2022[1] also incorporates the results of a self-evaluation relating to national provisions for decommissioning of facilities and the management of radioactive waste and spent fuel (IAEA GSR Part 1 (Rev 1), Requirement 10).

Generation of spent fuel and radioactive waste in Sweden and existing facilities for their management

Figure 1 shows the location of nuclear facilities in Sweden. Spent nuclear fuel and nuclear waste emanates mainly from the twelve electricity-producing nuclear power reactors located at four sites in southern Sweden: Barsebäck, Forsmark, Oskarshamn and Ringhals. Nine of these reactors are of BWR type (ASEA-ATOM design) and three are of PWR type (Westinghouse design). All of these reactors were taken into commercial operation between 1972 and 1985. The two BWR units B1 and B2 at the Barsebäck site were shut down permanently in 1999 and 2005, respectively. The two oldest BWR units O1 and O2 at the Oskarshamn site were permanently shut down in 2015 and 2016. Of the two oldest units at the Ringhals site, R1 (BWR) was permanently shut down in December 2019 and R2 (PWR) was shut down in December 2020.

Other fuel cycle facilities include the Westinghouse fuel fabrication plant in Västerås and the former uranium mining and milling facility in Ranstad. The Ranstad facility was constructed and operated in the 1960s. The uranium open-cast mine and the mill tailings deposits were restored and covered in the 1990s. The industrial facility has been free-released from regulatory requirements since 2019.

Spent fuel from the nuclear power reactors is shipped to the centralised storage facility, Clab, close to the Oskarshamn nuclear power plant, which has been in operation since 1985.

Short-lived low- and intermediate level waste, predominantly consisting of operational wastes from nuclear facilities, is disposed of in the repository for low and intermediate level short-lived waste, SFR, in Forsmark, Östhammar municipality. SFR was commissioned in 1988 and is situated close to the Forsmark nuclear power plant. Long-lived low- and intermediate level waste is stored at the nuclear power plants, in Clab or at facilities controlled by different licensees on the Studsvik Tech Park, awaiting the development and planned implementation of a geological repository for such wastes.

Spent fuel and nuclear waste has also been generated from the operation of three research reactors (all of which are now decommissioned and dismantled) and from Sweden's first prototype nuclear power reactor (PHWR-type) in Ågesta, which was in operation between 1964 and 1974 and mainly used for district heating in a suburb of Stockholm. The oldest research reactor R1, situated on the campus of the Royal Institute of Technology in Stockholm, was in operation between 1954 and 1970. Two additional research reactors R2 and R2-0, situated at Studsvik, were in operation between 1960 and 2005. Studsvik has been the site of the national centre for nuclear research activities and now (renamed the Studsvik Tech Park) hosts facilities for nuclear fuel and materials testing as well as facilities for waste treatment and storage.

[1] *Kingdom of Sweden IRRS ARM Summary Report*, SSM Report 2022-11, September 2022.

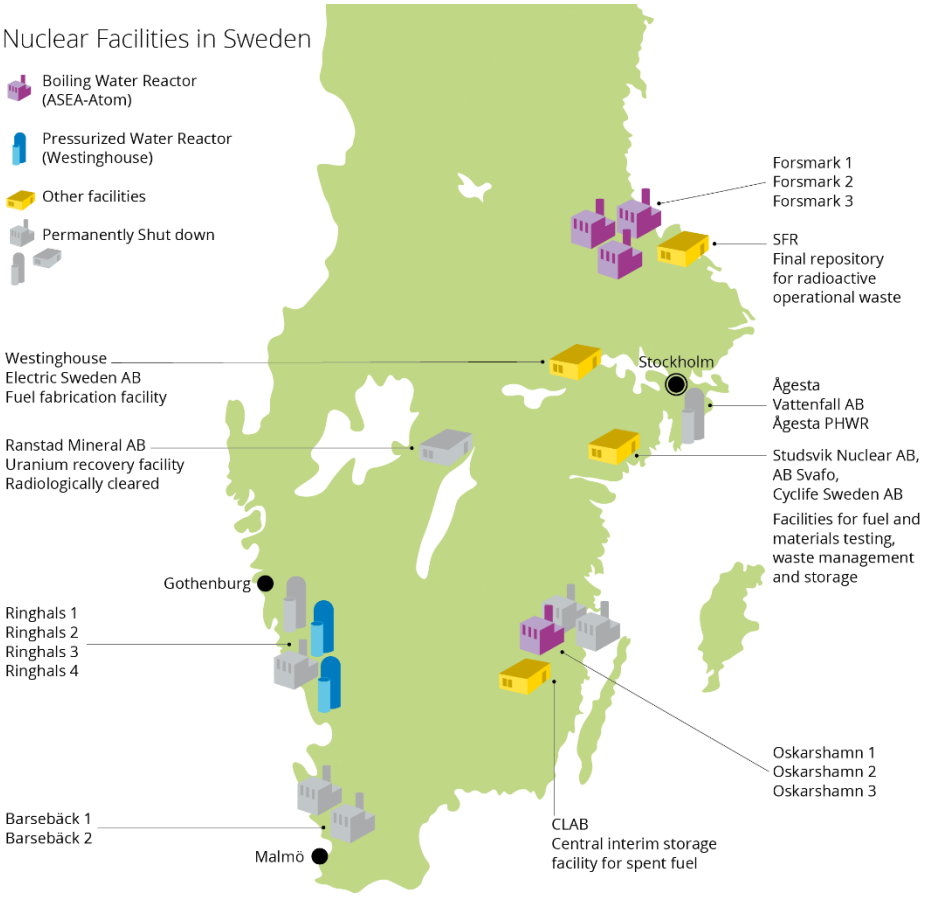

Figure 1 - Nuclear facilities in Sweden

Not explicitly shown on Figure 1 is Chalmers University of Technology in Gothenburg, which is subject to licensing under the Act on Nuclear Activities owing to the quantity of nuclear material it holds in connection with its research activities, which exceeds the threshold defined in the Act. The map also does not explicitly show the location of licensed shallow land burials for very low-level waste on the sites of the Forsmark, Ringhals and Oskarshamn nuclear power plants, as well as the Studsvik Tech Park.

There are thousands of activities outside the nuclear fuel cycle where ionising radiation is used for different purposes: at hospitals, educational and research facilities, non-nuclear industries and so forth. These activities generate relatively small volumes of radioactive waste compared to the volumes generated within the nuclear fuel cycle.

Radioactive waste will also arise from the European Spallation Source (ESS) accelerator facility, currently being commissioned at Lund in southern Sweden. Current plans envisage the facility to become fully operational in 2025 and that it will be in operation for around 40 years. The ESS facility is not a nuclear facility, but it will house considerable quantities of radioactive material and significant volumes of radioactive waste will be generated at the facility.

Legislative framework

The framework of Sweden's legislation in the field of waste management, nuclear safety and radiation protection, is to be found in following items of primary legislation:

- The Act (1984:3) on Nuclear Activities, which defines the licensing requirements for the construction and operation of nuclear facilities and for handling or using nuclear materials (including nuclear waste).
- The Radiation Protection Act (2018:396), which defines the requirements for protection of people and the environment and for radiological work from the harmful effects of radiation. The Act applies to radiation protection in general and, in this context, it provides provisions regarding worker's protection, radioactive waste management, and the protection of the general public and the environment.
- The Act (2006:647) on Financing of the Management of Residual Products from Nuclear Activities which deals with the main financial aspects, and defines the responsibilities pertaining to the management and disposal of spent nuclear fuel and radioactive waste from nuclear activities.
- The Environmental Code.

These Acts (decided by the Riksdag) are supplemented by a number of ordinances and other items of secondary legislation (decided by the Government), which contain more detailed provisions for particular aspects of the legal framework. Operation of a nuclear facility can only be conducted in accordance with a licence issued under the Act on Nuclear Activities as well as with a licence issued under the Environmental Code. The Act on Nuclear Activities is mainly concerned with issues of nuclear safety and security, while the Environmental Code regulates general aspects of the environment and the possible impacts of "environmentally hazardous activities", to which nuclear activities are defined to belong. The Act and the Code are applied in parallel and neither of them is superior to the other.

More detailed information on the regulatory framework applicable to spent nuclear fuel and radioactive waste management, including decommissioning, in Sweden has been presented and reviewed in the context of the IRRS mission that took place in November 2022.

Waste minimisation and graded approach

The provisions of the Environmental Code aim to promote sustainable development, which means that current and future generations are assured of a healthy and good environment. This includes provisions in Chapter 15 of the code, which define overarching requirements regarding implementation of the waste management hierarchy for wastes of all types. Furthermore, application of the Environmental Code is intended to promote the sustainable use of raw materials and energy. In addition, Chapter 3, Section 9 of the Radiation Protection Act requires that those who carry out an activity with ionizing radiation must, as far as possible and reasonable with regard to existing technical knowledge and economic and societal factors, take measures to limit the generation of radioactive waste. Work is being done by SSM to ensure that these principles are applied in the reports regarding the management of radioactive waste that licensees are obliged to submit to the Authority in respect of their waste management plans.

Licensing of nuclear activities under the Act on Nuclear Activities as well as licensing of activities involving radiation under the Radiation Protection Act allows for application of the concept of graded approach, i.e. with due consideration to the scope and nature of the activity at hand. A major review and revision of the entire Code of statutes issued by SSM as authorised by the Government (SSMFS) is currently underway. Among other things, this process has the aim of more explicitly implementing the principle of graded approach throughout regulations on nuclear safety and radiation protection. General regulations that apply to all activities with ionising radiation and specifically to nuclear power plants have already been updated in this way, not least by more extended reference to the principle of reasonable practicability in relation to the managing nature of the hazard presented by a particular facility or activity. Regulations relating to the final disposal of spent fuel and radioactive waste remain under review at the time of preparing this report, but it is intended that similar approaches will be adopted.

Avoiding undue burden on future generations

Legal requirements on safety objectives related to licensees' responsibilities to manage and dispose of spent nuclear fuel and radioactive waste, alongside the establishment and administration of the Nuclear Waste Fund, have the overall aim of preventing undue burdens from being passed on to future generations. Legislative provisions under the Act on Nuclear Activities, requiring that the operator of a geological disposal facility for radioactive waste cannot be relieved from its responsibilities as a licensee until conditions established by the Government for its final closure have been fulfilled, are also intended to minimise the long-term burden that may be passed on to the State.

Responsibilities for R&D

The Act on Nuclear Activities obligates the utilities that are licensed to operate nuclear power reactors, in cooperation, to develop and implement the R&D programme needed for the safe management and disposal of spent nuclear fuel and nuclear waste, as well as safe decommissioning and dismantling of nuclear power plants. Every three years, on the behalf of the operators, the Swedish Nuclear Fuel and Waste Management Company (SKB) submits a report on this programme to the regulatory authority for review. The programme must contain an overview of all research and technical development needed to be able to design, construct and operate planned facilities for spent nuclear fuel and waste management, and should specify in more detail the measures that are intended to be taken within six years. Starting in 1986, SKB has submitted successively updated programmes every three years. Since 1992, this programme has been denoted as the programme for Research, Development and Demonstration (the 'RD&D programme'). Over time, an overall system for handling and final disposal of the residual products from nuclear power production has been developed.

The structure and focus of the programme have varied over time. RD&D-program 2022 [5] includes the following parts:

- Part I, SKB's operations and action plan, which reports the operations and action plan for taking care of and final disposal of spent nuclear fuel and nuclear waste from the operation and decommissioning of the Swedish nuclear power reactors. There are also motives for the research, development and demonstration needed to be able to build and put new facilities into operation.

- Part II, Waste and final disposal, which reports the need for continued research, development and demonstration during the RD&D period, mainly in process understanding, knowledge and competence in the design and construction of barriers and components, and knowledge and competence in control and testing to verify that the requirements fulfilled.
- Part III, Decommissioning of nuclear facilities, which reports the planning for the decommissioning of the Swedish nuclear power reactors and SKB's facilities.

SKB has also established a number of research and demonstration facilities in support of its research and development activities (see Topic 4).

Regulatory body

The Swedish Radiation Safety Authority (SSM) is a central administrative authority under the auspices of the Ministry of Climate and Enterprise[2]. SSM is the regulatory body in Sweden authorised to supervise spent fuel management and radioactive waste management in the areas of nuclear safety and security, radiation protection and nuclear non-proliferation. SSM's missions and tasks are defined in the Ordinance with instructions for the Swedish Radiation Safety Authority (2008:452) and in the Government's annual appropriation directions.

The Director General of SSM is appointed by the Government for a fixed term (extension is possible) and is not replaced if there is a change of Government. Whereas Government matters are decided on collectively by the Ministers, and the Government directs its authorities through budget appropriations and ordinance decisions on tasks and the general orientation of operations, it has no powers to intervene in the SSM's decision-making regarding the application of legislation or in discharging its authority in individual cases. An individual minister cannot interfere in a specific case handled by an administrative authority. Ministerial rule is prohibited in Sweden.

SSM has a legal mandate under the Act on Nuclear Activities and under the Radiation Protection Act, which enables the Authority to issue legally binding safety and radiation protection regulations for nuclear facilities and activities involving the use of ionising radiation through its Code of Statues (SSMFS). In the preparation/development of SSM's regulations, EU legislation as well as IAEA safety standards, international recommendations, industrial standards and norms, and the rulemaking of other authorities are considered. SSM also has the mandate to decide on additional conditions or sanctions on licensed facilities and activities. SSM has extensive legal powers to enforce its decisions and is authorised to decide on measures that are needed and to issue orders and prohibitions in individual cases in order to enforce primary legislation, regulations in SSMFS Code of Statutes or applicable licensing conditions.

One important regulatory code issued by SSM is The Swedish Radiation Safety Authority's regulations on basic requirements for licensed activities with ionising radiation (SSMFS 2018:1) [6]. The overarching provisions that it contains establish fundamental requirements in the area of nuclear safety and radiation protection and are applicable to all licenced facilities and activities involving the handling of radioactive material.

[2] The former Ministry of the Environment has since 1st January 2023 been subsumed within a new government department that combines its functions with those of the former Ministry of Industry.

The regulatory activities of SSM are largely financed through yearly state budget appropriations and reimbursements from the Nuclear Waste Fund, as decided by the Government. The costs of the regulatory activities and related research financed through budget appropriations are largely recovered from the licensees in the form of fees paid into the state budget. The amounts of the fees are proposed annually by SSM and decided by the Government. In addition, some additional resources are provided in the form of fees for reviewing special applications or licensing work that are paid directly to the Authority.

Other key actors in the national framework for spent fuel and radioactive waste management

Below is a brief description of some key actors within the overall national framework for spent fuel and radioactive waste management.

The Swedish Nuclear Fuel and Waste Management Company

The Swedish Nuclear Fuel and Waste Management Company (SKB) is a private non-profit company, jointly owned by the nuclear power plant licensees. It has been established to carry out certain specific responsibilities that the licensees are obliged to undertake according to the Act on Nuclear Activities and the Financing Act. SKB is responsible for establishing the RD&D programme as well as cost calculations and submitting them for regulatory review every third year, on behalf of the licensees. The nuclear power plant licensees have also given SKB the responsibility to construct and operate facilities for the geological disposal of spent nuclear fuel and nuclear waste, including a facility for the encapsulation of spent fuel prior to disposal, as well to operate the interim storage facility for spent nuclear fuel.

In addition to the nuclear waste that SKB receives from the reactor owners, SKB also receives radioactive waste from healthcare, research and industry. This is regulated by agreements between SKB and the companies that generated the waste or otherwise handle it on behalf of another organisation, regardless of who has the legal responsibility for the waste.

Cyclife Sweden AB

Cyclife Sweden AB is a wholly owned subsidiary of the Électricité de France (EDF) Group and the only commercial provider of radioactive waste treatment services in Sweden for generators of both nuclear and non-nuclear radioactive waste. The company operates facilities on the Studsvik Tech Park for incineration, pyrolysis and metals treatment, on behalf of Swedish and international customers. It also has facilities for the conditioning and packaging of disused sealed sources and other radioactive wastes generated in Sweden by healthcare, research and industry. The company operates on a commercial basis and is not therefore obliged to accept any waste.

Contractual agreements for the management of non-nuclear radioactive wastes from Swedish customers involve a transfer of responsibility for the wastes to Cyclife, which means that the company is responsible for their subsequent packaging and interim storage up to and including final disposal. Cyclife does not routinely accept radioactive waste or

disused sealed sources for storage only. However, at the moment the company does store smaller amounts of radioactive waste and disused sealed sources, for a few customers.

AB Svafo

AB Svafo is a non-profit company owned by the nuclear power plant companies Ringhals AB (RAB), Forsmarks Kraftgrupp AB (FKA) and OKG AB. It operates a centre on the Studsvik Tech Park for the treatment and storage of legacy radioactive wastes from historic activities in Sweden. The historical wastes originate in part from state-controlled research, development and demonstration activities from the emergence of the Swedish nuclear programme up to 1991. They also include non-nuclear radioactive wastes from healthcare, industry and government agencies such as the Armed Forces. In addition to its responsibility for legacy wastes, AB Svafo also has responsibility for the decommissioning of historic nuclear research and development facilities.

The Swedish National Debt Office

The Swedish National Debt Office (the Debt Office) is a public authority responsible to the Ministry of Finance, and is the financial regulator for the nuclear waste financing system. Amongst other tasks, the Debt Office reviews and audits cost calculations submitted by SKB and, based on those estimates, calculates and proposes nuclear waste fees and collateral amounts to the Government for the coming period. The Debt Office also reviews the credit risk of the guarantees that the licence holders propose for the collateral amounts.

The Nuclear Waste Fund

The Nuclear Waste Fund is a government authority with its own board but no employees. The board decides on the Fund's strategic and tactical asset allocations within regulated limits. Administration and asset management of the Fund is outsourced to another government agency (the Legal, Financial and Administrative Services Agency). The fund is segregated from the rest of the public sector, and fund assets can only be used for specific parts of the programme as determined by the relevant legislation. Each licensee owns a share of the fund proportionate to the fees that it has paid into the system and the return on those investments.

Communication and public information

The legal framework for licensing nuclear activities contains provisions governing transparency, openness and public participation. Swedish official documents are publicly available and the right to anonymously request or access a public document is protected. This applies unless a decision has been made to classify information within the documents under the Public Access to Information and Secrecy Act (2009:400). Reasons for secrecy might include interests of national security, international relations, commercial relations, or individuals' right to privacy. SSM provides information services to the public concerning its regulatory activities and regularly publishes reports to inform interested parties and stakeholders. The SSM website is used to provide information on current events and authority decisions. SKB report series are made public as well and can be downloaded from their website.

The licensing review for a spent fuel repository in Sweden provides an example of how communication efforts have supported a transparent and predictable siting and licensing process, with active involvement of stakeholders.

SKB's siting of a spent fuel repository and a facility for the encapsulation of nuclear fuel (referred to as the KBS-3 system) has engaged local communities in open dialogue. The municipalities concerned have been involved on a voluntary basis and with the possibility to withdraw at all stages, from the initial feasibility studies to the detailed site investigations. This voluntary participation has also benefited from the understanding that an eventual host municipality ultimately has the right to veto a Government decision for a nuclear installation.

Preceding the licence application that was submitted in March 2011, SKB conducted a number of consultation meetings with stakeholders to inform about the planned activities and to obtain comments on issues that needed to be addressed in the formal Environmental Impact Assessment (EIA). The experiences from the RD&D review process and the participation by the regulatory authority in these meetings contributed to building public and local communities' confidence in the regulator's independence and in the overall licensing process.

To enable an active public participation during the licensing process, host municipalities and regional authorities have received financial support through the nuclear waste fund. Even certain environmental organisations, meeting defined criteria for eligibility, have received financial support through the nuclear waste fund for participation in consultation processes leading up to the hearings in the Land and Environment Court related to licensing under the Environmental Code. These stakeholders were involved in the pre-licensing process, are well informed and have over time built a good capacity for constructive dialogue. After completion of the hearings, the organisations have continued have continued to receive financial support, but from the state budget instead of the nuclear waste fund.

In order to support the initial review and analyse the quality of SKB's application, SSM arranged for an international peer review of the post-closure safety case, organised by the OECD Nuclear Energy Agency. Results were made available and communicated by the review team to the public and stakeholders in meetings at SSM and the host municipality in 2012.

SSM also distributed SKB's licence applications according to the Act on Nuclear Activities as part of a broad national consultation. During the continued licensing review, all relevant documents, including detailed supporting documentation to the licence application, supplementary information requests by SSM together with SKB's responses, external experts' technical review reports and SSM's review statements, were successively published on SSM's website. These have also included minutes from dialogue meetings between SSM and SKB, and the publication by SSM of a comprehensive report with preliminary conclusions from its scrutiny of the licence application ahead of its formal statement to Government.

A similar consultation and review process was used for the extension of the existing repository for short-lived low and intermediate level waste, SFR. It was, however, less

complex than for the KBS-3 system since it concerned an existing facility and only one municipality.

Topic 2: National strategy for radioactive waste and spent fuel management – scope, milestones, timeframes and progress indicators

Overall framework for the national strategy

There are three major strategic planning components that form the basis within Sweden for development of strategies and plans for radioactive waste and spent nuclear fuel management are based. These components are:

- The National System of Environmental Objectives (*Miljömålsystemet*)
- The reactor owners programme for research, development and demonstration (RD&D programme)
- The financing system

The National System of Environmental Objectives

The National System of Environmental Objectives [7] consists of sixteen national environmental quality targets that are followed up annually by the authorities responsible for the targets. An in-depth evaluation of the goals is made every four years. SSM is the goal manager for the environmental quality goal "A Safe Radiation Environment". The purpose of this goal is described as being that human health and biodiversity must be protected from the harmful effects of radiation. This goal can be further broken down and for radioactive substances it is expressed as "*Emissions of radioactive substances into the environment are limited so that human health and biodiversity are protected*". An important contribution to achieving this goal is recognised as being the use of the best available technology to limit the generation of radioactive waste and to limit releases of radioactive isotopes to the environment. This goal is mainly followed up through SSM's supervision activities within the context of legislation and regulation.

The RD&D programme for spent nuclear fuel and nuclear waste

According to Section 12 of the Act on Nuclear Activities [1], the licence holders for nuclear power plants are obliged jointly to establish (or have established) a RD&D programme, which is to be submitted to the Government every third year. The programme must address the responsibilities of all nuclear facility licence holders for the decommissioning and demolition of their facilities, as well as the safe management and disposal of the radioactive waste from these facilities (legally classified as "nuclear waste") and nuclear materials (such as spent nuclear fuel) not intended for re-use. The programme provides an overview of all necessary measures together with a more detailed

presentation of the measures that are planned for the coming six years. The purpose of the RD&D programme is to show how the reactor licence holders fulfil their obligations as defined under the Act on Nuclear Activities. The latest version of the RD&D programme was presented in September 2022 [5].

The financing system

The financing system is set up to, among other things, finance the RD&D programme. However, it is also designed to cover the costs of decommissioning and demolition of nuclear facilities, as well as the construction, operation and closure of facilities for the disposal of spent fuel and decommissioning wastes from nuclear activities (see Topic 6). Cost estimates developed on behalf of the nuclear power plant licensees are prepared by SKB and revised on the same recurring three-year timescale as the RD&D programme.

Overview of the Swedish system for management of spent nuclear fuel and radioactive waste

The greater part of radioactive waste in Sweden comes from the production of electricity by means of nuclear power reactors. The main driver for implementing systems for the management and disposal of spent nuclear fuel and nuclear waste is the general requirement according to Section 11 of the Act on Nuclear Activities [1] that obligates nuclear power reactor operators to develop the necessary infrastructure for safe management and disposal of their wastes.

Obligations on all nuclear licensees relating to responsibility for the costs of waste management and decommissioning, as controlled by the Act on Financing of the Management of Residual Products from Nuclear Activities [4] (the “Financing Act”), are specified in Section 13 of the Act on Nuclear Activities. Furthermore, according to Chapter 5, Section 18, of the Radiation Protection Act [2] all those who carry out an activity involving ionising radiation and that generate radioactive waste (whether from nuclear or non-nuclear activities) are obliged to have financial provisions for the safe management and disposal of their waste, as well as any necessary decommissioning and clean-up costs.

The four licence holders for nuclear power plants in Sweden (both operational and decommissioned) are responsible for the safe management and storage of spent nuclear fuel and nuclear waste generated at their sites, as well as decommissioning of the reactors and associated facilities. The licensees and their owners have joint ownership of the Swedish Nuclear Fuel and Waste Management Company (SKB), which assists them in executing their responsibilities. It is therefore SKB that presents the reactors licensees’ collective strategy for the management and disposal of spent nuclear fuel and nuclear waste (the RD&D programme). The nuclear power plant licensees have also given SKB the responsibility to construct and operate geological disposal facilities for the spent nuclear fuel and nuclear waste.

Figure 2 illustrates schematically the overall system for management of spent nuclear fuel and nuclear waste from nuclear power plants as developed by and on behalf of the nuclear power plant licensees. So far, the operational parts of the system consist of the Central Interim Storage Facility for Spent Nuclear Fuel (Clab) and the repository for short-lived low and intermediate level waste (SFR). In addition, shallow land burials are undertaken

for very low-level waste from operation at three of the four nuclear power plant sites. The overall system also includes the ship m/s Sigrid, used for waste and spent nuclear fuel transport (see further below), as well as transport casks and containers. Facilities that remain to be realised are the encapsulation plant for spent nuclear fuel and the repositories for spent nuclear fuel and for long-lived low and intermediate level waste. Furthermore, the existing repository for short-lived low and intermediate level wastes, SFR, is to be significantly extended in order to accommodate the disposal of decommissioning waste. SKB's latest RD&D programme from 2022 [5] focuses on these matters.

As can be seen from the Figure 2, in addition to the spent nuclear fuel and nuclear waste received from the nuclear power licence holders, SKB also receives radioactive waste for disposal from research, medicine and industry, including both nuclear and non-nuclear licensees. This is regulated by commercial agreements between SKB and the licence holders responsible for this waste. SKB currently has agreements with AB Svafo, Studsvik Nuclear AB, Cyclife Sweden AB, European Spallation Source ERIC (ESS) [3] and Westinghouse Electric Sweden AB (WSE). Under the terms of the agreement between SKB and ESS, SKB undertakes to account for the facility's wastes in its repository development and related activities but there is no binding commitment to accept such wastes without reservation.

The part played by Cyclife Sweden AB in the national system for radioactive waste management is not explicitly shown in the illustration in Figure 2. The company plays a significant role as a commercial actor in connecting the infrastructure developed for the management of radioactive waste from nuclear facilities ("nuclear waste") to that required for non-nuclear activities (medical applications, industry, research activities and consumer products). It should be emphasised, however, that there is no legal obligation on SKB to accept radioactive waste generated by non-nuclear activities for disposal in facilities developed on behalf of the owners of the nuclear power reactors.

By and large, this approach to integrating the management of nuclear and non-nuclear radioactive wastes has functioned effectively over the years. The structure was also reflected in the one-off compensation payment that the Government in 1984 agreed with the predecessor of Cyclife Sweden AB, Studsvik Energiteknik AB (also the predecessor of Studsvik Nuclear AB), to cover future costs for disposal in SFR of radioactive waste originating from non-nuclear activities [8]. Nevertheless, there are certain weak points with regard to the way in which holders of other nuclear and non-nuclear radioactive waste are able to fulfil their statutory responsibility for the waste, both in the present and in the future [9]:

- Cyclife Sweden AB is the only recognised radioactive waste management facility in Sweden for treating nuclear and non-nuclear radioactive waste from other waste producers. The company operates on a commercial basis and is not obliged by legislation to accept any waste for management at its facilities. Contractual agreements for the management of non-nuclear radioactive wastes involve transfer of responsibility for the wastes to Cyclife, which means that the company is responsible for their subsequent packaging and interim storage prior to final

[3] The 'European Spallation Source ERIC' (ESS) will be operating a new neutron source. This source is based on a large accelerator that bombards a heavy target material (tungsten) with protons. The neutron source makes it possible to study materials in their smallest components. According to the current plan, the ESS facility should be operational in 2025 and it is envisaged that the facility will be in operation for about 40 years. The ESS facility is not a nuclear facility, but it will house considerable quantities of radioactive material and significant volumes of radioactive waste will be generated.

disposal. If there is judged to be significant uncertainty regarding the possibility, or costs, of conditioning and packaging the waste in a form that is acceptable for final disposal, Cyclife may decline to provide a service. Cyclife does not routinely accept radioactive waste or disused sealed sources for storage only. However, at the moment the company does store smaller amounts of radioactive waste and disused sealed sources, for a few customers.

- There are no designated centralised interim storage facilities available for radioactive wastes. This means that anyone with legal responsibility for radioactive waste that is not accepted for treatment by Cyclife Sweden AB has no other route to turn to and is obliged to continue to store the untreated wastes on site until a final disposal route can be secured.
- Only limited amounts of long-lived radioactive nuclides can be disposed of in SFR, even after its extension is complete. This kind of waste therefore has to be safely stored until the planned SFL geological repository is in operation, which, according to current plans, will be in the mid-2050s. Moreover, the final costs for disposal of long-lived waste in SFL are very difficult to determine today. Cyclife Sweden AB has indicated that it might be too much of a financial risk for the company to assume responsibility for the interim storage and disposal of long-lived radioactive waste. Also, even though SKB has entered into agreements on final disposal of nuclear and non-nuclear radioactive waste with both Cyclife and ESS, these agreements do not necessarily mean that SKB will accept waste for disposal without reservation.
- Other nuclear and non-nuclear activities can be expected to continue to generate radioactive waste for many years to come, most likely after both SFR and SFL have been closed. This issue has become particularly visible with the planning and construction of the ESS facility and the need for the licence holder for the facility to fulfil its responsibilities according to the Radiation Protection Act for the wastes that it will generate. The ESS facility is expected to produce appreciable amounts of radioactive waste, both from operation and from its eventual decommissioning. According to current plans, ESS will continue operation until 2065, whereas SKB plans to close SFL in the 2060s.
- Cyclife is not permitted to accept and take responsibility for nuclear materials as defined by the Act on Nuclear Activities, other than relatively small amounts of natural or depleted uranium, or thorium (up to 5 kg, either in pure form or as a chemical compound, may be permitted by exception under the Nuclear Activities Ordinance). This restricts the type of wastes that Cyclife may accept, where the materials involved (e.g. radiation shields manufactured from depleted uranium, as used in certain non-nuclear activities) would cause such limits to be exceeded. The holders of such wastes therefore have to store the material pending a solution.

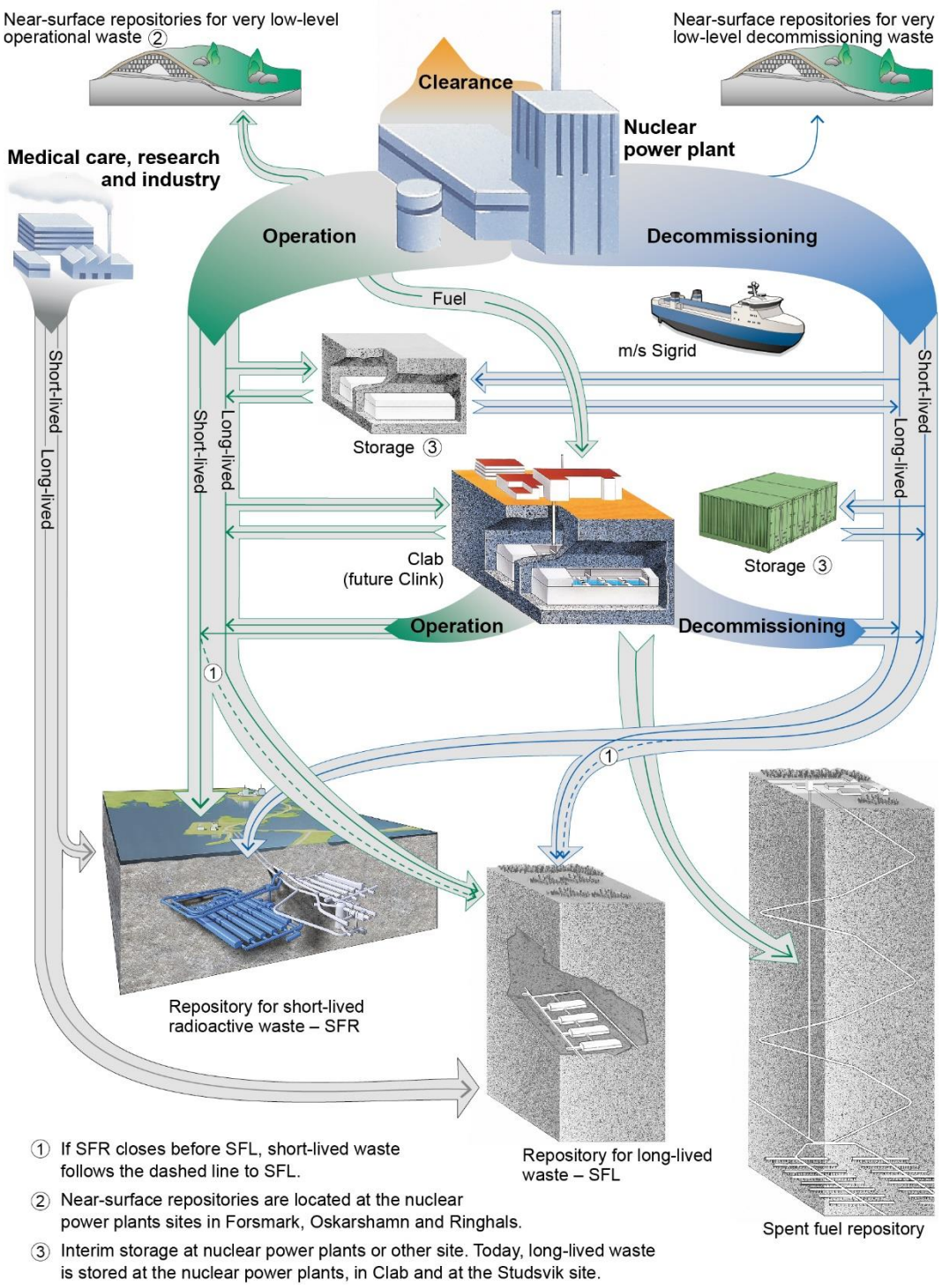

Figure 2 - The system for management and disposal of radioactive waste and spent nuclear fuel generated in Sweden (courtesy SKB)

Clearance

Material may be cleared for unrestricted use or for disposal as conventional waste according to approved procedures as prescribed in SSM's regulations (SSMFS 2018:3). As a complement to clearance, different nuclear licensees have developed procedures to identify such materials, building structures, and areas that do not belong to the controlled areas and have not been contaminated or activated by the licensed activity. These procedures are reviewed by SSM and, if accepted enable wastes to exempt from control as radioactive wastes.

Legacy wastes

In the Swedish context, legacy (otherwise known as "historic") wastes consist of those that were generated by research and development activities at the early stages of the Swedish nuclear programme, as well as certain other non-nuclear activities that took place in Sweden up to 30 June 1991. The legacy wastes are stored on the Studsvik Tech Park in AB Svafo's facilities and responsibility for their management in accordance with the provisions of the Act on Nuclear Activities has been transferred to AB Svafo. Non-nuclear radioactive wastes in this context include waste from healthcare, as well as industry and government agencies such as the Armed Forces. The management and disposal of the legacy waste have been financed to a certain extent by funds that were generated and dispersed to different organisations through a special law, the so-called Studsvik Act, which was repealed in 2017. These funds are, however, widely considered not to be sufficient to cover all the future costs associated with handling and final disposal of the legacy waste. At the time of preparing this report, the Government was therefore undertaking a review of current financing arrangements for different actors in connection with their identified responsibilities for the management and disposal historical wastes.

Legacy wastes vary with regard to their classification, the degree of accuracy with which they have been characterised, and the conditioning that was carried out when packaging was first undertaken. Individual waste items may contain a mixture of different types of waste from a variety of different sources. Treatment and (further) conditioning of such wastes are typically managed on a case-by-case basis and SSM has opted to have early insight into such plans, to ensure appropriate regulation and control. The final waste packages must, however, fit into the available waste streams of the disposal programme and, so far as possible, fulfil the general requirements of the regulations.

AB Svafo has a waste plan for characterisation and reconditioning of legacy wastes that are currently stored on the premises of the company. The plan also includes safe interim storage of the waste until it can be disposed of in SFR or SFL.

Orphan sources

Under the European BSS Directive, each EU Member State is required to ensure that the competent authorities are prepared to resume control over orphan sources. This responsibility has been assigned to SSM through the Radiation Protection Ordinance (2018:506), and the State provides financial resources for the management and disposal of orphan sources through a special governmental funding arrangement. This special funding arrangement, established in 2006, enables SSM to use up to SEK 3 million per year to secure the safe management of orphan sources.

Several orphan sources are recovered every year and SSM is usually able to commission Cyclife Sweden AB to manage these. When Cyclife accepts to manage orphan sources, the company also assumes the ownership of the sources. The orphan sources are transported to the Studsvik Tech Park, where they are treated, conditioned and stored pending disposal. However, in the event that an orphan source is of a nature where a treatment method or a disposal solution is lacking, Cyclife will not accept it, despite the availability of financing. The orphan source must then be stored by the finder while awaiting the choice of a suitable management method. In practice, this means that a private person or a recycling facility could become an involuntary holder of radioactive material for which they may lack competence and necessary facilities to manage. SSM has a growing list of cases with orphan sources that Cyclife has not accepted. So far, however, no orphan sources categorised as high activity sealed sources have been found in Sweden.

Transport system

Transportation of spent nuclear fuel and radioactive waste from nuclear power plants and nuclear licensed facilities on the Studsvik Tech Park to Clab and SFR is predominantly by sea, because all these facilities, except for Westinghouse's nuclear fuel factory and Ågesta NPP, are situated at or near to the coast. The transportation system used by SKB has been in operation since 1982 and consists of a purpose-built ship, transport casks and containers, as well as terminal vehicles for loading and unloading.

Wastes transported to Cyclife Sweden AB for treatment from waste producers in Sweden are typically carried by road, with licensed transport services provided by Cyclife for small volumes as part of a total service package. Shipments of larger items for treatment (such as disused steam generators from the Ringhals nuclear power plant) have taken place by sea, using quay facilities at Studsvik that are also available for shipments of waste items for treatment under contract on behalf of customers from other countries. Current plans for waste transports from the ESS facility in Lund envisage that the majority of transports will take place by road.

Main milestones and timeframes for achievement

The licensees of the nuclear power plants in Sweden are responsible for managing the spent nuclear fuel and nuclear waste that they generate. They are also responsible for setting up the necessary infrastructure and thereby the plans for its implementation. The licensees' obligations in this regard are executed by their jointly owned company SKB.

Time plan for the nuclear waste management programme

SKB's planning for new facilities reflects in part the stepwise decision process surrounding licensing and permitting that is derived from legal requirements, licensing conditions and SSM's regulations (see also under Topic 5). Planning for new facilities is based on the different licences and consents that are required according to this stepwise process and the steps constitute milestones. The most important milestones, which are common to all the planned facilities, are:

- Government approval of a licence under the Act on Nuclear Activities and decision on permissibility according to the Environmental Code to construct, own and operate a new nuclear facility.
- Formal licensing under the Environmental Code, with licence conditions established by the Land and Environment Court.
- Approval by SSM to start construction, following review and approval of a preliminary safety analysis report (PSAR).
- Approval of the safety analysis report (SAR) prior to trial operation and routine operation.
- Approval of a final safety analysis report prior to a Government decision to regarding final closure of the repositories.

The above milestones consist of two stages: firstly SKB's preparation of its applications and related safety analysis reports (SARs), and secondly SSM's and/or other regulatory authorities' approval of the applications after completing their review.

SKB's operations and those of its owners are affected by external factors, which requires that business activities, planning and the organisation itself are flexible and that decisions to work according to changed priorities may be necessary in the planning of activities and milestones for the waste programme. Time plans are reviewed and updated every three years as part of the preparation of the RD&D programme, reflecting progress that has been made in the previous period, and including any necessary changes arising from technical or administrative factors. The most recent outline of SKB's overall planning for implementation and operation of its waste management programme is described in the RD&D report published in September 2022 [5]. Current and planned facilities are described in more detail under Topics 4 and 5.

The 2022 RD&D programme reflects recent government decisions on admissibility according to the Environmental Code and licensing according to the Act on Nuclear Activities for increased storage capacity at the Clab interim storage facility for spent nuclear fuel, the extension of the SFR repository for short-lived wastes, and the KBS-3 system for disposal of spent nuclear fuel. In its business planning, SKB has taken a cautious approach to setting milestones because of the uncertainties associated with legal appeals that may be expected to arise in connection with forthcoming steps in the ongoing approvals process. Based on these preconditions, SKB has adopted the following overall strategic orientation for its forwards planning:

- The application for permission for extended intermediate storage in Clab up to 11 000 tonnes is prioritized ahead of the KBS-3 system and the expansion of the disposal facility for short-lived low and intermediate level waste (SFR) in the continued approval processes under the Environmental Code and the Act on Nuclear Activities. The goal is for SKB to obtain the necessary new permits for Clab before the current licensed capacity 8 000 tonnes is fully utilised.
- The expansion of SFR, from the current capacity of 63 000 m^3 to 180 000 m^3, is prioritized ahead of the KBS-3 system in the continued approval processes under the Environmental Code and the Act on Nuclear Activities. The SFR extension, which is needed to be able to manage waste from the decommissioning of nuclear power reactors, is smaller in both scope and complexity than the necessary developments to implement KBS-3 system and is expected to provide valuable experience for the construction of the Spent Fuel Repository.

Continued work with the repository for long-lived low and intermediate level waste (SFL) has been given a lower priority. The focus during the forthcoming R&D period is on working with the inventory, preliminary acceptance criteria and investigations on waste containers. When necessary data are available regarding the inventory, which also includes legacy wastes, they will constitute the basis for a comprehensive analysis of post-closure safety, which is a necessary condition for being available to be able to apply for the required repository licences. This means that the planned start of construction for SFL has been postponed several years compared with previous RD&D reports.

In a change from previous descriptions of its long-term plans, and in recognition of the uncertainties that persist, SKB has chosen in the visualisation of its time plans within the most recent RD&D report [5] to focus on the order in which specific activities are planned, rather than publishing specific dates. Nevertheless the time plans provide an indication of assumed time frames based on the fact that the publication dates for three-yearly updates of the RD&D programme are also shown. The results of this for the programme as a whole are visualised in the overall planning chart shown in Figure 3.

Plan of action for decommissioning of nuclear facilities

Chapter 5, Section 4 of the Radiation Protection Act [2] requires building structures and areas that may have been contaminated by radioactive substances from a licensed activity involving ionising radiation to be cleared from regulatory control as soon as is reasonably practicable. At the time of preparing this report, the final stages of preparing the site of the former research reactor R2 for radiological clearance were being undertaken on the Studsvik Tech Park. Dismantling and demolition is currently ongoing at five reactors: Barsebäck 1 and 2, Oskarshamn 1 and 2, and Ågesta. Final clearance of the buildings on these sites is planned to be completed in the period between 2025 and 2035. The intention is to achieve complete clearance of the Barsebäck site from regulatory control a little way into the 2030s.

The reactors at Ringhals 1 and 2 no longer contain nuclear fuel and preparations are being made to start dismantling and demolition, which is also planned to be complete during the early 2030s. Since dismantling and demolition at all these sites will commence, or has commenced, before the extended SFR facility is ready to receive short-lived radioactive waste from dismantling, the licensees must provide interim storage of this waste at the site or elsewhere.

Plan of action for transportation

SKB together with the reactor owners undertakes transport of spent nuclear fuel and nuclear waste from the nuclear reactors in Sweden to Clab and SFR. The majority of such transports are carried out with the ship m/s Sigrid. Shipments from other nuclear facilities, particularly those located on the Studsvik Tech Park, is also carried out, but is limited by comparison with the volumes coming from the reactor sites. It is recognised that there will be increased transport volumes when the extended SFR and subsequently SFL start to receive waste for disposal. There is currently an overcapacity in the transportation system and it is expected to be able to manage the increased transport volumes.

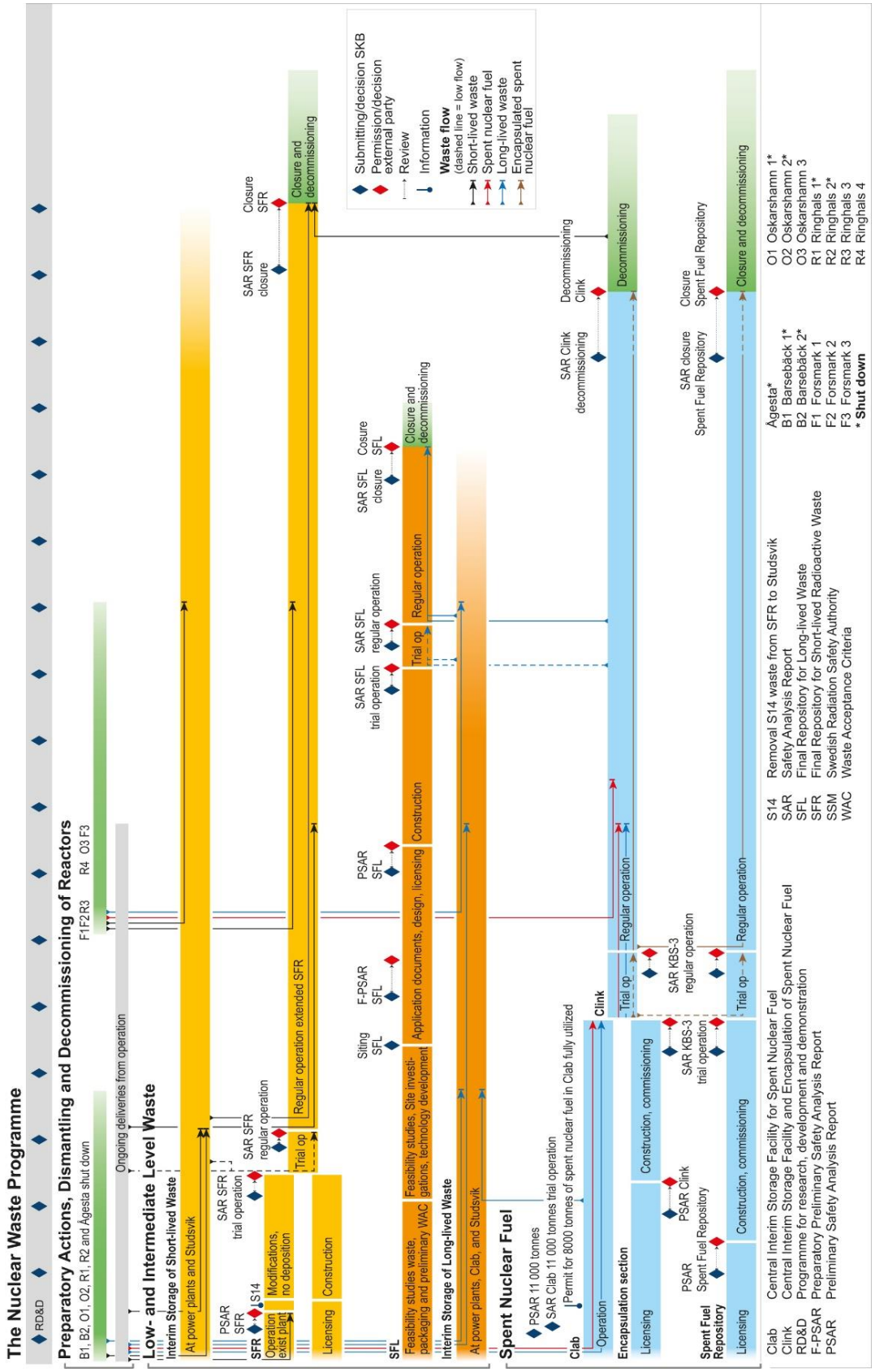

Figure 3 - Activity plans and milestones for SKB's nuclear waste programme and plans for decommissioning and dismantling of nuclear reactors [5] (courtesy SKB)

Process for development, review, approval and update

The Act on Nuclear Activities obligates the utilities that operate nuclear power reactors, in cooperation, to develop and implement the programme for Research, Development and Demonstration (the RD&D programme) needed for the safe management and disposal of spent nuclear fuel and nuclear waste, as well as safe decommissioning and dismantling of nuclear power plants.

Every three years, on the behalf of the nuclear reactor operators, SKB submits a report on this programme to the regulatory authority for review. SSM invites a large number of interested parties to comment on the report. The report is expected to include an overview of all measures that may be necessary and must specify the actions to be taken within a period of at least six years. When the review is completed, SSM submits its statement and the RD&D programme to the Government. Until the last reporting cycle in 2019, the Swedish National Council for Nuclear Waste (whose mandate was brought to an end by the Government in December 2022) also submitted its own independent evaluation of the programme to the Government. Based on the review recommendations, the Government approves or rejects the general direction of the continued programme. In connection with the decision, the Government may also issue conditions on the content of future research and development work.

The most recent RD&D programme was published by SKB [5] and submitted to SSM for review in September 2022.

All licensees for under the Act on Nuclear Activities must submit a cost estimate to the Swedish National Debt Office every three years regarding their future costs for disposing of all residual products and decommissioning of all facilities. The reactor owners coordinate within the financing system through the jointly owned company SKB and follow the plans reflected in the RD&D programme. The cost estimates are reviewed by the Swedish National Debt Office who then propose fees for nuclear waste based on the estimates. The government then decides on fees for the coming three years. Further details relating to the cost estimation process and financing system is provided under Topic 6.

Key performance indicators

Sweden does not have a national system for formal monitoring of the progress of implementing the nuclear waste management programme. As described above, SKB, on the behalf of the operators of nuclear power plants, submits a report on the RD&D-programme for nuclear waste every three years to SSM for review and the Government to approve (the latest programme was presented in September 2022 [5]). The report includes an overview of planned measures, identifying specific actions to be undertaken within the next six years.

In its review SSM invites a broad range of interested parties (for example municipalities hosting waste management facilities, academia, NGOs, County Administrative Boards and relevant authorities) to comment on the programme. When SSM has completed its review, the findings and recommendations are submitted to the Government, which decides whether the programme should be approved or not. The Government may in its decision stipulate conditions for continued development of the programme. The entire process is thus open and transparent and serves the purpose of monitoring both what has

been achieved since the previous programme and what is planned for the future. Furthermore, the process has now been in operation for over 30 years as a means for providing oversight of the national programme for management of nuclear waste. The programme has now reached the stage where government approval has been granted for the proposed long-term management system for spent nuclear fuel.

According to the Act (2006:647) on the Financing of Management of Residual Products from Nuclear Activities (the Financing Act) [4] and related Ordinance, the operators of nuclear power plants are obliged to pay fees to the nuclear waste fund, to cover all costs for RD&D, construction, operation and decommissioning of facilities, including reactors, as well as closure of repositories. SKB coordinates the cost estimates on behalf of the nuclear power plant operators and submits them every three years to the National Debt Office, which reviews the estimates and calculates the fees to be paid as well as the required financial guarantees. The fees and guarantees are then decided, based on the National Debt Office's proposals, by the Government for a period of three years. This system thus provides a mechanism for monitoring that sufficient funds will be available for the implementation of the nuclear waste programme.

Progress with implementation

In 2011, the Swedish Nuclear Fuel and Waste Management Company (SKB) submitted its licence applications for an encapsulation plant in Oskarshamn and a deep geological repository for spent nuclear fuel in Forsmark. The Land and Environment Court examined SKB's application under the Environmental Code, which addresses the whole KBS-3 system covering both facilities. The regulatory authority, SSM, reviewed SKB's applications under the Act on Nuclear Activities. Both the Court and SSM submitted their findings to the Government in January 2018[4]. The Government in January 2022 granted separate licences under the Act on Nuclear Activities to construct and operate the encapsulation facility and the geological repository for spent nuclear fuel. At the same time, the Government also formally approved the KBS-3 system of encapsulation and disposal of spent nuclear fuel by declaring it permissible under the Environmental Code.

In 2014, SKB submitted licence applications under the Environmental Code and the Act on Nuclear Activities for an extension to the repository for short-lived low and intermediate level waste at Forsmark (SFR) to enable it to accommodate short-lived wastes from dismantling and demolition. The Land and Environment Court and SSM submitted their findings to the Government, recommending approval of SKB's proposed extension and continued operation of the facility, in late 2019. The Government in December 2021 issued a licence under the Act on Nuclear Activities covering both continued operation of the existing SFR and construction and operation of the planned extension. At the same time, the Government also formally determined that the extension to SFR was permissible under the provisions of the Environmental Code.

Implementation of the licensing and approvals process by SSM (according to the Act on Nuclear Activities) and the Land and Environment Court (according to the Environmental Code) is now continuing with a focus on detailed requirements and conditions for the construction and operation of the facilities. In March 2022, SKB submitted a formal request to the Court for a licence for the extension to SFR to be issued according to the

[4] Further information on specific aspects of the review reviews undertaken according to the parallel licensing processes is provided in the description the status of the safety demonstration for the spent fuel repository under Topic 5.

Environmental Code, based on the Government's approval of the project. Hearings were held in late November 2022, and the licence, with conditions relating to (e.g.) noise, transport and releases of non-radioactive substances to water during construction, was granted by the Court later the following month. At the time of writing this report, SKB planned to apply to SSM for permission to start construction of the repository extension during the first quarter of 2023, in accordance with Government conditions on the licence under to the Act on Nuclear Activities. Construction of the extension is estimated to take approximately six years in total; there will be suspension of waste disposals to the existing facility while underground construction work takes place.

With regard to the KBS-3 system, further implementation of the licensing and approvals process by SSM and the Land and Environment Court is also now continuing. SKB plans to submit a request to the Court for a licence according to the Environmental Code for the KBS-3 system in the first half of 2023; subsequent Court hearings with regard to the formal licensing process and related conditions are expected to take place in 2024. Once the Court proceedings have been completed, SKB will apply to SSM for a permit to start construction of the spent fuel repository, in accordance with conditions imposed by the Government's licensing decision under the Act on Nuclear Activities. Sometime later, SKB expects to apply to SSM for a permit to start construction of the encapsulation facility, based on a PSAR for the combined facility, Clink. According to current prognoses, construction of the repository for spent nuclear fuel is planned to start during the second half of the 2020s, and will be in operation (together with the encapsulation plant) during the second half of the 2030s [5].

As briefly mentioned earlier in discussion of the forward plan, the Government in August 2021 approved SKB's plans to the augment the storage capacity at the interim storage facility for spent nuclear fuel (Clab) in a separate decision from the remainder to SKB's licence applications relating to the KBS-3 system. At the end of 2021 SKB submitted a request for the Land and Environment Court to issue a formal licence under the Environmental Code. In June 2022 the Court decided on detailed licence conditions, following public hearings that were held by the Court in May.

In parallel with its request to the Court, SKB also formally applied to SSM to implement modifications to the design and operation of Clab, based on submission of a preliminary safety analysis report (PSAR), addressing the implications of increased quantities of fuel storage within the facility. SSM concluded that the submitted material was not adequate and rejected the application in May 2022[5]. A revised application for consent to implement modifications, including a new PSAR addressing safety improvements at the facility relating to the increase in storage capacity, was submitted to SSM by SKB at the end of 2022.

Sources of uncertainty in the waste management programme

SKB's and the licensees' planning for management and disposal of the waste is based on the conditions and assumptions that currently apply for the nuclear power and nuclear waste programmes. In general, as noted above, the achievement of specific milestones and content of deliveries may be affected by delays and appeals associated with the

[5] Further information relating to SSM's review of the preliminary safety analysis report for modifications to Clab is provided in the description the status of the safety demonstration for the interim storage facility under Topic 5.

ongoing licensing and approval stages. The following is a number of possible changes to external conditions affecting the programme and what their consequences may be.

Licensing process

The licensing process for waste management facilities, including repositories, is fundamental for the implementation of the nuclear waste programme. From SKB's perspective, it is essential that the scope of any licence decided by the Government does not unduly constrain the possibilities to further develop or modify the facilities as new knowledge becomes available and experiences from construction and operation is gained. For the same reason it is important that the requirements and conditions decided by SSM and the Land and Environment Court in relation to the permits they issue enable the approval of subsequent modifications to facilities and activities, made with the aim of optimising industrial implementation, where this can be achieved without compromising long-term safety. This is considered by SKB to be in accordance with the Act on Nuclear Activities, which stipulates that a licence holder shall take advantage of scientific and technological development.

Operating lifetimes of nuclear power reactors

The waste system will be affected by changes in the planned operational lifetimes for nuclear power reactors. With operation life extension, the volume of wastes to be disposed will increase. The spent fuel repository could technically be possible to extend beyond the current planned capacity; however, the licence is based on a total volume that is determined on the basis of current plans for the operation of the existing reactors, together with that from those already shutdown. The designed capacity in the extension of SFR is judged to provide a sufficient margin for additional operational waste in case of extended operating times. The amount of decommissioning waste is not expected to be significantly affected by extended operating times. If necessary, it would be possible to adjust the final disposal volume in SFL until the time at which a licence application was submitted.

Conversely, a shortening of the planned operating times would entail a reduced quantity of spent nuclear fuel and operational waste and thus lead to reduced storage requirements (and potential overcapacity) in the repository systems.

Commissioning of the extended repository for short-lived radioactive waste (SFR)

When Units 1 and 2 of the Barsebäck nuclear power plant were permanently shut down in 1999 and 2005, respectively, an approximately 10-year long care and maintenance phase was planned. At that time, it was expected that short-lived LLW and ILW from dismantling and demolition could be disposed of within an extended SFR at around 2020. As the process of extending SFR became delayed, the licensee of the Barsebäck NPP decided to commence with dismantling and demolition of the reactors in accordance with the original schedule and to store instead the decommissioning waste in newly constructed interim storage facilities on-site. A similar interim storage solution was chosen by the licensees for handling the decommissioning waste from Oskarshamn Units 1 and 2 and Ringhals Units 1 and 2. Dismantling of the two units in Oskarshamn

commenced in parallel to the dismantling activities at the Barsebäck site. Dismantling and demolition of the two reactor units at Ringhals NPP units is planned to commence in 2023.

The planned management solution for LLW and ILW arising from the dismantling and demolition of the Ågesta reactor is interim storage in AB Svafo's storage facilities on the Studsvik Tech Park. Demolition wastes from the former R2 research reactor are already being held in AB Svafo's interim storage facilities.

A further delay to implementation of the SFR-extension could lead to the need for increased interim storage capacity at the power plant sites. The clearance of the Barsebäck site (currently under decommissioning) may be delayed unless waste from dismantling and demolition (both short-lived and long-lived) can be transported to another site. By contrast, earlier commissioning of the extended SFR facility would entail decreased need for interim storage of short-lived decommissioning waste on the reactor sites. SKB's plans do not, however, have a margin for earlier commissioning.

Decommissioning waste from the interim storage facilities is planned to be disposed of as soon as the respective final disposal facilities are available, i.e. starting around 2030 for short-lived LLW and ILW in SFR and in the mid-2050s for the long-lived ILW in SFL.

Final disposal of very low-level decommissioning waste

Since the activity level in the very low-level waste exceeds clearance levels, the management options that exist today are disposal via shallow land burial or in the waste vault for low-level waste (BLA) in SFR. The substantial uncertainties associated with forecasts of the amount of very low-level waste from decommissioning mean that it is important to study several different alternatives for final disposal. Improved methods for separation at source, as well as the use of decontamination or incineration to decrease the volume of radioactive waste that needs to be disposed of, may also affect the amount of waste assigned to different categories. The disposal volume within the planned extension to SFR is based on the assumption that it will be required to accommodate all low-level waste from dismantling and demolition, as well as some very low-level decommissioning waste [5]. Future updating and refinement of estimated waste volumes in different categories, including optimisation of routes for treatment and disposal, are therefore potentially constrained by the planned and authorised disposal capacity within SFR.

Siting and commissioning of the repository for long-lived waste (SFL)

The development of SFL is in a relatively early stage. Before the repository can be commissioned for active operation, several important milestones must be reached, such as evaluation and assessment of the safety after closure, siting, preparation of applications, licensing, construction, etc. According to SKB's plans, the aim is to commission SFL in the mid-2050s. Because the development of the concept and siting plans are still at a comparatively early stage, there are, however, uncertainties in the current planning. A delay in the commissioning would entail a prolonged interim storage of the long-lived waste, both at the power plants and at the Studsvik Tech Park. This could, in turn, affect the nuclear power licence holders' and AB Svafo's ability to decommission all remaining nuclear facilities on their sites.

Commissioning of the spent fuel repository and Clink

According to the current plans, trial operation of the Spent Fuel Repository and Clink will commence in the late 2030s, which means that SKB will begin unloading of the spent nuclear fuel from Clab's storage pools at that time. The licensed storage capacity for Clab is being increased to 11 000 tonnes in order to be able to accommodate the spent fuel generated up to this point in time. This will achieved by storing the spent fuel in so-called compact canisters instead of normal storage canisters, and if needed by unloading disused core components and BWR control rods that are currently stored in the Clab storage pools for storage at another site, as well as by upgrading the cooling system for the facility. If commissioning of Clink and/or the spent nuclear fuel repository were to be delayed by more than ten years, even the increased storage capacity in the existing Clab storage pools would be insufficient.

Provision for public consultations and participation in decision-making in relation to the waste management programme

The right of public access to official records is inscribed in the Swedish constitution. The Swedish right of public access to official records not only gives the public and mass media the right to gain insight into SSM's organisation and its work, but also the right to access the Authority's official documents, provided they are not subject to secrecy on the grounds of security or for commercial reasons.

The legal framework for licensing of nuclear activities contains provisions governing transparency, openness and public participation. According to the Environmental Code, a prospective licensee is required to submit a plan for the formal process of consultation with stakeholders in order to develop an Environmental Impact Assessment.

Through the mandatory review of RD&D programme reports, SSM supervises the development of management and disposal systems in the pre-licensing process. The review process includes opportunities for broad public participation in the development of the Swedish reactor licence holders' system for managing spent nuclear fuel and nuclear waste. Formal consultation during the licensing process for new facilities is another area where the public and other organisations are involved.

To enable active participation in formal consultations, municipalities and national authorities receive financial support through the nuclear waste fund. Certain non-governmental organisations, meeting defined criteria for eligibility, have also received financial support through the nuclear waste fund for participation in consultation processes leading up to the hearings in the Land and Environment Court related to licensing under the Environmental Code. After completion of the court's hearings, the organisations have continued have continued to receive financial support, but from the state budget (distributed via SSM) instead of the nuclear waste fund. At the time of preparing this report, the Government was reconsidering arrangements for future long-term financing of stakeholder engagement.

Preceding the Government's licensing decision for a nuclear facility (and certain other developments requiring a decision on permissibility according to the Chapter 17 of the Environmental Code [3]) the host municipality has a right to veto, in so far as it is expected to formally declare its support for or rejection of the decision. The

Environmental Code nevertheless allows for the Government to make an exception to this if it is clearly in the national interest to do so.

Local safety boards are established in municipalities to inform the public about safety and radiation protection work and preparedness at nuclear sites. A party that holds a licence to operate a nuclear power or research reactor, or a facility for the production, management, processing, storage or disposal of nuclear material or nuclear waste, is under an obligation to provide the local safety board with the information.

At the clearance of an area with restricted use, a formal consultation shall take place with relevant authorities and local stakeholders for the areas future use and needs of restrictions.

Topic 3: Inventory of spent fuel and radioactive waste

Waste classification scheme

There is no legally defined waste classification scheme in Sweden for radioactive waste. There is, however, an established waste categorisation system, developed by the Swedish nuclear industry and described in a Waste Handbook [10] developed in cooperation with SKB. In the handbook it is stated for example which information SKB needs in the specifications from the waste producers and what information the waste type descriptions must contain.

The characterisation system is largely destination-driven and customised concerning existing and planned repositories (end points) as shown in Table 1.

Cleared material is defined according to Chapter 2, Section 5 of the Radiation Protection Act as material that may have been contaminated by radioactive substances from an activity involving ionising radiation, but which from the point of view of radiation protection, do not need to be covered by the requirements of the Act. Rules for clearance of materials, structures and areas have been applied for many years; however, SSM recently updated its regulations with regard to the new Radiation Protection Act's provisions for exemptions from regulatory control and published them as SSMFS 2018:3 [11]. Material may be cleared for unrestricted use, for disposal as conventional non-radioactive waste (in municipal landfills) or for incineration using specific furnaces (only applicable to contaminated oil). A licence under the Environmental Code [3] is nevertheless required for such waste management practices.

Very low level waste short-lived (VLLW-SL) is suitable for disposal in shallow land burials that are licensed by SSM under the Act on Nuclear Activities [1] or may be subject to conditional clearance in accordance with the regulatory authority's requirements and decisions.

Low and intermediate level waste short-lived (LILW-SL) is treated and packaged according to a standardised system with predefined waste type descriptions (WTD) and disposed of in the repository for operational waste (SFR) in rock caverns within crystalline bedrock beneath the Baltic Sea, covered by about 60 metres of rock. The main difference between LLW-SL and ILW-SL is that for LLW-SL, the surface dose rate on the waste package (and unshielded waste) must be less than 2 mSv/h while for ILW-SL, the surface dose rate on the waste package must be less than 500 mSv/h.

Low and intermediate level waste long-lived (LILW-LL) will be disposed of in a deep geological repository situated in rock caverns in crystalline bedrock. Until this repository has been constructed, the long-lived waste is stored at the reactor sites, at the Studsvik Tech Park, or in storage pools in the interim storage facility for spent nuclear fuel (Clab).

Spent nuclear fuel is stored in fuel pools at the nuclear power plants for at least nine months before it is transported to the central interim storage facility for spent nuclear fuel (Clab). The safety and security measures taken at the NPPs do not differentiate between

spent or partially spent fuel. According to the current plans, following a storage period in Clab of about 30-40 years, fuel elements will be encapsulated in copper canisters, with strength provided by a cast iron insert, and transported to the spent nuclear fuel repository for disposal. The proposed disposal method (known as KBS-3) is based on the conceptual design of a deep geological repository in hard rock, with a system of engineered barriers ensuring post-closure safety through containment over very long periods of time. Spent nuclear fuel is not legally classified as a waste until it has been emplaced in a disposal facility, according to Section 2 of the Act on Nuclear Activities [1].

Table 1 - The waste classification scheme developed by SKB

	Definition	**Specific considerations**	**Destination**
Cleared Material	Material with so small amounts of radioactive nuclides that it can be released from regulatory control	-	No repository needed
Very low level waste, short-lived (VLLW-SL)	Contains small amounts of short lived nuclides with a half-life less than 31 years, dose rate on waste package is less than 0,5 mSv/h. Long lived nuclides with a half-life greater than 31 years can be present in restricted quantities	-	Shallow land burial
Low level waste, short-lived (LLW-SL)	Contains small amounts of short lived nuclides with a half-life less than 31 years, dose rate on waste package (and unshielded waste) is less than 2 mSv/h. Long-lived nuclides with a half-life greater than 31 years can be present in restricted quantities.	-	Repository for short-lived radioactive waste (SFR)
Intermediate level waste, short-lived (ILW-SL)	Contains significant amounts of short lived nuclides with a half-life less than 31 years, dose rate on waste package is less than 500 mSv/h. Long-lived nuclides with a half-life greater than 31 years can be present in restricted quantities.	Requires radiation shielding during transport	Repository for short-lived radioactive waste (SFR)
Low and intermediate longlived, waste (LILW-LL)	Contains significant amounts of long lived nuclides with a half-life greater than 31 years, exceeding the restricted quantities for short lived waste	Requires special containment during transport	Repository for long-lived radioactive waste (SFL)
Spent fuel/High level waste (HLW)	Typical decay heat >2kW/m^3 and contains significant amounts of long lived nuclides with a half-life than 31 years, exceeding the restricted quantities for short lived waste	Requires cooling and radiation shielding during intermediate storage and transport	Repository for spent fuel

Table 2 compares the SKB waste classification scheme with the IAEA definition in IAEA Safety Series GSG-1 [12]. National reporting of waste inventories is made according to both the Swedish and the IAEA classification system.

Table 2 - Mapping of radioactive waste categories used in Sweden against the classification scheme defined by IAEA

	IAEA Distribution (%)			
Sweden	VLLW	LLW	ILW	HLW
VLLW-SL	100			
LLW-SL		100		
ILW-SL		100		
LILW-LL			100	

Radioactive waste inventory in the Swedish National Plan

Under the Ordinance with instructions for the Swedish Radiation Safety [13], Sweden has implemented the European Union's directive on the responsible and safe management of spent fuel and radioactive waste in its legislative framework (2011/70/Euratom). The Ordinance requires the Authority to ensure that there is a current national plan in place, which corresponds to the content required under Article 12 of the directive. The Swedish National Plan, first notified to the European Commission in 2015 as a description of the national programme, provides a comprehensive account of Swedish policies, the legal, regulatory and organisational system, in addition to the strategies governing the management of spent fuel and all radioactive waste in Sweden. In addition, the plan accounts for the origin, treatment, transport, interim storage and final disposal of spent nuclear fuel and radioactive waste in Sweden. It also gives an account of the quantities of spent nuclear fuel and radioactive waste produced, as well as estimates of future quantities. Sweden's third national report within the framework of the Euratom directive was submitted in 2021 [9], and is supported by an updated version of the National Plan [14]. There were, however, no significant changes from the previous version and the update (largely reflecting the three-yearly updates to the nuclear industry's RD&D and programme and its cost assessments) was not therefore formally notified to the Commission.

Categories of radioactive material not included in the national inventory

Radioactive material excluded from the national inventory, as reported in the Swedish National Plan (i.e. the tables with declared waste amounts), includes disused sealed radiation sources that have not been declared as radioactive waste. The majority of disused sealed sources are returned to the supplier abroad but every year Cyclife Sweden AB also acquires some disused sealed sources, some of which can be recycled whereas the rest will be destined for disposal. Furthermore, although the National Plan includes a

general description of naturally occurring radioactive materials, NORM, they are not reported as part of the national inventory.

Yearly reporting of radioactive waste

The compilation of waste data reported in the Swedish National Plan [14] is based on the data reported by the licence holders to SSM. According to Chapter 5, Section 13 of SSM regulations SSMFS 2018:1 [6], all licence holders are required to submit a report to SSM by the end of each March each year concerning the radioactive waste that was held in association with the licensed activity at the end of the previous calendar year[6]. These yearly reports comprise a summary account of the following:

- the amount of waste that has arisen or has by other means been brought to the facility where the licensed activity is conducted;
- waste that has been transferred to a disposal facility or has been transported from the facility for treatment or storage in another facility, or that has been cleared;
- waste that at the turn of the year is present at the facility, the radionuclide inventory of the waste and information on its location; and
- experiences from handling the waste and a follow-up of established plans.

In order to ensure that reporting is made as uniformly as possible and thus to facilitate SSM's compilation of data on spent nuclear fuel and radioactive waste, SSM has distributed a template to the licence holders of nuclear installations. The waste is reported according to SKB's destination-driven waste classification scheme described above: VLLW-SL, LLW-SL, ILW-SL, LILW-LL and HLW. The licence holders also report if the waste originates from operation or demolition of nuclear facilities, and whether it is conditioned or unconditioned. The majority of radioactive waste originating from non-nuclear activities is owned and stored by Cyclife Sweden AB and thus included in Cyclife's reporting. Cyclife even stores waste on behalf of some nuclear licensees, without taking over ownership – this waste is also included as part of Cyclife's reported waste inventory.

The licensee reports include other information than waste data, such as waste management plans, ongoing or planned dismantling and demolition, radiological events, radiation doses from releases of radioactive substances, radiation doses to the public, occupational radiation doses. As a general rule, the waste reports are accepted by SSM, without further quality review. Plans to undertake such quality reviews have been given a low priority due to lack of personnel resources.

Table 3 shows the total amounts of waste in storage for different waste classes and their planned disposal route, table 4 shows the total amounts of disposed waste and table 5 the amount of spent nuclear fuel in storage. All data in the Tables are from the latest published compilation in 2019 [9].

[6] SKB is granted a permanent exemption to the March reporting deadline in respect of the SFR disposal facility, owing to the need to account for reporting of waste producers. Licence conditions for SFR specify instead a reporting deadline of 30 June.

Table 3 - Solid Radioactive Waste in Storage

Waste Class	Estimated Disposal Volume (m^3)	Planned Disposal Route
VLLW-SL	5 250	Shallow land burial
LILW-SL	9 750	SFR
LILW-LL	11 750	SFL

Table 4 - Solid Radioactive Waste Disposed (as disposed volume)

Waste Class	Volume (m^3)	Disposal Route Used
VLLW-SL	27 900	Shallow land burial
LILW-SL	39 900	SFR
LILW-LL	0	-
HLW	0	-

Table 5 - Spent fuel in Storage (tonnes U)

Type	Current Amount (NPP) (tonnes U)	Current Amount (Research Reactors and others) (tonnes U)
Total Spent Fuel Storage	7288	3
Wet storage (AR)	486	-
Wet storage (AFR)	6802	3
Dry storage (AR)	-	-
Dry storage (AFR)	-	0.04[7]
Total spent fuel held in storage for other countries (amounts also included above)	-	-

AR = “at reactor site”, including fuel pools at NPP
AFR = “away from reactor site”

Additional record-keeping requirements for nuclear licensees

In addition to general requirements for annual reporting of waste inventory on all licence holders for activities involving ionising radiation, a licence holder for nuclear activities is subject to specific requirements regarding the management of spent fuel and nuclear waste from their business (SSMFS 2021:7 [15][8]). Among other things, these require that the licensee shall, so far as it is reasonably practicable, keep complete and up-to-date

[7] These low-burnup research reactor fuel residues have previously been described [9] as being in wet storage (AR), but they are in fact stored within the AM facility on the Studsvik Tech Park, as described in Topic 4.
[8] Note that the English translation of this regulation, provided in the reference material for the ARTEMIS review, is based on the pre-publication version that was subject to final national consultation earlier in 2021.

records of all spent fuel and nuclear waste generated or present at the facility where the activities are carried out or have been carried out (Chapter 5 of SSMFS 2021:7).

The information that shall be kept in such records is on a more detailed level than what is submitted in the annual reports. For each item, information shall be provided on:

- identity
- origin
- the amount of waste/spent fuel
- any packaging
- who is obliged to manage the waste/spent fuel
- the amount of materials relevant to nuclear and radiation safety during the continued waste management
- radionuclide-specific content of radioactive substances, with reference date
- dose rate, with distance and reference date
- whether the waste item is subject to nuclear safeguards
- its position at the facility, indication of any other facility where the waste is located or indication that the waste has been transferred to another party or cleared
- where applicable, the date of relocation to another facility, transfer to another party or clearance, and
- where applicable, where and when any previous processing or storage of the waste took place.

Public access to inventory information

The right of public access to official records is inscribed in the Swedish constitution. All official documents are public unless a decision is made to classify them according to the Public Access to Information and Secrecy Act [16]. SSM's online register (e-registry) is available to the general public from the Authority's website[9]. All reports issued by SSM can be ordered and some are also downloadable from the SSM website. In that way, information on spent fuel and radioactive waste, including waste inventories, is already available to the public in different reports (e.g. [9] [14] [17] [18]) but is not currently available in the form of a searchable database.

An SSM project that has unfortunately had low priority owing to lack of resources is the development of an electronic national database for radioactive waste, with the aim that waste data can be automatically compiled based on input by the licensees. This would also facilitate publication of compiled information on SSM's website, allowing for simpler access and compilation of information. For the purposes of national and international reporting within the framework of the Joint Convention and European Directive, the national inventory is compiled every three years, but in the future – with the planned database – it would be possible to compile and publish the information more frequently.

[9] At the time of preparing this report, SSM's public e-registry was unavailable owing to an ongoing technical upgrade. SSM's intention is that the service will be resumed by the middle of 2023.

Import and export

One of the fundamental principles for the management of spent fuel and radioactive waste in Sweden is that each country is to be responsible for the spent nuclear fuel and radioactive waste generated in that country. This principle is reflected in current Swedish legislation, both in the Radiation Protection Act [2] and in the Act on Nuclear Activities [1]. Disposal of spent nuclear fuel and radioactive waste from a foreign country is not allowed in Sweden other than in exceptional cases.

Where waste treatment and fuel inspection and testing services are provided for international customers at Swedish facilities, foreign radioactive waste arising from these services must be transferred back to the country of origin within a timeframe for treatment specified by SSM at the time of issuing permits for import. Only small quantities of waste and/or fuel residues (typically in the form secondary or decommissioning wastes that cannot readily be sorted according to the origin of contamination) may be exempted from the general prohibition on disposal of waste from a foreign country. Such an exemption requires Government approval

Cyclife Sweden AB provides services for the treatment of radioactive waste, such as incinerating combustible waste and melting scrap metal, from both national and international customers based on commercial contracts. A principal precondition for such contractual agreements with international customers is that the radioactive material and residual radioactive waste from the treatment process is returned to the customer. However, small quantities of waste from the treatments of different batches of waste cannot easily be isolated. Cyclife Sweden AB therefore has a licence from the Government that enables them to accumulate small amounts of radioactive waste arising from the treatment of foreign waste for subsequent disposal within Sweden [19]. This waste is reported annually to SSM as part of the radioactive waste arising from Cyclife's activities.

Studsvik Nuclear AB (SNAB) provides services in nuclear fuel and materials technologies to the nuclear power industry. Testing of materials and reactor fuel is performed in its own laboratories on site. This includes investigations of nuclear waste and used fuel under contract to national and international customers, where examination and materials testing is undertaken. Owing to the nature of the methods used for examination and testing, SNAB is permitted by the terms of a specific licence from the Government to retain small amounts of waste and nuclear material for subsequent disposal in Sweden [20]. Conditions attached to the Government licence describe how SNAB should handle imported materials in order to minimise the quantity of waste requiring disposal in Sweden, and require SNAB to report annually on the amount of foreign waste and foreign spent fuel residues that it has received and how much has been retained.

It is also prohibited by law to dispose of Swedish spent fuel or radioactive waste in another country, unless a number of conditions are fulfilled in line with for example the Council Directive 2011/70/EURATOM and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. There have been some exceptions to this policy throughout the years when spent fuel and radioactive waste have been exported to other countries and vice versa. In particular, Swedish policy for management of spent fuel and radioactive waste was originally based on the assumption that reprocessing and plutonium recycling would form attractive and desirable elements of the nuclear fuel cycle. As commercial nuclear power plants were

built in the early 1970s, arrangements were made to send the spent nuclear fuel abroad for reprocessing. This was carried out before a general prohibition on export of radioactive waste was introduced into legislation through amendments to the Act on Nuclear Activities and revision of the Radiation Protection Act. Reprocessing of spent fuel is not included in the Swedish fuel cycle at all today.

Below is a summary of spent fuel and nuclear material that have been exported according to bilateral agreements and past contracts.

- Reprocessing contracts between OKG AB (the operator and licence holder for the Oskarshamn nuclear power plant) and the Sellafield reprocessing facility involved the transfer of some 140 tonnes of spent nuclear fuel to the UK between 1972 and 1982. The reprocessing took place in 1997 and resulted in the recovery of 136 tonnes of uranium and 833 kilograms of plutonium. Possession of the plutonium was transferred from OKG to the UK Nuclear Decommissioning Authority, NDA, by international agreement in 2014. The material, which is presently stored at the Sellafield site, is to be managed together with existing UK plutonium for future use in UK reactors in line with UK policies. The uranium has been shipped to Russia and used to produce new fuel for OKG.
- A further 78 tonnes of fuel from Barsebäck Kraft AB (BKAB) and Ringhals AB (RAB) was sent for reprocessing at La Hague in France in the late 1970s. Equivalent quantities of fuel residues were converted to MOX-fuel that was subsequently used in German reactors, under the terms of a multilateral agreement between Sweden, France and Germany. The agreement involved ownership of 23 tonnes of used MOX-fuel from Germany being accepted by SKB for storage at the Clab facility.
- About 3.3 kilograms of separated plutonium and approximately 9 kilograms of natural and depleted uranium, mainly from reprocessing of some spent fuel from the Ågesta reactor, was exported to US Department of Energy in 2012 within the framework of the Global Threat Reduction Initiative (GTRI). All remaining fuel from the operation of the Ågesta reactor is currently stored at Clab awaiting future disposal in Sweden.
- The fuel used in the R1 research reactor (now fully dismantled) consisted of rods of metallic uranium enclosed in an aluminium alloy casing. This type of metallic fuel is not however suitable for the anticipated method for disposal of spent nuclear fuel in Sweden. The intact part of the spent fuel (originally stored on the Studsvik Tech Park) was therefore separated from the corroded parts and in 2007 sent to the United Kingdom for reprocessing. Residual waste from the reprocessing activities was sent back to Sweden in 2009. The separated plutonium (1.2 kilograms) remains in storage in United Kingdom, following transfer of ownership to UK Nuclear Decommissioning Authority in 2014, together with that from reprocessing of spent fuel from OKG AB. The corroded parts of the R1 fuel are still being temporarily stored at the Studsvik Tech Park awaiting conditioning prior to disposal.
- Spent fuel from the closed (now fully dismantled) R2 research reactor at the Studsvik Tech Park has been exported to the United States according to contractual agreements.

Table 6 summarises how much spent nuclear fuel Sweden has sent to other countries throughout the years. This represents historical data as the national strategy for spent fuel since the beginning of the 1980s has been direct disposal without reprocessing. As can be seen, Sweden does not have any reprocessing activities at all.

Table 6 - Spent nuclear fuel sent for reprocessing (in the country or sent to another country)

Type	Amount (NPP) (tonnes U)	Amount (Research Reactors and others) (tonnes U)
Total amount of national Spent Fuel sent for reprocessing (in Sweden)	–	–
Total amount Spent Fuel sent to reprocessing (in another country)*	236	–
Total amount of Spent Fuel received from another country for reprocessing	–	–
Total amount of spent fuel reprocessed in Sweden	–	–
Current reprocessing capacity in Sweden	–	–

(*) includes spent fuel repatriated for other purposes

Future sources of spent fuel and radioactive waste

The waste inventories in the National Plan cover only spent fuel and radioactive waste from currently existing reactors and other facilities and activities. If new reactors were to be constructed, the total volumes of spent fuel and radioactive waste will become larger than anticipated within the industry's current programme for management and disposal of spent fuel and nuclear waste.

Estimation of future waste arisings

Forecast arisings of spent fuel and nuclear waste in the National Plan are based on the assumption that the current six nuclear reactors in operation will continue to operate for up to 60 years, and that decommissioning wastes will arise from these and the seven other nuclear power plants that are now closed. In the forecast for 2030, the amount of waste in storage is expected to be higher that today because of a planned pause for six years in disposal of waste to SFR due to the construction of the extended SFR. In the forecast for 2050, it is assumed that no additional shallow land burial facilities will be constructed. Table 3.7 shows prospects for amounts of radioactive waste and spent nuclear fuel for 2019, 2030 and 2050.

Table 7 - Prospective future waste arisings (volumes of radioactive waste and spent fuel arising, waste and spent fuel management facilities) [9]

Type	Total amount* (2019-12-31)	Total disposal capacity (2019-12-31)	Total forecast at 2030	Total disposal capacity in 2030	Total forecast at 2050	Total disposal capacity in 2050
Spent Fuel Storage	7 288 tonnes U		9 500 tonnes U		4 000 tonnes U	
Total amount spent fuel sent to reprocessing	236 tonnes U		0		0	
Total amount spent fuel disposed	0	0	0	0	8 000 tonnes U	12 600 tonnes U
Waste in storage	**26 750 m^3**		**44 000 m^3**		**15 000 m^3**	
VLLW	5 250 m^3		2 000 m^3		0 m^3	
LILW-SL	9 750 m^3		30 000 m^3		5 000 m^3	
LILW-LL	11 750 m^3		12 000 m^3		10 000 m^3	
Waste in disposal	**66 800 m^3**	**101 540 m^3**	**112 000 m^3**	**234 000 m^3**	**199 000 m^3**	**250 000 m^3**
VLLW	27 900 m^3	38 540 m^3	52 000 m^3	54 000 m^3	54 000 m^3	54 000 m^3
LILW-SL	39 900 m^3	63 000 m^3	60 000 m^3	180 000 m^3	140 000 m^3	180 000 m^3
LILW-LL	0 m^3	0 m^3	0 m^3	0 m^3	5 000 m^3	16 000m^3

(*) Estimated disposal volume

Forecasts of operational waste and spent nuclear fuel arisings in the National Plan [9] are based on operating experience and knowledge regarding how waste generation has fluctuated in previous years. As regards waste from dismantling and demolition of nuclear facilities, uncertainties in the estimated waste quantities are presented in the decommissioning studies. Aside from the waste associated with the facilities themselves – which includes iron/steel, concrete and sand – a certain fraction of secondary waste is expected to arise in conjunction with dismantling and demolition operations.

The forecasts for very low-level demolition waste are considered to be particularly uncertain. International experience shows that significant volumes of waste material classified as VLLW in the estimates can potentially be declassified altogether. Other factors that can affect future waste volumes are the extent to which different volume reduction and decontamination treatments are carried out. This mainly applies to the waste from dismantling and demolition. Examples are the degree of packing that can ultimately be achieved and whether further volume reductions can be achieved by melting low-level process systems. The amount of waste sent to SFR is also governed by the extent to which clearance practices and the use of shallow land burials will be applied in

the future. The possibility of depositing the very low-level waste from dismantling and demolition by shallow land burial instead of in SFR would mean a significantly reduced waste volume within the waste vaults for low-level waste in the planned extension to the SFR facility. At present, however, all materials from dismantling and demolition that are assumed not to be capable of clearance, and thereby classified as short-lived waste, have been included in estimates of the required volume for the extended SFR. For very low-level operational waste, however, it is assumed that further disposal by shallow land burial will take place.

Radioactive waste from non-nuclear activities is included in the waste forecasts presented in Table 7 based mainly on information provided by Cyclife Sweden AB and ESS. The forecasts from ESS (approximately 2 500 m^3 of radioactive waste) are, however, somewhat uncertain. Since ESS still is not fully constructed and trial operation recently started, there is only limited information on the amount and composition of this waste. According to ESS the major part of waste that will need to be disposed of, will in fact be short-lived low and intermediate level waste.

Responsibility for estimation of future waste arisings

Each nuclear licensee is responsible for estimating waste arisings from the decommissioning of its facilities, while SKB is responsible for compiling the inventory and imposing requirements for the waste (waste acceptance criteria) so that it can be transported and disposed of within the appropriate repository. Plant-specific and scenario-specific decommissioning studies have been performed for all Swedish nuclear facilities in order to estimate waste quantities, timetables and costs. The studies serve as a basis for determining capacities in SKB's planned waste management system and fees to be allocated to the nuclear waste fund (see Topic 7).

Estimates of the quantity of waste that need to disposed of in the future are nevertheless subject to a range of uncertainties, some of which are not based on purely technical factors. For example, changes in legislation and political decisions, as well as changes in operating conditions and closure dates for the different nuclear power plants, cannot be ruled out.

Management of future waste arisings

Based on the forecasts and the identified uncertainties, an assessment has been made of how these should be included in the dimensioning of the expansion of SFR. The dimensioning waste volume for the expansion of SFR has been decided to be approximately 117 000 m^3, which will result in a total storage volume of 180 000 m^3. A difference from previous forecasts is that the nine BWR reactor vessels are now planned to be segmented instead of being deposited in their entirety. The decision regarding the dimensioning waste volume is based on an effort to balance the requirement to dispose of all waste that may arise, against the risk of the facility being oversized. Low-level waste that cannot be accepted for disposal to the existing facility is temporarily stored at the waste generators until the extended facility has been brought into operation.

Topic 4: Concepts, plans and technical solutions for spent fuel and radioactive waste management

General principles

Governing principles for the management of radioactive waste form part of SSM's fundamental regulatory provisions regarding protection of the general public and the environment in relation to licensed activities involving ionising radiation (Chapter 5 of SSMFS 2018:1 [6]). In particular, for all activities that produce radioactive waste:

- A documented waste management plan shall be prepared showing how and when radioactive waste generated by, or introduced into, the activity is to be managed. The plan shall be based on an assessment of different ways for managing the wastes and shall be kept up-to-date (Section 9).
- Radioactive wastes with different characteristics shall as far as reasonably practicable be separated at the point of arising and subsequently kept separate (Section 10).
- Radioactive wastes shall be managed in accordance with their characteristics and how it is planned that they should be disposed of.

Furthermore, regulatory provisions specifically related to the management of radioactive waste and nuclear materials from nuclear facilities establish obligations on nuclear licensees to establish waste acceptance criteria for each step of waste management involving processing, storage or final disposal (Chapter 3 of SSM2021:7). Waste acceptance criteria (WAC) must be subject to internal verification from a radiation safety perspective and form part of the safety report for the facility in which the waste items are produced or accepted for further management.

As noted under Topic 2, the greater part of radioactive waste in Sweden comes from the production of electricity by means of nuclear power reactors, and it is the licence holders for these nuclear power plants, through SKB, that have legal responsibility for the development and implementation of solutions for the safe management, storage and disposal of the wastes they generate. The waste classification system developed by the Swedish nuclear power industry in fulfilling its obligations according to the Act on Nuclear Activities (Topic 3) is destination-driven and therefore customised with regard to existing and planned repositories. This in turn influences arrangements for treatment and interim storage of wastes prior to disposal.

All licensees under the Act on Nuclear Activities remain responsible for the waste they produce until final closure of the repository in which they have been disposed, and are responsible for financing the costs of nuclear waste management. In the case of operational wastes, these costs are incurred in the form of direct payment of disposal fees to SKB; for residual wastes, payment is made in the form of fees paid into the nuclear

waste fund. Payments into the nuclear waste fund by nuclear licence holders without reactors[10] are intended to cover the costs of decommissioning their facilities, as well as their share of costs for final management of nuclear materials not intended for re-use and wastes arising from dismantling and demolition. SKB has contracts with these waste producers regarding the provision of disposal volume for their wastes in the design and operation of final repositories.

To fulfil the obligations of the nuclear power plant licence holders, SKB has defined a Waste Management Process as one of the main processes in its management system (see Figure 4). For the system to work effectively, it is essential that all other licensees whose radioactive wastes SKB receives and eventually disposes of align their waste management activities with this process. The overall waste management process is supported by another process for defining WAC for disposal. It is essential to secure that all handovers of waste in the waste management process are in compliance with the relevant WAC. It is also essential to keep records of all waste, since there can be a long time perspective (decades) from where the process starts to where it ends.

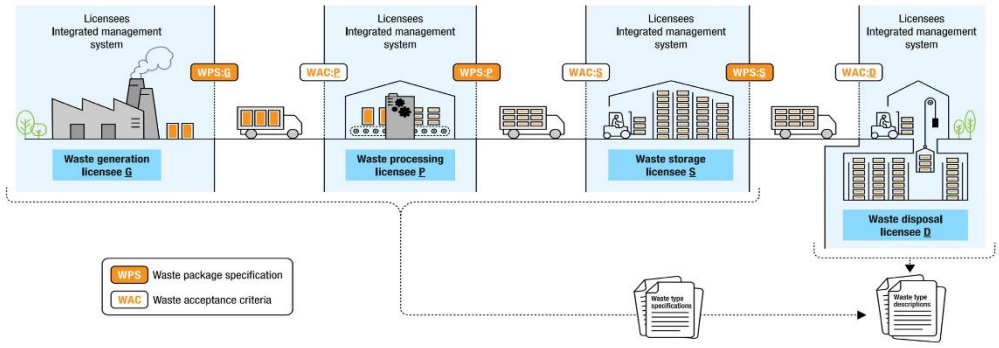

Figure 4 - Schematic description of the Waste Management Process

In order to increase the understanding of the Waste Management Process, WAC for disposal and other SKB-controlled and shared documents relating to the waste management system in Sweden, SKB has set up joint committees with all major waste producers. The central SKB-controlled and shared documents in the Waste Management Process are:

- A Waste Handbook that describes the Waste Management Process. In the handbook it is stated for example which information SKB needs in the specifications from the waste producers and what information the waste type descriptions must contain [10].
- WAC for disposal. This document is owned by SKB and stipulates the acceptance criteria applicable to SKB's repositories. All waste producers using SKB's repositories are obliged to follow these criteria[11].

In addition to these central documents, each licensee undertakes a breakdown of the Waste Management Process into underlying instructions, which are part of the individual waste generator's management system. Waste Type Descriptions (WTD), are then

[10] Further information on which licensees are responsible for financing different components of the National Strategy is provided under Topic 6.

[11] Recently published updated regulatory provisions related to the management of radioactive waste and nuclear materials from nuclear facilities (Chapter 3 of [15]) require that waste intended for disposal to a repository that is not yet in operation may not be processed in a manner that precludes modified treatment or further characterisation, unless specific approval is granted by SSM.

individually established by each waste generator, in collaboration with SKB, to provide a safety report for each waste type that is destined for disposal. The WTD covers all steps in the waste management process (waste production, conditioning, storage, transportation, reception and operational safety in the repository and post-closure safety) and verifies consistency with WAC for disposal. SKB produces the complete document based on a primary specification from the waste producer covering the first steps: waste production, storage and transportation.

Regulatory review of licensees' waste management plans and implementation of the Waste Management Process is central in SSM's regulatory oversight activities. In addition to baseline and needs-based inspections of waste management activities, SSM reviews the waste acceptance criteria documents for disposal developed by SKB as well as the waste type description documents developed by the nuclear waste generators. In addition, implementation of the Waste Management Process is regularly evaluated by SKB together with the waste generators, to ensure that disposal safety is not compromised. Furthermore, SKB regularly carries out its own audits the handling of radioactive waste at the nuclear power plants and other waste producers to ensure compliance with the Waste Management Process with regard to the waste it accepts for disposal. These audits are defined as 'process function audits' that complement the waste generators' own internal audits.

SKB has responsibility for the radiation safety implications of the wastes that it accepts for disposal, but the consignees retain responsibility for the waste packages themselves until final closure of the geological repository has been approved by the Government. Stricter use of, and confirmation of compliance with, waste acceptance criteria is intended to prevent potential problems from arising at a later stage after waste packages have been accepted at the disposal facility. Tighter controls on specifications for acceptability, intended to address the implications for long-term evolution of the repository environment, can present challenges for waste generators if strict limits are introduced on quantities of certain materials and substances that are already present in waste streams.

Arrangements between different private parties have been established to allow for the management and disposal of radioactive waste that does not originate from nuclear power plants within the infrastructure developed to manage and dispose of nuclear wastes and spent nuclear fuel. This includes radioactive waste from medical applications, industry, research activities and consumer products, for which a commercial waste management service is provided by Cyclife Sweden AB. When Cyclife Sweden AB agrees to receive the waste under such a contract with a non-nuclear holder of radioactive waste, the company also assumes the responsibility for the waste. Cyclife Sweden AB then arranges for disposal of the waste under the terms of its agreement with SKB. SKB has also agreed with the European Spallation Source (ESS) to account for its wastes in development activities relating to the planned repository for long-lived low and intermediate level waste, SFL. However, there is no binding commitment under current arrangements to accept such wastes without reservation.

In what follows, various components of the infrastructure for spent fuel and radioactive waste management in Sweden are described.

Pre-disposal management facilities, plans and activities

Non-nuclear radioactive waste

Cyclife Sweden AB is the only provider of radioactive waste treatment services in Sweden for generators of both nuclear and non-nuclear radioactive waste. The company operates facilities on the Studsvik Tech Park for incineration and pyrolysis (HA) as well as metals treatment (SMA). In addition it has facilities for the conditioning and packaging of disused sealed sources and other radioactive wastes (FR0-A and R0-A). Cyclife Sweden AB's operational licence permits the treatment of 600 tonnes of combustible waste and 5 000 tonnes of metal annually. In the case of disused sources and other wastes from medical use, research and industry, treatment methods may vary according to the nature of the material or source, its activity content and associated dose rate. Depending on such factors, treatment may comprise sorting, volume reduction, packaging and conditioning.

The company operates on a commercial basis and it therefore not obliged to accept any waste. Contractual agreements for the management of non-nuclear radioactive wastes involve a transfer of responsibility for their final management to Cyclife, which means that the company is responsible for their subsequent packaging and interim storage prior to final disposal. If there is judged to be significant uncertainty regarding the possibility, or costs, of conditioning and packaging the waste in a form that is acceptable for final disposal, Cyclife may decline to provide a service. Cyclife does not routinely accept radioactive waste or disused sealed sources for storage only. However, at the moment the company does store smaller amounts of radioactive waste and disused sealed sources, for a few customers. Moreover, Cyclife Sweden AB is not permitted to hold nuclear material as defined by the Act on Nuclear Activities, other than relatively small amounts (5 kg) of natural or depleted uranium, or thorium. This precludes the company from accepting certain types of wastes, whether from nuclear or non-nuclear licensees.

An organisation with legal responsibility for radioactive wastes that are not accepted by Cyclife Sweden AB for treatment is obliged to continue to store the untreated wastes on site until a final disposal route can be secured.

The majority of disused sealed sources are returned to the supplier abroad but every year Cyclife Sweden AB also acquires some disused sealed sources, including orphan sources, some of which can be recycled whereas the rest will be destined for disposal.

Wastes for which responsibility is transferred under contract to Cyclife Sweden AB are subsequently either sent for final disposal to the SFR repository for short-lived low and intermediate level waste (see below), or – in the majority of cases – stored locally awaiting final conditioning and packaging, pending the availability of a geological disposal facility for long-lived wastes (SFL, see below). Longer-term interim storage of disused sources takes place in the nearby rock cavern storage facility (AM) operated by AB Svafo (see below).

Cyclife's business operations include volume reduction by incineration and metal treatment of wastes for both Swedish and international customers. A principal contract condition for international customers is that the radioactive material and any related radioactive wastes are returned to the customer after treatment. In the case of incinerated wastes from overseas, this means that ash and dust will be returned to the country of

origin for further management. Likewise, slag and dust from metal treatment will be returned to the customer, whereas metal ingots produced by the melting process can typically be free-released. Approximately two hundred transboundary shipments of wastes (import for treatment at Cyclife Sweden AB and export of radioactive residues after treatment) take place every year.

Nuclear waste

Radioactive wastes arising from **nuclear power plant operations** are generally not stored or treated centrally but are conditioned (solidified, compacted, etc.) and packaged within facilities at the point of origin, at the reactor site. Exceptions to this are, however, disused reactor control rods and core components, which are managed as long-lived intermediate level waste according to industry's classification system. These are currently stored either in the storage pools of the central interim storage facility for spent nuclear fuel, Clab (see below) or in storage facilities at the power plants such as the rock cavern (designated BFA) at the Oskarshamn NPP. Moreover, some power plant wastes are sent for volume reduction treatment under commercial agreement for incineration or melting to Cyclife Sweden AB. As a general rule, radioactive residues from treatment are subsequently returned to the reactor sites for packaging and, where necessary, interim storage. Cyclife Sweden AB also provides a waste treatment service for pyrolysis and subsequent conditioning, packaging and interim storage of uranium-contaminated dry active waste from the Westinghouse fuel fabrication plant. Unlike in the case of non-nuclear radioactive waste, however, Westinghouse Electric Sweden AB pays fees into the nuclear waste fund for disposal of its long-lived wastes, and contractual arrangements do not involve Cyclife taking over final responsibility for these wastes.

Treatment and storage facilities on nuclear power plant sites are fully integrated with other operations on the reactor site. Whereas short-lived low and intermediate level radioactive wastes from operations at nuclear facilities can be sent after treatment for final disposal to the SFR repository (see below), there needs to be sufficient buffer storage capacity at the site of origin to allow for any periods where SFR is not able to accept such wastes. Moreover, there is currently no disposal route for wastes from demolition and dismantling of decommissioning facilities or for long-lived low and intermediate level wastes from nuclear facility operations.

At the Oskarshamn NPP, the storage facility for non-combustible low and intermediate level waste is located in a rock cavern (BFA). The scope of the facility's licence includes core components from all Swedish nuclear power plants, as well as operational wastes from the adjacent central interim storage facility for spent nuclear fuel, Clab. At the other nuclear power plant sites, there are dedicated storage buildings for low and intermediate level wastes. Some of these are subject to specific licensing arrangements, separate from those of the NPP on which site they are built, and are subject to conditions regarding which waste types may be stored. Some short-lived VLLW and LLW is temporarily stored in ISO-containers on hardened surfaces, with or without limited weather protection, prior to disposal.

It is judged that existing interim storage capacity at the Oskarshamn and Ringhals NPPs can accommodate wastes from ongoing demolition and dismantling activities up to a certain time, but that this capacity may need to be extended if commissioning of the planned SFR-expansion is delayed [5]. According to current plans, such facilities would also be used for storage of interim storage of long-lived low and intermediate level

radioactive wastes from dismantling of reactor components, pending the availability of a disposal route (SFL – see below). Interim stores have been constructed at Barsebäck NPP to accommodate low and intermediate level wastes (both short- and long-lived) from demolition and dismantling activities. There is, however, pressure from the local municipality for the site, which no longer has any power production operations, to be made available for other uses, which means that long-term interim storage of long-lived low and intermediate level wastes, in particular, is not considered an attractive option. The licence holder for Barsebäck NPP is therefore investigating options for longer-term interim storage at an alternative location [5].

In addition to arrangements for the treatment and storage of wastes from commercial nuclear power generation, AB Svafo on the Studsvik Tech Park operates a centre for the **treatment and storage of legacy radioactive wastes** from historic activities in Sweden. These historical wastes originate in part from state-controlled research, development and demonstration activities from the emergence of the Swedish nuclear programme up to 1991. They also include certain non-nuclear radioactive wastes from healthcare, industry and government agencies such as the Armed Forces. Pre-disposal management facilities operated by AB Svafo on the Studsvik Tech Park include:

- A treatment facility for intermediate level solid and liquid wastes (HM), which was previously used to process AB Svafo's waste, including that arising from dismantling of R2 research reactor (formerly located on the site of the Studsvik Tech Park). The facility now provides a service for the processing and packaging of certain non-nuclear intermediate level wastes and spent sources on behalf of Cyclife Sweden AB, as well as range of operational wastes (from fuel dissolution, sludges, ion-exchange resins and radioactive liquids) generated by the activities of Studsvik Nuclear AB. In both cases the organisations have operations on the same site. Solid waste treatment includes sorting, compaction, packing and conditioning by stabilising using concrete. Liquid wastes are treated by evaporation and solidification in a concrete matrix.

- A rock cavern storage facility (AM) for long-lived low and intermediate level wastes, which was originally constructed in the 1980s for interim storage of conditioned wastes from nuclear facilities run by the predecessors of current operators on the Studsvik Tech Park. The cavern is entered via a horizontal drift in the cliff and provides a rock cover of some 20 metres. Wastes stored within AM include operational waste from the former R2 research reactor, irradiated and contaminated material from the production of isotopes as well as from the fuel testing laboratory, start sources from an old research reactor, and operational waste from waste handling facilities.

  The facility was originally intended to store wastes arising on the site until a disposal facility for long-lived wastes (SFL – see below) was available, which at that time was expected to be around 2020. AB Svafo plans to keep the facility in operation until such time as SFL is taken into operation. The storage area is divided into two parts, depending on whether shielding from external radiation is required. As noted above, the AM facility also provides for long-term interim storage of a relatively small volume of radioactive waste from non-nuclear activities, which are related to Cyclife Sweden AB's operations. It also holds wastes produced during treatment at Studsvik of steam generators from the Ringhals NPP.

- Above ground interim storage facilities (AU and AUA) for conditioned long-lived waste. The AU facility is a simple unheated building that provides storage for drums of historical wastes, embedded in concrete, including waste originating from former nuclear-related research and development activities. The waste items were overpacked into larger drums in the 1990s and are ultimately intended for disposal to the planned geological disposal facility for long-lived wastes (SFL – see below). The recently-completed AUA facility has been designed to accommodate low and intermediate level decommissioning wastes from the R2 research reactor and the former Ågesta NPP (closed in 1974).

Studsvik Nuclear AB (SNAB) provides services in fuel and materials technologies to the nuclear power industry. Testing of irradiated materials and reactor fuel is performed in its own laboratories on site. The spent fuel storage pools under the control of SNAB (FA) are occasionally used for storage of spent fuel prior to examinations performed in the Hot Cell Laboratory (HCL), and for storage of Co-60 sources for medical use.

The HCL is primarily used to investigate irradiated nuclear fuel, although it is also used for studying other types of irradiated materials. In addition, the laboratory is used for conditioning, treatment and encapsulation of spent fuel fragments in packages suitable for interim storage in other facilities. The laboratory has seven cells with thick concrete walls, and lead-glass windows to protect personnel from ionising radiation. One of the cells is used for handling Co-60 sources from medical equipment. Except for a "library" that temporarily houses fuel pins that are the subject of investigation, all wastes are removed from the HCL after conditioning. Fuel pins no longer subject to investigation are packaged in a manner suitable for transfer to the Clab interim storage facility.

The Active Metal Laboratory (AKL), operated by SNAB, is primarily used to investigate irradiated metallic materials. The laboratory has several cells with lead shielding to protect personnel from ionising radiation. All waste is removed from the laboratory after conditioning. Studsvik Nuclear AB is also responsible for the liquid waste and sewage system on the Studsvik Tech Park. Wastes from the laboratories can be treated in Cyclife's facilities or stored in the rock cavern (AM), depending on the type of waste.

Spent nuclear fuel

As noted in Topic 2 with regard to the national strategy for management of spent nuclear fuel, the licence holders for nuclear power plants in Sweden use a centralised facility for the interim storage of spent nuclear fuel pending final disposal. The central interim storage facility, Clab, situated adjacent to the Oskarshamn NPP site, has been in operation since 1985. SKB is and has always been the licence holder, but operations until January 2007 were undertaken by the power plant operator. Prior to transportation to Clab, spent fuel from nuclear power reactors is temporarily stored in pools at the reactor site, for a period of at least nine months.

The Clab facility consists of two main parts: an above-ground reception building with water-filled pools for unloading fuel assemblies from the transport casks, and an underground section comprising the long-term storage pools. Fuel is transferred from reception to the storage area via a water-filled lift. Water in the pools covers the fuel to a depth of eight metres, providing radiation shielding, and is circulated via heat exchangers

in order to provide cooling. The rock cover above the storage pools is approximately 25-30 metres.

In addition to spent fuel from past and present commercial nuclear power operations in Sweden, the fuel in interim storage at Clab includes:

- 23 tonnes of used MOX-fuel from Germany, acquired under the terms of an exchange agreement relating to the reprocessing of fuel during the early stages of the Swedish commercial nuclear power programme;
- approximately 20 tonnes of historic used fuel from the former Ågesta NPP (closed in 1974);
- approximately 3 tonnes of used fuel residues from Studsvik Nuclear AB's post-irradiation inspection, testing and analysis activities.

Storage capacity at Clab is limited in two main respects: the permissible quantity of spent nuclear fuel that it is licensed to accommodate, and the number of physical storage positions in the pools. The quantity of spent fuel in storage is expected to reach the current authorised limit of 8000 tonnes during 2024. SKB's plans to expand the storage capacity at Clab from 8000 to 11 000 tonnes, primarily via more compact storage arrangements and without any physical expansion of the facility, were approved in decisions taken by the Government in August 2021. In June 2022, the Land and Environment Court established detailed licensing conditions with regard to licensing under the Environmental Code. Meanwhile (at the time of writing this report), SSM is continuing to pursue the ongoing authorisation process according to the Act on Nuclear Activities regarding the safety provisions relating to the increase in storage capacity, based on a preliminary safety report prepared by SKB, in fulfilment of conditions imposed as part of the Government's licensing decision.

According to current plans, following storage for a period of 30-40 years, the fuel elements will be prepared for direct disposal within an encapsulation facility that is to be constructed adjacent to Clab. Regular inspections of selected fuel elements are undertaken in order to monitor changes in their properties during storage.

The planned combined storage and encapsulation facility is known as Clink. A Government decision to approve SKB's plans for the encapsulation and final disposal of spent fuel was made in January 2022. Implementation of the licensing process by SSM (according to the Act on Nuclear Activities) and the Land and Environment Court (according to the Environmental Code) is now continuing, with a focus on detailed requirements and conditions for the construction and operation of Clink. SKB plans to submit an application to the Court in the first half of 2023 and the Court hearings with regard to the formal licensing process and related conditions are expected to take place in 2024. Sometime after the Court proceedings have been completed, SKB will apply to SSM for a permit to start construction of the encapsulation facility in accordance with conditions imposed by the Government's licensing decision under the Act on Nuclear Activities.

Low burnup, corroded metallic uranium fuel residues from the former R1 research reactor (approximately 36 kg) are currently stored as long-lived intermediate level waste in the AM dry storage facility on the Studsvik Tech Park, operated by AB Svafo. Other fuels from former research reactors have either been reprocessed (R1), owing to their

unsuitability for the anticipated method of disposal, or exported in accordance with contractual agreements (R2/R2-0) (see Topic 3).

Disposal management plans and activities

Shallow land burials

Shallow land burials are licensed by the Land and Environment Court under the Environmental Code [3] and by SSM under the Act on Nuclear Activities [1]. There are currently four nuclear sites in Sweden where shallow land burial of short-lived very low level radioactive waste is being, or has been, carried out. These are:

- Forsmark NPP site – one shallow land burial facility for operational VLLW. The burial facility remains operational following an extension to its licence in November 2013.
- Ringhals NPP site – one shallow land burial facility for VLLW from power plant operations. The burial facility remains operational. At the time of writing this report, preparations are being made to make a licence application for a new facility to provide capacity for both demolition and operational wastes.
- Oskarhamn NPP site – two (now completed) adjacent shallow land burial facilities for operational wastes, closed by the operator in 1999 and 2020, respectively. A licence application for a third facility, intended to provide capacity for demolition wastes, was submitted 2021. At the time of writing this report, licensing processes were continuing in the Land and Environment Court and at SSM.
- Studsvik Tech Park – one shallow land burial facility, now closed but remaining under the responsibility and licensed control of AB Svafo. The final disposal campaign was performed in 1999, and the licence to dispose waste expired in 2010.

Operational wastes from nuclear power plants that are disposed of via shallow land burial consist of lightly contaminated scrap and assorted residues from controlled areas within the site, including piping, tools, insulation materials and protective clothing, as well as rubbish in the form of plastics, paper, cables, etc. Wastes are typically packed in half-height ISO containers, which provide a measure of structural strength in construction of the facility or, for disposals around the edges of the waste mound, simply in bales. The dominant radionuclides are generally Co-60, Cs-137 and Ni-63. Licence conditions limit the total activity content of shallow land burial facilities to between 100 and 1100 GBq per burial, with a maximum content of 0.1-0.2 GBq of alpha-emitting radionuclides.

The closed shallow land burial facility on the Studsvik Tech Park differs from the above in terms of the nature of the wastes that it contains, but was subject to the same limit on contamination levels (<300 kBq/kg) for radionuclides with half-lives longer than five years that applied prior to 2010 for all such facilities. It contains very little combustible material and no baled wastes; all wastes are emplaced in metal packages. The dominant radionuclides are H-3, Eu-152 and Cs-137. The total activity limit for the facility was limited to 100 GBq, of which no more than 0.1 GBq alpha-emitting radionuclides.

The detailed design and layout of shallow land burials differ, but all facilities have a top sealing layer to reduce infiltration of water through the wastes. The design of the top

sealing layer differs between the facilities: bentonite liners, plastic membranes and massive layers of glacial clay or mixes of bentonite and sand have been used, as well as designs based on combinations of different features. The infiltration barrier is covered by a drainage layer and, on top of that, a protective layer of e.g. soil, to a depth of approximately 1 metre. At the relatively more recent shallow land burials at Ringhals and Oskarshamn, a geological barrier has been installed down-gradient of the burials. For the burials at Forsmark and on the Studsvik Tech Park, a natural or semi-natural geological barrier reduces leakages to the environment. There are monitoring programmes in place for sampling leachate water, for example with respect to radionuclides. The licence conditions include the requirement for a surveillance period of at least 30 years after final closure.

As noted above, shallow land burial of VLLW from future operations and from the demolition of decommissioned NPPs is planned by the NPP licence holders at Oskarshamn and Ringhals. The possibility of additional shallow land burial of future demolition wastes at Forsmark is also being considered, but not until after 2040. There are currently no similar plans at Barsebäck for shallow land burial of demolition wastes on site as VLLW. However, the potential for disposal of VLLW elsewhere, either within the extension to SFR or at the planned shallow land burial facility on the site of the Oskarhamn NPP, is under consideration [5].

Repository for short-lived low and intermediate level waste (SFR)

The SFR repository is situated beneath the Baltic Sea, covered by about 60 metres of rock beneath the seabed. Parts of the facility were commissioned in 1988. The facility was fully commissioned in 1992 and is operated by SKB.

Two one-kilometre-long access tunnels lead from the harbour in Forsmark to the repository area. The disposal facility itself currently consists of four 160 metre long waste vaults and a 70 metre high cavern in which a concrete silo has been constructed. Wastes are directed to different parts of the facility depending on factors such as activity content and chemical characteristics.

The underlying safety concept is based on: (a) limiting the content of longer-lived radionuclides within the wastes disposed of at the facility (see definition of short-lived waste in Topic 3), and (b) isolation of the wastes in bedrock with low groundwater flow to ensure that any releases to the environment are limited until the inventory has been significantly reduced by radioactive decay.

The different disposal areas within repository are as follows:

- The silo, which is used for those wastes that have the highest activity concentrations among those accepted for disposal (typically ion exchange resins in a cement or bitumen mix from nuclear power plants). It contains the majority (ca. 90%) of the total radioactivity currently disposed of to SFR. The maximum permitted surface dose rate per package is 500 mSv/h and all handling is performed remotely. The dominant radionuclides in terms of radioactivity at the time of disposal are Co-60, Cs-137 and Ni-63.

  The silo consists of a cylindrical concrete construction with shafts for different sizes of waste package. The concrete cylinder is approximately 50 m deep with a

diameter of approximately 30 m. The largest shafts measure 2.5 m by 2.5 m. Waste packages (moulds or drums) are placed in the shafts, normally in layers of four moulds, or 16 drums, and the spaces between the waste packages gradually backfilled with porous concrete. The silo walls consist of 0.8 m thick reinforced concrete, and there is a bentonite backfill, approximately 1.2 m thick, between the walls and the surrounding rock. The 1 m thick concrete floor at the bottom of the silo is placed on a layer of 90:10 sand/bentonite mixture.

- The waste vault for intermediate level waste (1BMA), in which the natural rock barrier is supplemented by a concrete technical barrier, dividing the vault into 15 compartments. The vault is designed to accommodate approximately 6% of the total radioactivity content in SFR, receiving packaged wastes that require remote handling (maximum surface dose rate per package 100 mSv/h), but with generally lower concentrations of activity than those contained in the silo. Wastes disposed of within BMA come from a range of sources; they include ion exchange resins from NPPs with a lower activity content than those disposed of in the silo, as well as a metal components and contaminated trash. The dominant radionuclides are Co-60, Cs-137 and Ni-63.

  Waste packages (moulds or drums) are placed in the concrete-walled compartments using remote equipment. The waste is stacked on top of the concrete floor in such a way that the concrete moulds act as support for prefabricated concrete slabs that are put in position as soon as the compartments are filled. It is also possible to backfill the void between the waste packages in a compartment. However, as this might lead to damage to the concrete barrier due to swelling of the bitumen-conditioned ion exchange resins after resaturation, this is not presently being planned. Finally, a layer of concrete will be cast on top of the lid. The 2 m space between the concrete structure and the rock wall will be filled with sand before closure to provide a permeability contrast with the concrete walls of the vault.

- Two waste vaults (1-2BTF) are designed to receive wastes that have been packaged for disposal in concrete tanks. Wastes in 1BTF consist of drums containing ash from incineration of short-lived combustible wastes as well as concrete tanks containing ion exchange resins and filter parts (from boiling water reactors at Barsebäck and Oskarshamn), whereas 2BTF consists only of the latter. In 1BTF also concrete moulds of the same types as being placed in the silo and 1BMA have been placed, however, with at lower surface dose rate. The maximum surface dose rate permitted on packages is 10 mSv/h. Radionuclide concentrations are relatively low, compared with BMA and the silo, and the dominant nuclides are Co-60 and Cs-137.

  The concrete tanks, each 10 m^3 in volume, are stacked in two levels, with four tanks in each row. A concrete lid is placed on the top of the stacks to provide shielding. The space between the tanks is backfilled with concrete and the space between the tanks and the rock wall will be backfilled before closure.

- The waste vaults for low level waste (1BLA) is designed to accommodate mainly lightly contaminated scrap metal (iron/steel, aluminium), cellulose (e.g. wood, textile, paper, plastics), other organic materials, non-organic materials (e.g. cables) and other waste such as insulation (e.g. rock wool). Some of the waste is

placed in steel drums, other waste types in bales. The wastes are transported to SFR from the waste generators packed in ISO-standard steel containers, which are stacked three high (six high in the case of half-height containers) and in two rows on the concrete floor. The maximum dose rate permitted on the surface of the waste packages is 2 mSv/h. The dominant radionulide is Co-60.

In recent years, measures to minimize water dripping have been improved in the silo, 1BLA and 1BMA by installing a suspended ceiling. These will be dismantled before the repository is closed.

The available disposal capacity within SFR (63 000 m^3 total) is currently approximately two-thirds full. Plans to extend to the facility by a further 117 000 m^3, enabling it to accommodate short-lived wastes from the decommissioning and dismantling of nuclear power plants and other nuclear facilities as well future operational radioactive waste from Swedish nuclear facilities, were approved by the Government in December 2021. Capacity will be increased by excavating additional rock caverns at a depth of approximately 120 m below the sea bed, compared with 60 m for the existing facility.

The extension follows the same safety concept as the existing facility, limiting the quantity of longer-lived radionuclides that may be disposed, as well as being sited within the natural crystalline rock barrier providing an environment that isolates the wastes, limits groundwater flow, and restricts possible releases. The design of the extended facility includes four additional rock caverns analogous to 1BLA, with no engineered barriers, and one vault analogous to 1BMA, albeit with modifications to the design of the concrete barrier. Furthermore, a vault will be constructed to accommodate segmented reactor vessels from the dismantling of boiling water reactors.

Implementation of the licensing process by SSM (according to the Act on Nuclear Activities) and the Land and Environment Court (according to the Environmental Code) is now continuing with a focus on detailed requirements and conditions for the construction and operation of the facility. In March 2022, SKB submitted a request to the Court for a licence to be issued according to the Environmental Code, based on the Government's approval of the project. Hearings were held in late November 2022, and the licence, with conditions relating to (e.g.) noise, transport and releases of non-radioactive substances to water during construction, was granted by the Court later the following month. At the time of writing this report, SKB planned to apply to SSM for permission to start construction of the repository extension during the first quarter of 2023, in accordance with Government conditions on the licence under to the Act on Nuclear Activities. Construction of the extension is estimated to take approximately six years in total; there will be suspension of waste disposals to the existing facility while underground construction work takes place.

Repository for long-lived low and intermediate level waste (SFL)

SFL is a planned geological repository for long-lived low and intermediate level radioactive waste. SKB's development work is primarily conducted on behalf of the licence holders for commercial nuclear power plants. However, SKB has also signed agreements with other waste producers, e.g. licensees on the Studsvik Tech Park, to plan for accommodating their long-lived wastes within SFL. According to SKB's development of an outline concept, the repository will be divided in two separate parts: one part (BHK) for the metallic waste consisting of internal highly activated core components from

boiling water reactors as well as the entire reactor pressure vessels from the pressurized water reactors. The other part of the repository (BHA) is intended mainly for the disposal of legacy wastes.

The volume of waste to be disposed of to SFL will be relatively small compared with that for SKB's other facilities, being estimated at approximately 16 000 m^3, with about one third of the total volume coming from nuclear power plants. The remainder comes from the facilities that are now operated by Studsvik Nuclear AB, Cyclife Sweden AB and AB Svafo, and includes wastes generated or managed by their predecessors on the Studsvik Tech Park. Fees paid to Cyclife Sweden AB for the management of certain long-lived wastes from non-nuclear activities include allowance for the costs of disposal to SFL. Furthermore, an agreement has been signed by SKB and the consortium responsible for the European Spallation Source (ESS) accelerator facility with the objective that SKB should explore possibilities for providing disposal capacity for radioactive waste from the facility. Although the major part of radioactive waste from ESS that needs to be disposed of is expected to be short-lived low and intermediate level waste, and therefore suitable in principle for disposal in SFR, the planned capacity at SFR (even after extension) is limited in terms of volume. The potential need for allocation of capacity within SFL to wastes from ESS is therefore addressed within the agreement.

The siting of the SFL repository and its depth will provide isolation through low permeability and low groundwater flow. SKB's plan is that the two parts of the disposal system will be constructed with different technical barriers. The rock cavern for disposal of metallic waste from decommissioning (BHK) involves the use of concrete as the principal technical barrier, providing low conductivity as well as chemical conditions that contribute to long-term retention of radionuclides through sorption and solubility limitation. The concept for disposal of legacy wastes (BHA) uses bentonite as the principal technical barrier, both as a physical barrier to groundwater flow and as a filter for colloids as well as retention of some radionuclides through sorption.

According to present plans [5] a licence application is planned for the mid-2030s, with operations commencing some 20 years later. Formal waste acceptance criteria for long-lived low and intermediate level wastes will be established in conjunction with an application for permission to take the facility into operation. Nevertheless, work is being undertaken by SKB (as outlined under Topic 5) to establish the requirements for construction, transport, operational handling and long-term safety performance of waste packaged. This is intended to guide planning for conditioning and packaging by those responsible for the wastes. SKB's ongoing development work will also be used to guide the definition of technical requirements related to site selection. Final conditioning of the wastes intended for disposal to SFL should not be undertaken, however, until a verified repository concept exists. If SFR closes before SFL, the SFL repository may be required to accept certain short-lived wastes. This would naturally affect the volume of wastes accepted at SFL.

Repository for spent nuclear fuel

The planned repository for spent nuclear fuel (*Kärnbränsleförvaret*) is based on the KBS-3 concept, a method for disposal in crystalline rock that has been developed over several decades by SKB on behalf of the nuclear power plant licensees, starting with the KBS-3 report in 1983. The design involves encapsulating fuel elements in copper canisters (providing corrosion resistant containment) with ductile case iron inserts (providing

mechanical strength). The canisters are then to be emplaced in individual vertical deposition holes, embedded in bentonite clay (providing protection against rock movements, preventing water penetration, protecting the canister from contact with corrosive agents, and restricting the transport of any release radioactive substances), at a depth of approximately 450 to 500 m in crystalline bedrock. The stability of the bedrock and the location of the deposition holes so as to avoid interaction with water-conducting fractures serves to maintain the performance of the engineered barriers and isolates the spent fuel from humans and the environment.

SKB submitted licence applications for the repository (to be located near to the Forsmark NPP in Östhammar municipality) and the related encapsulation facility at Oskarshamn (see above) according to the Act on Nuclear Activities and the Environmental Code in 2011. The applications were reviewed by SSM and the Land and Environment Court, respectively, and both submitted their findings and recommendations to the Government early 2018. A Government decision to approve SKB's plans for the encapsulation and final disposal of spent fuel according to the KBS-3 method at these locations was made in January 2022.

Implementation of the licensing process by SSM (according to the Act on Nuclear Activities) and the Land and Environment Court (according to the Environmental Code) is now continuing with a focus on detailed requirements and conditions for the construction and operation of the facilities. SKB plans to submit a request to the Court for a licence according to the Environmental Code in the first half of 2023; Court hearings with regard to the formal licensing process and related conditions are expected to take place in 2024. Once the Court proceedings have been completed, SKB will apply to SSM for a permit for starting construction of the repository in accordance with conditions imposed by the Government's licensing decision under the Act on Nuclear Activities. At later stages SKB will then have to apply again to SSM for approval to start trial and routine operations. According to current prognoses, construction of the repository for spent nuclear fuel is planned to start during the second half of the 2020s, and will be in operation (together with the encapsulation plant) during the second half of the 2030s [5].

Research and Development supporting concepts, plans and solutions

The Act on Nuclear Activities [1] requires the utilities that operate nuclear power reactors, in cooperation, to develop and implement the R&D programme needed for the safe management and disposal of spent nuclear fuel and nuclear waste, as well as safe decommissioning and dismantling of nuclear power plants (see also Topic 1). Since 1992 this been denoted as the programme for Research, Development and Demonstration, the RD&D programme. Every three years, on the behalf of the operators, Swedish Nuclear Fuel and Waste Management Company (SKB) submits a report on this programme to the regulatory authority for review.

SSM invites a large number of interested parties to comment on the report. The report [5] must include an overview of all measures that may be necessary to ensure safe management of nuclear wastes of and must specify the actions planned to be taken within a period of at least six years. Based on SSM's review recommendations, the Government approves or rejects the general direction of the continued programme. In connection with the decision, the Government may also issue conditions on the content of future research and development work.

An important goal of the programme was fulfilled when applications for licences to construct and operate an encapsulation plant and a disposal facility for spent nuclear fuel were submitted to SSM and the Land and Environment Court on 16 March 2011. As described above, the Government approved the application in January 2022 and implementation of the licensing process by SSM and the Land and Environment Court is now continuing with a focus on detailed requirements and conditions. A remaining important task is the development work related to the siting and assessment of the remaining repository for long lived LILW, SFL.

A significant component of the research and development work has been conducted at the Canister Laboratory and the Äspö hard rock laboratory (HRL). Adjacent to the Äspö HRL are also the Water Chemistry Laboratory, the Materials Research Laboratory and the Multi-purpose Test Facility. All laboratories are located in Oskarshamn municipality. At those laboratories, it is possible to test and demonstrate the technology in full scale and in a realistic environment.

Äspö Hard Rock Laboratory

The underground Äspö HRL is situated to the north of Oskarshamn's nuclear power plant. It consists of a tunnel and a shaft leading from the Simpevarp peninsula where the Oskarshamn nuclear power plant is located, to the southern part of Äspö down to a depth of 460 meters. The various experiments are performed in niches in the short tunnels that branch out from the main tunnel. The laboratory has mainly been used to investigate in a field environment how the key engineered components of the final repository for spent nuclear fuel (canister, buffer, backfill, tunnel seals) as well as the surrounding rock work together and meet requirements for containment and isolation. The experiments and tests in the underground part of the Äspö HRL will be completed in 2024 and the facility will then be closed. Any further tests related to the Spent Fuel Repository will be conducted at the site in Forsmark.

The Canister Laboratory

The Canister Laboratory (*Kapsellaboratoriet*), located in the port area of Oskarshamn, is mainly used for development activities relating to the construction, design and testing of the copper canisters. It has developed equipment for welding of copper lids and bottoms as well as for non-destructive testing of welds and of different parts of the canister that are developed there. Equipment and systems for handling spent nuclear fuel are also tested and developed in the laboratory.

Multi-purpose Test Facility, the Water Chemistry Laboratory and the Materials Research Laboratory

The Multi-purpose Test Facility (formerly called the Bentonite Laboratory) was established in 2007 and is adjacent to the Äspö HRL. One of the barriers in all final repositories is bentonite. In the repository for spent nuclear fuel, the copper canister is surrounded by highly compacted bentonite. Bentonite also surrounds the silo in SFR and is planned as a barrier in SFL. Bentonite will also be used for backfilling the tunnels in the repository for spent nuclear fuel. In the Multi-purpose Test Facility, SKB conducts

surveys of the properties of bentonite, among other things by simulating different water conditions in a controlled manner. Methods are also being developed there to fill in the repository's tunnels with backfill material and to build plugs to close the deposition tunnels.

Adjacent to the Äspö HRL are also the Water Chemistry Laboratory and the Materials Research Laboratory. The Water Chemistry Laboratory is accredited to analyze the chemical components in groundwater that are of particular importance for the function of the repository after closure. The activities in the Materials Research Laboratory focus on research on the physical and chemical properties of clay materials, mainly with regard to issues that are important for ongoing and future safety analyses.

International collaboration

SKB has extensive technical cooperation with corresponding organizations in many countries. SKB also participates in several committees within the IAEA, the EU and NEA and in a large number of research projects within these organizations. The collaboration with Posiva in Finland is the most developed and includes projects in repository and encapsulation technology as well as machine development and site investigation methodology.

In 2009, on SKB's initiative, the technology platform “Implementing Geological Disposal of Radioactive Waste Technology Platform” (IGD-TP) was formed within the framework of the EU research programme with the aim of contributing to the planning and coordination of the programme’s nuclear waste research. The platform’s vision is for the first European geological repository (in Finland) to be put into operation by 2025. SKB, together with representatives of eleven other European nuclear waste management organisations, is part of the platform’s steering group. In total, about 130 universities, colleges, research institutes and consulting companies participate in IGD-TP.

Topic 5: Safety demonstration of radioactive waste and spent fuel management activities and facilities

The safety case concept in the Swedish regulatory context

The focus and objectives for evaluating the long-term protective capacity and post-closure safety of final disposal facilities have been developed both internationally and in Sweden over several decades. Internationally, the term "safety case" is used to describe the most important arguments in support of e.g. disposal facility's protective capacity. It typically summarises results from the safety assessment, including demonstration of compliance. The safety case may also take into account supporting arguments, other information that supports the demonstration of protective capacity and other aspects invoked in support of a specific purpose in the establishment of a repository. It has, however, been noted (for example in the context of the OECD-NEA's Project on Methods for Safety Asessment of Geological Disposal Facilities for Radioactive Waste (MeSA)) that terminology and definitions, such as safety case, safety assessment and performance assessment, differ to some extent between countries. In many cases, the safety case is linked to the specific purpose of demonstrating protective capacity at a specific time in the development program of a repository.

The IAEA definition of the safety case for disposal of radioactive waste (e.g. Section 4 of IAEA SSG 23) encompasses the following components in a hierarchical manner:

- Safety strategy
- System description
- Safety assessment
- Limits, controls and conditions
- Integration of safety arguments

Management of uncertainty as well as iteration and design optimisation are aspects that need to be addressed in all aforementioned components. A management system should be applied throughout the safety case components, as should the involvement of the regulator and other interested parties.

In Swedish legislation and in SSM's regulations, however, there are no specific requirements linked directly to the reporting of a safety case *per se*. Instead, the various aspects of reporting associated with the development and maintenance of a safety case correspond to regulations on evaluation and analyses of the protective capability of the repository system. In the case of geological disposal facilities, for example, it is stated that the arguments for the protective capability of a repository should be evaluated and reported on in a systematic way. The reporting should include a logically structured argument for the protective capability of the repository with information on calculated risks, uncertainties in the calculations made and the credibility of the assumptions made.

To provide a good understanding of the results of the risk analysis, it should be evident how individual scenarios contribute to the level of risk posed by the repository.

The safety philosophy applied in the design of all Swedish nuclear facilities is based on the principles of defence in depth and of using multiple barriers to prevent the unplanned release of radioactive material to the environment. The safety strategy employed for different facilities reflects the overall obligations on licence holders regarding responsibility for and management of safety, as defined in section 10 of the Act on Nuclear Activities [1] and more detailed requirements in SSM's regulatory provisions. In the case of geological disposal facilities, for example, SSM's regulations (SSMFS 2008:21 and SSMFS 2008:37) stipulate passive safety, geological isolation and a multi-barrier concept as key elements of the general strategy. Deployment of these elements of a safety strategy should be applied using a graded approach, taking account of the nature of the hazards involved.

Requirements for safety assessment, safety review and reporting are specified in SSM's regulations concerning safety in nuclear facilities [21] (SSMFS 2008:1)[12]. With the exception of shallow land burial facilities for very low-level waste, which are regulated mainly on the basis of licence conditions stipulated for their operation and closure, these provisions apply to the operation of all types of nuclear installations other than nuclear power plants in operation, including facilities for treatment, storage and disposal of spent fuel and radioactive waste. Key elements of these provisions (Chapter 4 of SSMFS 2008:1) include:

- Safety analysis. Analyses of conditions of importance for the safety of a facility shall be carried out before a facility is constructed and taken into operation. The analysis shall subsequently be kept up-to-date. The safety analyses shall be based on a systematic inventory of such events, event sequences and conditions that could lead to a radiological accident.

  System descriptions, limits, controls and conditions are identified components of safety analysis for all facilities. For geological disposal facilities more specific requirements and expectations with regards to safety assessment are defined (SSMFS 2008:21, SSMFS 2008:37), see below. Management of uncertainty is an integral part of the safety assessment and SSM's regulations define requirements in general for all types of installation (chapter 4, SSMFS 2008:1) as well as more specifically for disposal facilities (SSMFS 2008:21).

  Design optimization is achieved either through iteration schemes in which the safety assessment is regularly updated, or through feedback from the regulator and other stakeholders in different steps of the pre-licensing, licensing or post-licensing phases.

- Safety report. According to section 5 b the Act on Nuclear Activities [1], a licence application shall include a description of how the general rules of consideration according to section 2 in the Environmental Code [3] have been

[12] SSM's code of statues is currently being restructured and modernised with the aim of clarifying and improving support for the implementation of regulations and thereby creating greater predictability for licensees. A new set of regulations for NPPs came into force on 1 March 2022, which removed nuclear power plants from the coverage of general requirements regarding the safety of nuclear installations within SSMFS 2008:1. Separate, parallel regulations are also being developed for "other nuclear facilities" and for geological disposal facilities, following the same underlying structure as those for NPPs. When these are completed and taken into force (target date 2025), the existing general regulations on safety within SSMFS 2008:1, as well as those specific to facilities for final disposal facilities (SSMFS 2008:21 and SSMFS 2008:37) will cease to apply.

applied. Among these general rules of consideration, the Environmental Code, which applies to both nuclear and non-nuclear activities, stipulates the use of best available technique.

Furthermore, according to section 5 c the Act on Nuclear Activities, a licence application shall include an environmental impact assessment in which the impact on human health and the environment have been assessed. SSM's expectations with regards to the analysis of the radiation safety in the licensing process are outlined in SSM's management system (steering document STYR2011-131), where the required demonstration supporting the licence application are clarified and described within a first preliminary safety report (F-PSAR). This safety report needs to include sufficient information for SSM to be able to assess whether the facility can be constructed and associated activities can be performed so that the regulatory requirements can be expected to be fulfilled. This steering document regarding authorisation of nuclear facilities is currently being updated.

After a licence according to the Act on Nuclear Activities has been granted, a preliminary safety report (PSAR) shall be prepared before construction of the facility is allowed to begin, within the aim of showing how relevant safety requirements will be met. The safety report (SAR) shall subsequently be updated to reflect the facility as it has been constructed, analysed and verified before trial operation of the facility is allowed to start. The SAR and associated documentation of operational limits and conditions for the facility must subsequently be supplemented on the basis of experience from a program of commissioning tests before the facility is allowed to be taken into routine operation. At each of the above steps, the safety report shall be evaluated and approved by SSM.

The safety report must subsequently be kept up to date. For example, modifications are to be assessed against conditions described in the SAR. Plans for substantial changes must be reflected in a new PSAR, which must be approved by SSM before being used as the basis for the implementation of changes as well as the basis for trial operation of the modified facility. New safety standards and practices, which have been assessed by the licensee and found applicable, shall be documented and inserted into the SAR as soon as corresponding modifications or other plant measures have been performed.

The content overall of the safety report for a nuclear facility is specified in the regulations SSMFS 2008:1, with additional requirements related to the SAR for geological disposal facilities defined in SSMFS 2008:21. Not only the safety systems, but all plant structures, systems and components of importance for the defence in depth are to be described in the SAR.

- Safety review. The purpose of safety review is to confirm that all applicable safety-related aspects of a specific issue have been taken into account and that appropriate regulatory requirements are met with regard to the safety in design, function, organization and operation of a facility. The review must be carried out systematically and be documented. A primary safety review is to be performed first within those parts of the organization responsible for the specific issues under consideration. A second, independent safety review shall then be performed by a separate internal function established for this purpose within the

licensee organisation, separate from those parts of the organisation responsible for design and operation.

- Safety programme. After a facility has been taken into operation, its safety shall be continuously analysed and assessed in a systematic manner. Any need for improvement regarding safety measures, engineering or organizational issues that arises as a result of such analyses and assessments shall be documented in a safety programme. The safety program must be updated on an annual basis.

- Periodic safety review of facilities. According to section 10 a of the Act on Nuclear Activities [1], licensees are required at least once every ten years to undertake a new systematic, integrated analysis and assessment of radiation safety within the facility. The periodic safety review should also address how the requirements according to the Act on Nuclear Activities, the Radiation Protection Act [2] and the Environmental Code [3], together with any relevant decisions and licensing conditions issued within the framework of this legislation, are complied with. The licensees should also evaluate how radiation safety can be maintained and strengthened until the next periodic safety review. For the SFR-repository, additional requirements regarding to periodic safety review have been issued by SSM as licence conditions.

- Modifications. A safety review shall be performed for any engineering or organizational modifications to a facility that can affect the conditions specified in the safety report, and essential changes to the report made accordingly. SSM shall be notified of planned modifications before they may be applied. SSM has the power to determine that additional or other requirements or conditions shall apply with respect to the modifications, and may prevent modifications from being implemented until it has conducted its own review.

- Post-closure safety of disposal facilities. Additional specific requirements relating to the long-term radiation protection and nuclear safety of a geological disposal facility are stipulated in the SSM's regulations concerning safety in connection with the disposal of nuclear material and nuclear waste (SSMFS 2008:21). Further regulatory provisions and general advice are also provided regarding the protection of human health and the environment in connection with the final management of spent nuclear fuel and nuclear waste (SSMFS 2008:37).

  The regulations SSMFS 2008:21 specify general requirements for the design of the repository and its barrier functions, as well as the analysis and reporting of safety. Safety after the final closure of a repository shall be maintained through a system of passive barriers, each of which should work, in one or more ways, to contain, prevent or delay the dispersal of radioactive material, either directly or indirectly through protecting other barriers in the disposal system. The barrier system should be durable against the conditions, events and processes that may affect the function of individual barriers and should be designed and implemented with regard to the implementation Best Available Technique.

  The safety assessment for a disposal facility shall address all features, events and processes that might lead to the dispersion of radioactive substances after closure. Such safety assessments are required as a basis for applications for construction, operation and closure of the disposal facility. The post-closure safety assessment should cover the length of time for which barrier functions of the disposal system

are required to manage the hazard associated with the wastes, though at least ten thousand years.

The regulations SSMFS 2008:37 comprise basic requirements for protection of human health (expressed as a risk target), general environmental protection goals, and issues relating to access and inadvertent human intrusion as well as the reporting for different time periods post closure. The corresponding guidance advises on the application of optimization and Best Available Technique, as well as a range of issues relating to the assessment and reporting of risk for comparison with the risk target.

In 2020, the Act on Nuclear Activities [1] was amended with the aim of clarifying overall requirements in relation to the final closure of a geological repository. Related amendments were also made in the Environmental Code. Closure requires a permit from the Government, for which an important basis will be a renewed analysis of the post-closure safety for the completed repository. When the licence holder has demonstrated that the closure has been undertaken in accordance with requirements and any conditions specified in the Government's permit, responsibility for the repository and its contents will transferred from the licensee to the State.

Status of safety cases for facilities for conditioning and treatment of radioactive waste

Radioactive waste management facilities at nuclear power plants

The operation of waste treatment facilities on nuclear power plant sites is fully integrated with the operation of the NPP. The safety procedures and safety documentation for these facilities constitute integrated parts of the safety procedures and safety documentation for the NPP. The safety documentation describes the facility and the waste handling activities, the content of radioactive substances, supervisory activities, as well as safety analyses.

Radioactive waste management facilities on the Studsvik Tech Park

Relevant facilities on the Studsvik Tech Park include (see Topic 4):

- The Hot Cell Laboratory (HCL) operated by Studsvik Nuclear AB
- The Active Metal Laboratory (AKL) operated by Studsvik Nuclear AB
- The Incineration and Pyrolysis facility (HA) operated by Cyclife Sweden AB
- The Metals Treatment facility (SMA) operated by Cyclife Sweden AB
- Conditioning and packaging facilities for disused sealed sources and other wastes from medical use, research and industry (FR0-A and R0-A) operated by Cyclife Sweden AB
- Treatment facility for intermediate level solid and liquid wastes (HM) operated by AB Svafo

Operation of radioactive waste management facilities are subject to the regulatory provisions outlined above, which require a safety analysis and safety report to be developed and subject to independent safety review within the licensee organisation. The facilities are subject to a safety programme and to periodic safety review as part of the

overall operations of the licensee, and are operated in accordance with authorised operational and limits and conditions.

Status of safety cases for interim storage facilities

Spent nuclear fuel storage and planned encapsulation

Prior to transportation to the central interim storage facility, spent nuclear fuel from nuclear power reactors is temporarily stored in pools at the reactor site, for a period of at least nine months. Safety cases for the fuel pools are fully integrated with the operation of the NPP. The safety procedures and safety documentation for these facilities constitute integrated parts of the safety procedures and safety documentation for the NPP.

The Clab facility, situated adjacent to the Oskarshamn NPP site, has been in operation in accordance with prescribed safety procedures and safety documentation since 1985. SKB is and has always been the licence holder, but operation until January 2007 was undertaken by the power plant operator. Following the submission in 2011 of SKB's licence application under the Act on Nuclear Activities for an encapsulation plant to be co-located with Clab, SSM identified areas of improvement relevant to the safety analysis report for Clab. SSM subsequently (2013) issued an improvement notice to SKB to update the safety analysis report for Clab in areas relating to safety requirements, safety analysis and safety classification. SKB has since modernized the safety analysis report for Clab in several steps between 2016 and 2020.

An updated safety analysis in support of the licence application for the combined encapsulation plant and storage facility was submitted by SKB in January 2015, in response to SSM's request for an improved system description and correspondingly updated first preliminary safety analysis report (F-PSAR). The scope of the safety analysis was also expanded by SKB to account for the safety implications of increasing the licensed interim storage capacity in the existing storage pools of Clab from 8 000 to 11 000 tonnes of spent fuel. Updating the supporting materials to the licence application under the Act on Nuclear Activities also led to supplementation of the EIA in support of the licence application under the Environmental Code. The F-PSAR describes how it is intended that radiation safety in Clink will be maintained in the combined facility with storage of up to 11 000 tonnes fuel.

Following SSM's and the Land and Environment Court's statements to the Government in respect of SKB's licence applications in January 2018, the question of increased storage capacity at Clab remained an integral part of the licence application for Clink until June 2021, when the Government sought consultation comments on the procedure of separating the two issues. SSM noted in its consultation statement that the Authority did not see any legal obstacles to such a separation, but identified potential complications as well as challenges regarding acceptance by some stakeholders unless decisions on applications as a whole were kept together. The Government decided in August 2021 to separate the processing of SKB's applications and to grant permission to extend the storage capacity at Clab.

In accordance with licence conditions attached to the Government approval for interim storage of up to 11 000 tonnes of spent nuclear fuel in Clab, SKB submitted a PSAR to SSM for approval in December 2021. However, the plant design reported in this PSAR differed in some key aspects from that in the safety analysis from 2015 that supported

SKB's licence application for the combined facility Clink. For example, SKB indicated that diversified safety systems relating to cooling the fuel pools, as well as the improved safety system regarding make-up water, would not be constructed as described in the original licence application. Based on the lack of justification for such divergence from the previously approved plans, as well as some other aspects of the safety analysis report, SSM rejected SKB's application for approval of the PSAR. A revised application for consent to implement modifications within Clab, including a new PSAR addressing safety improvements at the facility aimed at enabling safe storage within the existing pools of up to 11 000 tonnes spent nuclear fuel, was submitted to SSM at the end of 2022.

A Government decision to approve SKB's plans for the encapsulation and final disposal of spent fuel was made in January 2022. Implementation of the licensing process by SSM (according to the Act on Nuclear Activities) and the Land and Environment Court (according to the Environmental Code) is now continuing, with a focus on detailed requirements and conditions for the construction and operation of Clink. SKB plans to submit an application to the Court in the first half of 2023 and the Court hearings with regard to the formal licensing process and related conditions are expected to take place in 2024. Sometime after the Court proceedings have been completed, SKB will apply to SSM for a permit to start construction of the encapsulation facility in accordance with conditions imposed by the Government's licensing decision under the Act on Nuclear Activities, based on a PSAR for the combined facility, Clink.

Radioactive waste storage facilities at nuclear power plants

Arrangements for waste storage at nuclear power plant sites are generally fully integrated with reactor operations. The safety procedures and safety documentation for these facilities constitutes integrated parts of the safety procedures and safety documentation for the NPPs.

As noted above (Topic 4), the Oskarshamn NPP is the site of a storage facility for non-combustible low and intermediate level waste, located in a rock cavern (BFA), which is subject to separate specific licence conditions. This is because the scope of the facility's licence includes core components from all Swedish nuclear power plants, as well as operational wastes from the adjacent central interim storage facility for spent nuclear fuel, Clab. The nuclear facility licence for the BFA is somewhat unusual for Sweden inasmuch as it (like those for shallow land burial facilities) is time-limited.

Radioactive waste storage facilities on the Studsvik Tech Park

Storage facilities on the Studsvik Tech Park include (see Topic 4):

- The rock cavern storage facility (AM) for long-lived low and intermediate level wastes, operated by AB Svafo.
- Above ground interim storage facilities for conditioned long-lived legacy wastes and decommissioning wastes (AU and AUA) operated by AB Svafo.

Operation of interim storage facilities are subject to the regulatory provisions outlined above, which require a safety analysis and safety report to be developed and subject to independent safety review within the licensee organisation. The facilities are subject to a safety programme and to periodic safety review as part of the overall operations of the

licensee, and are operated in accordance with authorised operational and limits and conditions.

Status of safety cases for geological disposal facilities

Repository for spent nuclear fuel

Safety concept

As discussed under Topic 4, the planned repository for spent nuclear fuel (*Kärnbränsleförvaret*), located near to the Forsmark NPP in Östhammar municipality, is based on the KBS-3 concept, a method for disposal in crystalline rock that has been developed over several decades by SKB on behalf of the nuclear power plant licensees. The design involves encapsulating fuel elements in copper canisters (providing corrosion resistant containment) with ductile case iron inserts (providing mechanical strength). The canisters are then to be emplaced in individual vertical deposition holes, embedded in bentonite clay (providing protection against rock movements, preventing water penetration, protecting the canister from contact with corrosive agents, and restricting the transport of any release radioactive substances), at a depth of approximately 450 to 500 m in crystalline bedrock. The stability of the bedrock and the location of the deposition holes so as to avoid interaction with water-conducting fractures serves to maintain the performance of the engineered barriers and isolates the spent fuel from humans and the environment.

Licence applications for the spent nuclear fuel repository and the related encapsulation facility, adjacent to the Clab interim storage facility at Oskarshamn, were developed against the background of SKB's research, development and demonstration programme. A series of pre-licensing preparatory safety analyses relating to the KBS-3 disposal concept were carried out within the framework of this programme, with the aim of supporting technical development of the concept as well as guiding site selection. The series began with the KBS-3 report in 1983 (the first complete safety analysis of the KBS-3 method), followed by SKB-91 (focusing on requirements for the technical barriers), SR-95 (focusing on development of the safety assessment methodology) and SR-97 (aimed at providing a basis for site selection, as well as guiding the program for site-characterisation and development of technical barriers). Finally, the SR-Can safety analysis in 2006 was intended as a 'dress rehearsal' for development of the safety analysis (SR-Site) that supported SKB's licence application for the spent nuclear fuel repository.

These iterations of safety analysis have had multiple roles in building expertise, informing both concept development and site selection, improving the assessment methodology, and supporting the identification of areas requiring further research. Reviews of these assessments by SSM and its predecessors within the framework of regulatory review of the RD&D programme also provided opportunities during pre-licensing for the regulator to become familiar with key safety issues and to provide feedback to SKB on issues relevant to fulfilling regulatory requirements.

Status of safety assessment

SKB submitted licence applications for the repository at Forsmark in Östhammar municipality and related encapsulation facility in Oskarshamn municipality according to both the Act on Nuclear Activities (two separate facility licences) and the Environmental Code (one licence for the disposal system as a whole) in 2011. The applications were

reviewed by SSM and the Land and Environment Court, respectively, and both submitted their findings and recommendations to the Government early 2018.

The licence application for the repository for spent nuclear fuel, submitted in 2011, was supported by the safety assessment SR-Site, together with extensive background documentation. Additional in-depth assessments and analyses relating to a wide range of different aspects of the safety assessment SR-Site, based on SKB's reference design for implementation of the KBS-3 disposal method at Forsmark, were reported between 2013 and 2015 during the regulatory review of the licence application, in response to requests for supplementary information from SSM. SKB also submitted in April 2019 as part of the licensing process, at the Government's request following the submission of SSM's and the Land and Environment Court's findings, results from additional theoretical and experimental studies relating to potential copper corrosion mechanisms, together with an updated analysis of their implications for radiation safety (SKB TR-19-15).

This later supplement to the licence application was partly in response to the Land and Environment Court's conclusion that a decision regarding the permissibility of the disposal concept in accordance with the provisions of the Environmental Code required further information in order to clarify the long-term protective function of the copper canisters in the KBS-3 disposal concept. From SKB's perspective, such work had already been planned as part of the updated supporting material for next update of the safety analysis, to be submitted to SSM as part of an application to commence construction of the repository, once a licence had been granted. The central conclusions of SKB's safety analysis, that a KBS-3 repository can be constructed and safely operated at the Forsmark site in compliance with regulatory requirements for long-term radiation protection and safety, remained unaltered and were confirmed by SSM in its review of the supplementary material provided to the Government.

In September 2021, the Government sent a further consultation request to bodies including the SSM. The purpose was to obtain comments, partly on two recently conducted studies by independent researchers relating to the structural materials of the copper canister (copper and nodular iron), and partly on those stages in the so-called LOT experiment that SKB had completed in 2019. The LOT experiment (LOT: Long-term test of buffer material) is a series of long-term field tests conducted by SKB in the Äspö Hard Rock Laboratory near Oskarshamn, for the purpose of evaluating the initial development of bentonite clay, and to some extent also copper, after repository closure.

The Government wished to obtain guidance on whether the findings in the two research studies had any significance for SKB's safety case and therefore for the Government's decision on SKB's licence application. In addition, the Government wished to know if additional information gained from the recently completed stages of the LOT experiment changed the perspective on canister integrity that SKB had put forward in its safety case. SSM's assessment was that the two research studies essentially relate to aspects of the protective capabilities of the copper canister that had already been addressed by SKB and previously examined in the regulatory review, and hence that the studies do not affect the previous judgement that SKB's repository concept has the potential to comply with regulatory requirements. Based on SSM's review of SKB's quality management in connection with the LOT experiment, together with the findings of the recently completed stages, it was concluded that the results did not motivate any requirement to update SKB's safety analysis in order to support a licensing decision.

On 27 January 2022, the Swedish Government issued a licence according to Act on Nuclear Activities to construct, possess and operate a geological disposal facility for spent nuclear fuel and to construct, possess and operate a facility for encapsulating the spent nuclear fuel, adjacent to the existing interim storage facility. The Government the same day decided that the final disposal facility for spent nuclear fuel and encapsulation facility were permissible according to the Environmental Code. The licences under the Act on Nuclear Activities include as a licence condition the requirement that SSM shall conduct a continued, step-wise review process prior to the facilities are being constructed, taken into trial and routine operation.

SKB plans to submit a request to the Court for a licence according to the Environmental Code in the first half of 2023; Court hearings with regard to the formal licensing process and related conditions are expected to take place in 2024. Once the Court proceedings have been completed, SKB will apply to SSM for a permit to start construction of the repository in accordance with conditions imposed by the Government's licensing decision under the Act on Nuclear Activities. This application will be supported by a new safety analysis reflecting SKB's more recent development of the reference design to describe in more detail the planned construction. According to current prognoses, construction of the repository for spent nuclear fuel is planned to start during the second half of the 2020s, and will be in operation (together with the encapsulation plant), following further updates of the safety analysis, during the second half of the 2030s [5].

Repository for short-lived low and intermediate level waste (SFR)

Safety concept

SFR is a repository for short-lived low and intermediate level waste and is based on two primary safety principles:

a) limiting the content of longer-lived radionuclides within the wastes disposed of at the facility (see definition of short-lived waste in Topic 3); and
b) isolation of the wastes in bedrock with low groundwater flow to ensure that radionuclides are retrain and any releases to the environment are restricted until the inventory has been significantly reduced by radioactive decay.

The present facility consists of four 160-metre long waste vaults and a 50-metre deep concrete silo and is situated at a depth of 60 meters below the bottom of the Baltic Sea. The barrier system is adapted using a graded approach to the radiological properties of the waste, where the most radioactive waste is deposited in the silo, which has a bentonite barrier and a concrete barrier. Intermediate level waste is also deposited in the 1BMA vault, which apart from the natural rock barrier is constructed with a technical concrete barrier. Some low- and intermediate level waste is deposited either in 1-2BTF vaults (mainly in concrete tanks or steel drums containing ashes). In the 1BLA vault (regular ISO-containers) LLW is deposited.

The planned extension of the facility, which obtained a licence from the Swedish Government in late 2021, will follow the same safety concept, but is to be constructed at a greater depth, 120 m, below the bottom of the Baltic Sea. Four analogous rock caverns to 1BLA, identified as 2-5BLA, will be constructed with the natural rock barrier as the only barrier for retention of radionuclides in LLW, and one waste vault analogous to 1BMA, identified as 2BMA, will be constructed, although not using reinforced concrete in the technical concrete barrier, to accommodate ILW from decommissioning. A further

simple vault, 1BRT, for the disposal of segmented reactor vessels from boiling water reactors, will also be constructed.

For all repository waste vaults, both existing and planned, the crystalline bedrock contributes to isolate the deposited waste through retention of radionuclides. This is primarily achieved through the relatively low groundwater flow in the bedrock beneath the Baltic Sea as well as the chemically reducing conditions that are expected to be achieved in the repository environment post-closure. The natural rock barrier is essentially common to both the existing facility and the planned extension, although it differs in some respects as the planned extension is to be built at a greater depth.

The location under the seabed contributes to the long-term protective capacity of the repository. In addition to maintaining a low hydraulic gradient, thereby contributing to the low rate of groundwater flow through the repository, it also significantly limits the risk of inadvertent intrusion (for example by well drilling) until – after some 1000 years – the seabed is expected to be exposed as a result of isostatic land rise.

The long-term protective capacity of SFR, as well as the planned extension, is maintained by a barrier system where the number of barriers and their function has been adapted to the content of radionuclides within the wastes and other properties. The technical barriers (concrete and bentonite), the grout infill applied to create a disposal monolith in some disposal vaults, and to some extent the wastes themselves and their containers, contribute to the long-term protective capacity, partly by upholding a chemical environment that contributes to reducing radionuclide mobility, and partly by maintaining a low groundwater flow through the repository near-field.

Status of safety assessment

In 2014, SKB submitted licence applications according to the Environmental Code and the Act on Nuclear Activities relating to construction of the planned extension to SFR. The licence application under the Act on Nuclear Activities included a systematic and comprehensive preliminary safety assessment (given the name SR-PSU) relating to the design, operation and post-closure radiation safety of the facility as a whole. The licence applications were reviewed by the Land and Environment Court and SSM, respectively. In 2019, the Court and SSM submitted their findings and recommendations to the Government. Both the Court and SSM recommended the Government to approve the applications.

On 22 December 2021, the Swedish Government decided to grant a licence under the Act on Nuclear Activities and permissibility under the Environmental Code for the extension and continued operation of SFR. The licence under the Act on Nuclear Activities contains conditions for a step-wise process for the construction and test operation of the extension, and for routine operation of the integrated facility. This means that before each step, SKB must submit a safety report, which must be reviewed and approved by SSM before the step may commence.

Implementation of the licensing process by SSM (according to the Act on Nuclear Activities) and the Land and Environment Court (according to the Environmental Code) is now continuing with a focus on detailed requirements and conditions for the construction and operation of the facility. In March 2022, SKB submitted a request to the Court for a licence to be issued according to the Environmental Code, based on the Government’s approval of the project. Hearings were held in late November 2022, and

the licence, with conditions relating to (e.g.) noise, transport and releases of non-radioactive substances to water during construction, was granted by the Court later the following month.

SKB intends to apply to SSM for permission to start construction towards the end of the first quarter of 2023. According to SKB's current plans, construction will commence in the second half of 2024, provided that the Court's and SSM's decisions are positive. In preparation for this, the safety analysis that supported SKB's licence application has been updated with more detailed information of SKB's plans, and to take into account SSM's comments and expectations from the previous review stage, so that it can be submitted as a PSAR for regulatory approval prior to starting construction of the facility. Subsequently, after construction of the extension is complete, an updated safety analysis report will prepared to reflect the as-built facility and submitted for regulatory review prior to trial operation. At this point, the existing safety analysis report that underpins the operation of the existing disposal facility for short-lived operational LILW will be replaced by the updated safety analysis report describing trial operation of the extended facility. Before the extended facility is allowed to begin routine operation, the safety analysis report must be supplemented with experience gained from trial operation.

The approved safety case for SFR and its extension does not account for the presence of known quantities of non-conforming waste sent from the Studsvik site, which were accepted for disposal within the 1BLA waste cavern between 1994 and 2005. These waste consignments are not thoroughly characterised but are thought to include significant quantities of certain long-lived radionuclides, including Ra-226 sources from previous military use (night aiming devices) as well as a potential inventory of Pu-239/240, which contribute to very high calculated conditional doses in the event of human intrusion. SSM has required as part of its regulatory oversight that these consignments be retrieved and removed before waste is emplaced in the planned extension to the facility. Interim storage, characterisation and potential reconditioning of the retrieved waste packages will be required before they can be accepted for disposal, most likely at the SFL repository. At the time of preparing this report, SKB had appealed SSM's improvement order, citing challenges beyond the company's control with regard to implementing routes for receiving and handling the retrieved wastes. The Government and the Administrative Court will now handle the issue.

Repository for long-lived low and intermediate level waste (SFL)

Safety concept

SFL is a planned geological repository for long-lived low and intermediate level radioactive waste. According to SKB's development of an outline concept, undertaken on behalf of the licence holders for commercial nuclear power plants, the repository will be divided in two separate parts: one part (BHK) for the metallic waste consisting of internal highly activated core components from boiling water reactors as well as the entire reactor pressure vessels from the pressurized water reactors. The other part of the repository (BHA) is intended mainly for the disposal of legacy wastes.

The siting of the repository and its depth will provide isolation of the wastes in host rock with low groundwater flow. SKB's plan is that the two parts of the disposal system will be constructed with different technical barriers. The rock cavern for disposal of metallic waste from decommissioning (BHK) involves the use of concrete as the principal technical barrier, providing low conductivity as well as chemical conditions (high pH and

low redox potential) that contribute to long-term retention of radionuclides through sorption and solubility limitation. The concept for disposal of legacy wastes (BHA) uses bentonite as the principal technical barrier, both as a low permeability physical barrier to groundwater flow and as a filter for colloids as well as retention of some radionuclides through sorption.

Status of safety assessment

It was originally planned that a geological repository for long-lived LILW would be constructed as a part of that developed for spent nuclear fuel. Alongside the SR-97 safety assessment for the spent nuclear fuel repository that was presented in 1999 to support the subsequent site selection programme, SKB also developed a first assessment for the SFL-repository. At this time, the SFL-repository consisted of two separate parts, both with concrete engineered barriers, in which the reactor internals and the legacy wastes would be disposed. The conceptual design was based on the principle that the engineered barriers would constitute a hydraulic cage. In addition to these two parts, waste from the decommissioning of Clab and other similar waste was planned to be disposed of in a separate part of the repository.

Reviews of this assessment for SFL conducted by the then radiation safety authorities, as well as a separate international review conducted by a review team selected by the NEA identified a number of shortcomings. In particular, it was noted that Features, Events and Processes relating to the disposal system itself (i.e. internal FEPs such as significant cracking or degradation of concrete structures) or those relating to its environment (i.e. external FEPs such as the impact of climate change and glaciations) had not been sufficiently treated. Because consideration must be given to possible internal and external FEPs in the selection of a repository design as well as in identifying the desired properties of the location where is should be situated, the authorities concluded that the analysis did not provide sufficiently clear guidance in the pursuit of these goals.

SKB subsequently decided (around year 2000) to continue the development of SFL as a separate repository, rather than as part of the spent fuel repository. The disposal concepts for SFL and the spent fuel repository are different and have reached quite different levels of technical readiness (SFL is still largely at a conceptual level). Furthermore, SFL is needed much later than the spent fuel repository partly because it will need to accommodate waste from last reactors to be decommissioned.

In 2013, SKB presented an options study of different strategies intended to guide the evaluation and selection of repository concepts for further assessment. This subsequently led to the publishing in 2019 of a new safety evaluation report, known as SE-SFL[13]. SKB emphasised that evaluation approach used in SE-SFL was not intended to provide a comprehensive safety report demonstrating compliance with regulatory requirements, but rather an evaluation with the aim of guiding the continued development of SFL in terms of site selection, the development of technical barriers and to provide a basis for developing waste acceptance criteria. Hence results of the safety evaluation have been used to identify priority areas where the level of knowledge level needs to be raised and the disposal concept further developed to support a comprehensive safety report for SFL demonstrating compliance with regulatory requirements, as well as the development of provisional acceptance criteria for the wastes intended for disposal in the repository.

[13] SKB Technical Report TR-19-01, Post-closure safety for a proposed repository concept for SFL – Main report for the safety evaluation SE-SFL, Sept 2019.

The safety evaluation was carried out using site data for one of the candidate sites (Laxemar, close to the Oskarshamn NPP) that had previously been characterized in detail (although not subsequently selected) as a part of the site selection process for the spent nuclear fuel repository.

The methodology for the evaluation is adapted to the purpose of the study and differs somewhat from those for SFR and the spent nuclear fuel repository. Instead of safety assessment based on comprehensive identification and development of scenarios for analysis, evaluation cases were selected in order to explore the implications of, and sensitivity to, different assumptions. Hence, for example, the SE-SFL safety evaluation does not fully take into account all potential aspects of future climate development or barrier degradation. The evaluation cases include a basic variant with the assumption that the current climate continues for one million years, a variant with a simplified glaciation cycle, and another variant with an extended greenhouse effect. Some alternative cases, such as reduced groundwater flow, alternative approaches to for the concrete backfill, and an assumed well intersecting the transport path from the repository, are also included.

SSM undertook a review of the SE-SFL as part of its continued oversight of the industry's RD&D programme, concluding that the safety evaluation represented an important step forward in development of the disposal concept. It was seen by SSM as positive that a site with relatively complete site data has been chosen as a basis for the safety evaluation. Given the purpose of the safety evaluation, however, SSM considered that it could have benefited from a more realistic representation of the initial states of engineered technical barriers and examination of their evolution, in order to provide better feedback to further development. For example, in the base case, SKB assumed that the bentonite barrier in the repository part BHA does not degrade over the entire analysis period of one million years, which SSM concluded would need to be better justified as an assumption within a full-scope safety analysis.

SSM also noted in its review comments that SE-SFL had shown that the performance of the disposal concept appeared to be significantly sensitive to the assumed hydraulic conductivity of the host rock, which has implications for site selection. For example, SSM concluded that a site with a very low hydraulic conductivity seems to be necessary to achieve a performance on par with SSM's risk criterion for post-closure safety. Specifically, the relatively long-lived and non- or weakly sorbing radionuclides such as Cl-36, Mo-93 and C-14 were identified as particularly challenging with regard to the repository's retardation capacity, and therefore central considerations for both concept development and, perhaps above all, site selection. SSM also pointed to the need for further development of waste acceptance criteria relating to the disposal concept in order to guide waste generators with regard to priorities for characterisation of their wastes. This was judged to be particularly important in developing strategies for the characterisation of some legacy wastes.

SKB's plans and strategies for the development of SFL is described in the RD&D-programme, which is presented every three years (most recently in September 2022) [5].

Status of safety cases for shallow land burials

As noted in Topic 4, shallow land burials are licensed by the Land and Environment Court under the Environmental Code [3] and by SSM under the Act on Nuclear Activities [1] . Their operation is regulated by conditions stipulated separately by the Court and by

SSM in the licensing process[14]. Shallow land burials for very low-level operational waste (VLLW) from NPPs are currently licensed for the sites at Forsmark, Oskarshamn and Ringhals. A similar shallow land burial of radioactive wastes from industry, research and medical care is located on the Studsvik Tech Park. The latter facility is now closed (the licence to dispose of waste expired in 2010) but remains under the responsibility and licensed control of AB Svafo.

The detailed design and layout of shallow land burials differ, but all facilities have a top sealing layer to reduce infiltration of water through the wastes. The design of the top sealing layer differs between the facilities: bentonite liners, plastic membranes and massive layers of glacial clay or mixes of bentonite and sand have been used, as well as designs based on combinations of different features. The infiltration barrier is covered by a drainage layer and, on top of that, a protective layer of e.g. soil, to a depth of approximately 1 metre. At the relatively more recent shallow land burials at Ringhals and Oskarshamn, a geological barrier has been installed down-gradient of the burials. For the burials at Forsmark and on the Studsvik Tech Park, a natural or semi-natural geological barrier reduces leakages to the environment. There are monitoring programmes in place for water sampling, for example with respect to radionuclides. The licence conditions include the requirement for a surveillance period of at least 30 years after final closure.

At the time of writing this report, licensing processes were continuing in the Land and Environment Court and at SSM with regard to establishing a third facility on the Oskarshamn site, intended to provide capacity for the disposal of operational and demolition VLLW. The scope of the licence application and related safety report for the facility includes the potential to accommodate decommissioning waste from Barsebäck NPP and suitable waste from Clab. Preparations are also being made to submit licence applications for a new shallow land burial facility to accommodate operational and demolition VLLW at Ringhals.

Status of safety cases for decommissioning of NPPs

Decommissioning, dismantling and demolition of licenced nuclear facilities requires a new licence according to the Environmental Code reflecting the change in activity on the site. However, under the Act on Nuclear Activities decommissioning is conducted on the basis of the existing licence for the facility. The scope of the safety programme and reporting for the facility is, however, progressively reduced and modified to reflect changes in key safety-related considerations during the various stages of the dismantling and demolition process. Furthermore, notification of the transition to dismantling and demolition is made in accordance with Article 37 of the Euratom Treaty.

Barsebäck NPP

All spent nuclear fuel was removed by 2006, and reconditioning and handling of remaining nuclear waste from the operational phase is ongoing. Preparations for and detailed planning of dismantling and demolition have intensified since 2016. A decommissioning licence according to the Environmental Code was obtained from the

[14] Recently published updated regulations related to the management of radioactive waste and nuclear materials from nuclear facilities (SSMFS 2021:7) now explicitly incorporate disposal via shallow land burial as part of their scope of application (e.g. in terms of requirements for formal waste acceptance criteria as part of the safety documentation). However, there is a transitional period before these formally come into force.

Land and Environment Court in 2019. Modifications to safety reporting in accordance with radiation safety regulations were reviewed and approved by SSM prior to the transition to dismantling and demolition. A number of specific regulatory injunctions were issued by SSM, in particular with regard to challenges associated with demonstrating that conditions are met for site clearance.

Segmentation of the reactor pressure vessels and the reactor pressure vessel internal components, as well as large parts of the turbines, has been completed. The turbines and generators have been removed, and removal of the biological shield is ongoing. The final dismantling and demolition work started in 2020. Release from control in accordance with regulatory requirements for a nuclear licensed site is planned for mid-2030s.

Oskarshamn NPP

The owner of the nuclear power plant decided in October 2015 to permanently shut down the two oldest BWR units 1 and 2 at the Oskarshamn NPP before the end of 2017. Oskarshamn 1 was permanently shut down in June 2017. In practice, Oskarshamn 2 was never restarted following an extended period of shutdown that began in 2013 with the aim of completing the final stage of a modernisation and uprating programme. The necessary licences for decommissioning units 1 and 2 according to the Environmental Code were obtained in 2019. Modifications to safety reporting in accordance with radiation safety regulations were reviewed and approved by SSM prior to the transition to dismantling and demolition.

Dismantling of the internal reactor parts from Oskarshamn unit 1 and 2 was completed in 2020; large scale dismantling and demolition is now underway.

Ringhals NPP

The owner of the nuclear power plant decided in 2015 to permanently shut down the two oldest reactor units 1 (BWR) and 2 (PWR) at the Ringhals NPP before the end of 2020. Unit 2 was permanently shut down in December 2019 and unit 1 was permanently shut down in December 2020. The necessary licences for decommissioning units 1 and 2 according to the Environmental Code were obtained in April 2020. Dismantling of the internal reactor parts from both units 1 and 2 is planned to start in 2023.

Ågesta PHWR

The Ågesta reactor was permanently shut down in 1974. A licence according to the Environmental Code for dismantling and demolition of the reactor was obtained in 2019. Modifications to safety reporting in accordance with radiation safety regulations were reviewed and approved by SSM prior to the transition to dismantling and demolition.

Dismantling activities commenced in 2020 with the aim that they should be completed during 2025.

Studsvik materials testing reactors

The R2 and R2-0 research reactors on the Studsvik Tech Park were in operation between 1960 and 2005. Dismantling and decommissioning began in 2015 under the ownership and control of AB Svafo and is currently in its final stage. Applications for clearance of the remaining buildings and sub-surface structures were submitted to SSM during 2022.

Installations in Ranstad

The uranium mining and milling facilities in Ranstad were constructed and operated in the 1960s. Decommissioning of the industrial facilities has been completed and in 2019 SSM approved the clearance of the industrial site, which is now released from regulatory control.

Only the mill tailings deposits now remain under institutional control. This means that the relevant area is classified within local and regional spatial plans as an environmental risk area. Annual monitoring is performed by the County Administrative Board according to a defined programme, based on advice provided by SSM. This programme includes taking water samples for analysis of parameters such as pH, temperature, and the content of relevant contaminants, including some radionuclides (Ra-226). The current plan is that controls will be performed for a total of 30 years.

Topic 6: Cost estimates and financing of radioactive waste and spent fuel management

Responsibility for the National Strategy cost assessment

A company or other entity with a licence to conduct nuclear activities, as issued to nuclear power stations and other facilities under the Act on Nuclear Activities [1] (hereinafter licensee) is obligated to implement and finance the measures required to ensure the safe management and final disposal of the operation's residual products, e.g. spent nuclear fuel and decommissioning waste. These financial obligations are regulated by the Financing Act [4].

Licensees under the Act on Nuclear Activities are obligated to carry out and finance the safe decommissioning and demolition of facilities after operations have ceased. All nuclear power companies and other licensees have the full financial responsibility for all their respective costs. According to the Financing Act, a licensee under the Act on Nuclear Activities is required to establish a cost calculation for the aforementioned activities and supply this to the financial regulator (The Swedish National Debt Office, hereinafter the Debt Office) every third year.

Approach to preparation of the National Strategy cost assessment

There are two types of licensee under the Act on Nuclear Activities: those that possess and operate a nuclear power reactor and those who perform other activities involving nuclear materials and radioactive waste. The process description outline below refers primarily to the procedure for estimating costs for the nuclear reactor licensees, which represents the vast majority of total costs.

A licensee without a reactor is also obliged under Sections 11 and 12 of the Ordinance on Financial Measures for the Management of Residual Products from Nuclear Activities (Ordinance 2017:1179) to submit cost estimates for the expected costs of nuclear waste management, decommissioning and final disposal, together with any related research and development activities. However, this is done individually by each company (and not SKB – see below). Generally, the procedure is somewhat simplified compared to the approach described below, owing to the fact that costs for these licensees are typically much lower than for reactor owners. Furthermore, the costs for disposal in the case of nuclear power plant licensees reflect their specific obligations under the Act on Nuclear Activities to provide, develop and implement the necessary facilities, whereas those for other licensees are based on estimates provided by SKB according to the fraction of total disposal volume required.

Step-wise process for estimating expected costs

The Swedish Nuclear Fuel and Waste Management Company (SKB), jointly owned by the nuclear power plant licensees, has been established to carry out certain responsibilities of the licensees. This includes obligations for establishing the cost calculations required according to Sections 8 and 9 of the Ordinance on Financial Measures for the Management of Residual Products from Nuclear Activities (Ordinance 2017:1179) and submitting these to the Debt Office every third year. SKB calculates the costs using a four-step process.

In the first step, SKB calculates the costs associated with a reference scenario (reference costs). The reference costs are based on the licensees' current plans and assumptions in terms of operational lifetimes for the reactors and the corresponding expected volumes of waste and spent nuclear fuel that are generated. SKB uses a facility-based bottom up-approach for producing the cost schedule. For power plants in operation, the calculations are based on descriptions of each facility and forecasts for their costs for spent fuel and waste management as well as for decommissioning. For facilities that are not yet in operation, the calculation is based on existing information as well as experience from similar and prototype equipment. The costs of dismantling and demolition of the power plants can be directly attributed to each licensee. For facilities that are used by all nuclear power plant licensees, such as the geological repository for spent nuclear fuel, the total cost is allocated between licence holders based on agreements between them. The result from the first step is a cost schedule for the annual costs for the entire duration of the nuclear waste programme (currently estimated to be completed in about 60 years from now).

In the second step, the reference costs are scaled down by SKB to fit the assumptions that are stipulated by legislation. Hence, for example, according to the Financing Act operational waste should not be included. Furthermore, each reactor is assumed to have a nominal operational lifetime of 50 years as opposed to the reference scenario above in which the reactors are assumed to operate for 60 years. The nominal operational lifetime is, however, extended by six years when the reactor has been in operation for 44 years or more (hereinafter the six-year rule). The six-year rule accounts for long-term operation beyond 50 years and successively expands the assumed operating time as appropriate with each update of the cost assessment. This rule applies if there is no reason to suspect an earlier shutdown. When the licensees announced the premature shutdown of Barsebäck 1 and 2, Oskarshamn 1 and 2, and Ringhals 1 and 2, the cost calculations and fee payments were updated accordingly.

In the third step, calculated costs are adjusted with respect to prospective real price and cost changes[15] in e.g.:

- payroll costs,
- labour productivity and
- prices for machinery investments and other inputs.

As a fourth step, SKB then adds an "uncertainty premium" (contingency) to the cost estimate. The premium is calculated using a stochastic simulation model which takes into account cost and schedule risk for the different projects within the nuclear waste programme that are the responsibility of the nuclear power plant licensees. Input values in the form of risk factors and their probability distributions are supported by the use of the

[15] Real price changes are defined as price changes relative to the Swedish Consumer Price Index.

so-called “successive principle” whereby a reference group makes assumptions on probabilities of various events as well as their consequences for cost and schedule if they occur. The uncertainty premium is defined as the difference between the mean value of the stochastic simulation results and the deterministic cost estimate from the third calculation step. The total uncertainty premium is distributed over time to obtain the annual expected costs that are then used in the calculation of fees and collateral (further described below).

The latest audited cost estimate, Plan 2019, amounts to expected total costs of SEK 116 billion in 2019 prices, and is shown in Figure 5 below. A revised cost estimate, Plan 2022 [22], was published in September 2022 and is, at the time of preparing this report, currently under review for verification by the Debt Office.

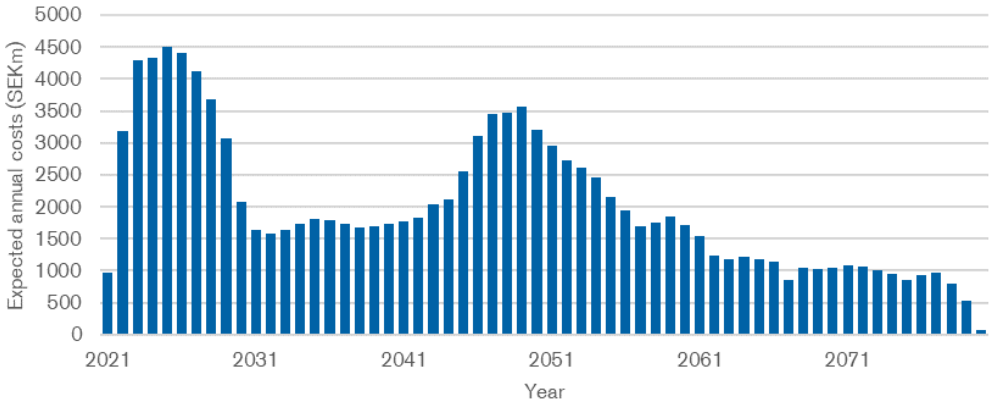

Figure 5 - Expected total cost for all nuclear licensees (SEK millions)

The total costs estimated by the licensees are augmented to include those incurred by the State in relation to:

- supervision of licensed activities supported by the nuclear waste fund,
- asset management within the nuclear waste fund,
- regulatory reviews of the cost calculations themselves,
- provision of financial support to enable the capacity building and participation of municipalities in decision processes for spent fuel management and nuclear waste disposal.

The calculation of these overhead costs is coordinated by the Debt Office, in cooperation with the relevant authorities. The aggregated costs are then allocated to respective licensees based on an allocation key derived from SKB’s cost calculation.

The Debt Office is responsible for regulatory review of the cost calculations, which is performed every third year in connection with SKB submitting an updated cost estimate. After the Debt Office’s review of the cost estimate, the results are then used in the calculation of fees and collateral amounts to be paid by the licensees, as described in more detail below.

Components of the cost estimates

The following costs are included in the reference cost estimates produced by SKB:

- the decommissioning and demolition of the reactors and related facilities after operations have ceased;
- the operation and final closure/decommissioning of existing facilities:
  - the repository for short-lived waste (SFR)[16]
- the central interim storage for spent nuclear fuel (Clab) the construction, operation and closure/decommissioning of planned centralised facilities:
  - the repository for short-lived decommissioning waste (extension of SFR)
  - the encapsulation plant for spent nuclear fuel (Clink)
  - the repository for spent nuclear fuel (SFK)
  - the repository for long-lived waste (SFL)
- all research, development and demonstration activities with regard to the facilities mentioned above;
- information to the public (given by the licensees, the State and municipalities);
- the State's and municipalities' work relating to issuing permits for the final repositories: and
- the State's costs for supervision, asset management of the Fund and cost calculation reviews.

Responsibility for financing different components of the National Strategy

Licensees are responsible for financing the safe management and final disposal of residual products from their operations as well as the safe decommissioning, dismantling and demolition of their facilities when operations have ceased. Licensees also finance the State's costs for supervision, licensing of repositories, asset management of the nuclear waste fund, cost calculation reviews and support to certain municipalities etc. Current licensees under the Act on Nuclear Activities that are responsible for financing under the Financing Act include:

- Licensees with nuclear power reactors:
  - Barsebäck Kraft AB (two reactors, none in operation)
  - Forsmarks Kraftgrupp AB (three reactors, all in operation)
  - OKG AB (three reactors, one in operation)
  - Ringhals AB (four reactors, two in operation)
- Licensees without nuclear power reactors
  - AB Svafo
  - Chalmers tekniska högskola AB
  - Cyclife Sweden AB
  - Vattenfall AB (with respect to the closed Ågesta reactor[17])
  - Ranstad Industricentrum AB
  - Ranstad Mineral AB

[16] Costs relating to the disposal of operational wastes from nuclear facilities are incorporated in the comprehensive reference cost estimates produced by SKB, but – because they are financed directly by the payment of fees by the operators – are subsequently excluded from the scaled-down costs used as a basis for cost estimates in accordance with the Financing Act.

[17] Vattenfall AB is treated as a licensee without any reactor according to the Financing Act and Act on Nuclear Activities, even though the Ågesta facility that it now owns (permanently closed in 1974) was technically a power reactor.

- Studsvik Nuclear AB
- Westinghouse Electric Sweden AB

Each licensee is responsible for financing their respective obligations according to the Financing Act and has an unlimited liability. In addition to the unlimited liability for the licensees, their parent companies also have a limited liability in the event that a licence holder cannot fulfil its obligations.

Arrangements for securing adequate and timely finances

The arrangement for securing adequate finances is based on two pillars or "lines of defence":

- The payment of fees into the nuclear waste fund, which are based on the expected financing needs.
- Two types of collateral that can be called on if a nuclear power reactor licence holder does not pay sufficient fees:
  - the Credit Risk Amount, which is calculated to cover the expected future financing needs; and
  - The Risk Margin, which is calculated to cover the financing needs with a high probability (e.g. in the event that costs turn out higher than expected)

In the case of nuclear permit holders without a reactor, only the Credit Risk Amount is applicable.

The financial standing for a licensee within the financing system for nuclear waste can be illustrated through a balance sheet as shown in Figure 6.

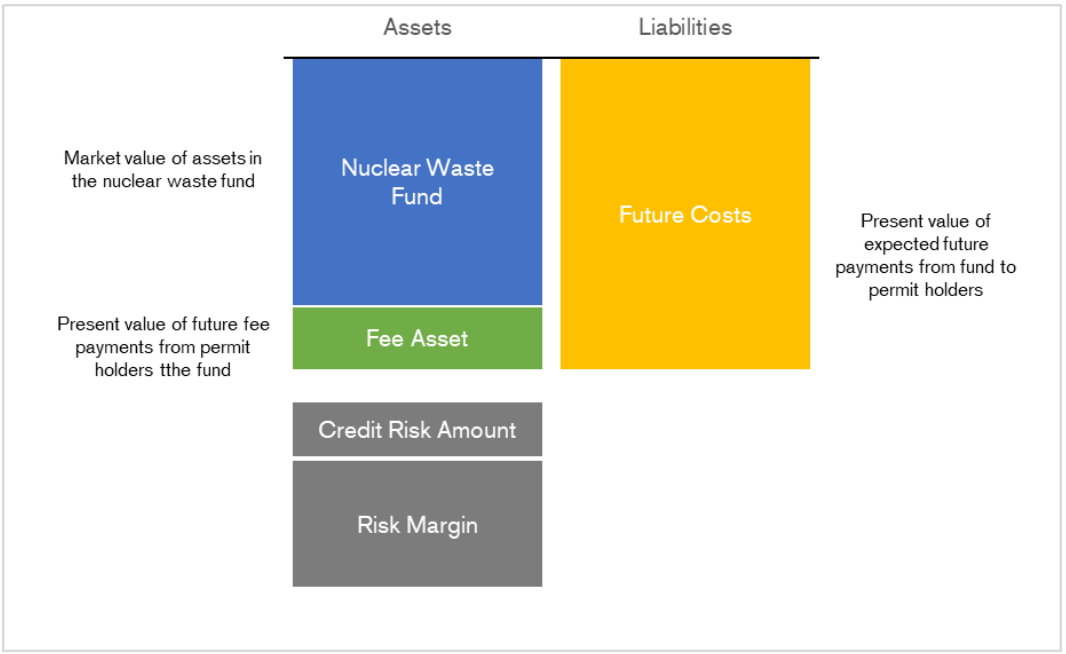

Figure 6 - Balance sheet for a nuclear power reactor licence holder

Fees and collateral

Nuclear waste fees

To secure the financing of their future obligations, licensees are required to pay a nuclear waste fee annually into the nuclear waste fund. The fee is decided every three years for the coming three-year period, and is calculated and decided separately for each licensee.

The fees are calculated by the Debt Office after review of SKB's cost estimates so that the present value of each licensee's expected future fee income, together with the asset value of its share of the fund, are equivalent to the present value of the licence holder's remaining expected costs for the programme. In other words, fees are calculated every three years to re-establish balance between the licensee's assets and liabilities.

As long as at least one of the licensee's reactors are in operation, the fee is paid as tariff on the electricity produced (SEK/kWh), meaning that the fee income is stochastic and depends on projections of the future realized electricity production. For licensees with no reactors in operation (e.g. Barsebäck Kraft AB), the fee is paid as a fixed annual amount, under the assumption that the licence holder's expected future costs will be paid off in three years.

Credit risk amount

Permit holders must also provide a guarantee equivalent to the credit risk amount (CRA). The CRA is calculated as the difference between the present value of the remaining costs of the program and the market value of the assets in the fund. It is therefore a form of collateral for the as yet unfinanced obligations to be covered by future fees.

All types of permit holders (both with and without reactors) have to pledge guarantees for the CRA.

Risk margin

Licence holders for nuclear power reactors must also provide a second type of guarantee, called the risk margin (RM). The RM is calculated for each licensee as the notional amount that needs to be added to the nuclear waste fund today in order that, together with the credit risk amount, it will be able to finance the nuclear waste program with a probability of 90 percent, in the event that no further fees are paid into the fund.

The RM is calculated using an asset-liability model developed by the Debt Office and an external consultant, Ortec Finance. It considers uncertainties in the future costs of the program (liabilities) as well as uncertainties in future investment returns of the fund (assets). Using this approach, all items of the balance sheet are modelled stochastically and simultaneously, considering time- and cross dependencies in assets and liabilities.

Licence holders without a reactor do not have to pledge a guarantee for the RM.

The CRA and RM are generally guaranteed by a parent company guarantee from the ultimate parent of the licensee. The collateral can be called upon by the Government in the event that the licensee fails to pay the decided nuclear waste fees (which would be considered a "default" in the financing system).

Current financing via fee payments and pledged collateral
Tables 8 and 9 below summarise the nuclear waste fees and requirements for pledged collateral for each of the licensees listed above, including both those with nuclear power reactors and those licensed to conduct other forms of nuclear activity.

Table 8 - Nuclear Waste fees, credit risk and risk margins for licensees with nuclear reactors (2022-2023)

Reactor owner	Nuclear waste fee	Credit risk amount (SEK million)	Risk margin (SEK million)	Pledged collateral (SEK million)
FKA	3,0 öre/kWh	5 485	15 834	21 319
OKG	5,6 öre/kWh	6 113	8 628	14 741
RAB	4,5 öre/kWh	5 846	14 219	20 065
BKAB	0 kronor per år	0	3 052	3 052

Table 9 - Nuclear waste fees, credit risk amounts and pledged collateral for licensees without nuclear reactors

Permit holders	Nuclear waste fee 2023-2025 (SEK thousand)	Credit risk amount (SEK thousand)	Pledged collateral (SEK thousand)*
AB Svafo	254 680	709 687	603 034
Vattenfall AB (regarding Ågesta Kraftvärmeverk)	43 804	122 062	0
Ranstad Industricentrum AB	0	0	0
Ranstad Mineral AB	0	0	0
Studsvik Nuclear AB	6 138	118 651	171 577
Westinghouse Electric Sweden AB	4 273	80 690	94 623
Cyclife Sweden AB	2 833	55 920	67 789
Chalmers University of Technology	103	2 000	1 857
Total	**311 831**	**1 089 010**	**938 880**

* The current collaterals are pledged according to previous credit risk amounts. The work with collaterals according to the newly decided credit risk amounts is in progress.

Stakeholders

Below is a brief description of the stakeholders within the financing system for nuclear waste, in addition to the licensees.

The Swedish Nuclear Fuel and Waste Management Company

The Swedish Nuclear Fuel and Waste Management Company (SKB) is jointly owned by the nuclear power plant licensees and has been established to carry out certain specific responsibilities that they are obliged to undertake according to the Act on Nuclear Activities and the Financing Act. SKB is responsible for establishing cost calculations and submitting them to the Debt Office every third year, on behalf of the licensees. The most recent cost calculation was submitted in late September 2022 [22].

The Swedish National Debt Office

The Swedish National Debt Office (the Debt Office) is a public authority responsible to the Ministry of Finance, and is the financial regulator for the nuclear waste financing system. Amongst other tasks, the Debt Office reviews and audits cost calculations submitted by SKB and, based on those estimates, calculates and proposes nuclear waste fees and collateral amounts to the Government for the coming period. The Debt Office also reviews the credit risk of the guarantees that licensees propose for the credit risk amount and risk margin.

The Government of Sweden

The Government is responsible for determining the levels of the fees and guarantees every third year, based on the proposals from the Debt Office. As such, there is no court or appeal process once the fees and collaterals have been decided.

The Nuclear Waste Fund

The Nuclear Waste Fund is a government authority with its own board but no employees. The board decides on the fund's strategic and tactical asset allocations within regulated limits. The administration and assets management is outsourced to another government agency (the Legal, Financial and Administrative Services Agency). The fund is segregated from the rest of the public sector, and fund assets can only be used for specific parts of the programme as determined by the relevant legislation. Each licensee owns a share of the fund proportionate to the fees that it has paid into the system and the return on those investments.

The Swedish Radiation Safety Authority

The Swedish Radiation Safety Authority (SSM) is the national regulator for nuclear safety and radiation protection. Amongst many other tasks, SSM is responsible for the supervision of licensees' nuclear power plants and other facilities as well as issuing permits required to build and operate new nuclear facilities after a Government licence has been granted. Until September 2018, before the responsibility was transferred to the Debt Office, SSM was also the financial regulator for the nuclear waste financing system. SSM still supervises the financing of waste management and decommissioning costs that are not covered by the Nuclear Waste Fund (e.g. with respect to the obligations under the Radiation Protection Act on non-nuclear generators of radioactive waste – see below).

Financing of the long-term management non-nuclear radioactive wastes

Licence holders for activities involving radiation but which do not constitute nuclear activities (i.e. industry, research and medical applications) are not subject to the provisions of the Act on Nuclear Activities or the Financing Act, but are nevertheless obligated to finance the cost of waste management through the provisions of the Radiation Protection Act [2]. Financial securities may be required from private organisations licensed under the Radiation Protection Act to ensure that all potential future costs of radioactive waste management from their activities can be met. The actual costs of waste disposal are typically paid in the form of fees to Cyclife Sweden AB, which then takes responsibility for the wastes it accepts for treatment and packaging for disposal to SKB's facilities. In 1984, the Government agreed to make a one-off compensation payment to the predecessor of Cyclife Sweden AB, Studsvik Energiteknik AB (also the predecessor Studsvik Nuclear AB), to cover the future costs for disposal in SFR of all radioactive waste originating from non-nuclear activities. Where radioactive waste is to be disposed to SFL, the fee paid by the waste generator to Cyclife Sweden AB includes the cost for this disposal.

The future disposal of radioactive waste from the research facility European Spallation Source (ESS) is, however, not covered by the same financing and contractual arrangements as those described above. SKB has agreed with ESS to explore whether capacity for disposal of low and intermediate level waste, including that arising from decommissioning, can be made available in its facilities. The statutes of ESS state that all member countries contribute with a specified amount for financing the decommissioning of the facility. Costs above the specified cost are expected to be covered by the host state (Sweden). There is ongoing discussion between the main stakeholders in Sweden regarding whether the term decommissioning also covers all related costs for the final disposal of related waste arisings or if additional financing arrangements will need to be established. The Swedish Radiation Safety Authority monitor such developments as part of the continuing licensing process during commissioning of the ESS.

There is also a state-sponsored financing scheme administered by SSM for the recovery of orphan sources and clean-up of non-nuclear legacy radioactive waste (see Topic 2). Where possible, recovered sources are submitted by SSM to Cyclife Sweden AB for treatment, conditioning and storage, pending final disposal. To date, no orphan high activity sealed sources have been found. The Government has also financed SSM to carry out a specific campaign (between 2016 and 2018) aimed at the collection, treatment and storage of radiation sources from disused industrial smoke detectors that had been incorrectly delivered to local recycling centres.

Topic 7: Capacity building for radioactive waste and spent fuel management – expertise, training and skills

Legal requirements on licence holders to ensure adequate education and training

Laws and Ordinances

The Environmental Code: The first of the general rules of consideration defined in the Environmental Code (Chapter 2, Section 2) requires that the person responsible for an activity that may cause environmental damage must acquire the necessary knowledge to reduce the risk of injury or other inconveniences to people and the environment. The second of the general rules of consideration (Chapter 2, Section 3) requires that in professional activities, the best available technology must be used to prevent, hinder or combat the occurrence of damage or other inconveniences to the environment or health.

The Radiation Protection Act (2018:396): According to Chapter 3, Section 9 of the Act, a party conducting an activity involving ionising radiation must take measures to limit, as far as is reasonably practicable, the generation of radioactive waste, the release of radioactive substances and the exposure of the environment to ionising radiation. The provisions of Chapter 3, Section 10 are intended to ensure that anyone working in the activity who may be exposed to ionising radiation has good knowledge of the conditions, terms and regulations under which the activity is conducted. Such a person should also have knowledge of the risks that may be associated with the activity, and the competence necessary for the satisfactory operation of radiation protection. According to Chapter 3, Section 11, a party conducting an activity involving ionising radiation or an activity in an environment involving ionising radiation must ensure that adequate financial, administrative and human resources are available to fulfil the obligations arising from the Act, regulations issued in connection with the Act and decisions issued in pursuance of the provisions of the Act.

The Act on Nuclear Activities (1984:3): According to Section 13 of the Act, the licensee for nuclear activities must have an organisation for its activities with financial, administrative and personnel resources that are sufficient to be able to fulfil its obligations for maintaining safety, including in the management of spent fuel and nuclear waste. In the case of contractors and subcontractors, the licensee must ensure that they have the human resources with the appropriate qualifications and skills required for the licensee to be able to fulfil its obligations.

SSM's regulations

In accordance with SSM's regulations concerning basic provisions for all activities involving ionising radiation (Chapter 3, Section 10 of SSMFS 2018:1) a licensee is required to ensure that those who work in the business have the skills and other qualifications needed for duties with an impact on radiation safety. Furthermore, the skills needed within the business and the skills that are available to the employer must be systematically identified and documented. Training or other measures shall be taken where necessary in order to achieve and maintain the necessary skills. For practices that are authorized by notification, it is required that those who work in the business have the necessary skills to take relevant protective measures during the execution of the work and in the event of an event of importance from a radiation protection point of view (Chapter 2, Section 9 of SSMFS 2018:2).

Specific requirements on information and training of personnel working on the site of licensed facility are detailed in SSM's regulations on Radiation Protection of Individuals Exposed to Ionising Radiation and Nuclear Facilities (Section 6-8 of SSMFS 2008:26).

Knowledge management at SKB

Strategic goals and planning

The general national trend of a declining interest for technical and scientific education is a problem for SKB and for Swedish industry as a whole. Besides leading to a shortage of graduates within the relevant areas, this also has negative effects on the opportunities for higher educational institutions to conduct educational programmes in relatively narrow areas such as nuclear technology, as well as their capacity to maintain important research environments. It is therefore important for society in general to increase the interest in natural sciences and technology so that a sufficient number of educated persons can graduate.

Maintaining interest in natural sciences and technology is a common issue for many actors where SKB, together with its owners, can contribute. SKB works together with its owners to increase the attractiveness of the nuclear industry. SKB intends to continue with measures to increase confidence in the company's mission and to highlight the many interesting and challenging tasks and roles needed in order for the mission to be accomplished. This involves collaboration with other companies and schools, primarily at the locations where SKB is active, and participation in labour market days, fairs and various industry events.

To secure competence in areas important for the final disposal of nuclear waste and the decommissioning of nuclear facilities is, for SKB and its owners, a strategically important issue in both the short and long term. Final disposal and decommissioning entail a broad need for competence in the fields of nuclear technology and radiation protection, but also in geoscience, geotechnology, materials science, construction technology, instrument and measurement techniques and competence concerning climate evolution. The starting point is that society is responsible for providing basic education (e.g. civil engineering) and for maintaining basic competence in relevant areas, but the industry will also need to make specific efforts related to its particular needs.

In order to secure competence in the country, collaboration with universities and university colleges will be a part of the long-term competence management, as will the continued encouragement of collaboration within the industry in order to both retain existing personnel and attract new personnel in these areas. For example, SKB's largest shareholder, Vattenfall AB[18], is funding an engineering programme focused on nuclear power at Uppsala University, as well as the Vattenfallgymnasiet (senior high school) in Forsmark, with the aim of securing access to qualified competence far into the 2040s. Furthermore, Forsmarks Kraftgrupp AB, Ringhals AB, and OKG AB (the operational nuclear power plant licensees) together with and Westinghouse Electric Sweden AB are funding the Swedish Centre for Nuclear Technology (SKC). SKC supports education, research and development within nuclear applications at universities and university colleges in Sweden.

Competence development within the organisation

SKB has implemented a process within its management system for systematically developing the organisation and ensuring the availability of qualified staff and competence. The process is based on a systematic approach for complying with internal and external requirements to ensure that adequate competence is available for maintaining high safety performance and achieving the goals of the company's activities in the short and long term. This process also clarifies roles and responsibilities within the process.

In conjunction with the annual planning of activities, a competence and staffing analysis is carried out. The competence analysis shows the competence needed in a position or role in order to perform required tasks in accordance with the needs of the activities. Roles of specific strategic importance or of importance for radiation safety are identified. The analysis is made on both individual and group level and with a timeframe of four to five years. Strategic competence analyses with a timeframe of about ten years are conducted regularly but with slightly longer intervals than the annual planning of activities. The purpose of the strategic analyses for the planned construction of new nuclear facilities is to identify staffing needs (competence and number of personnel) and how competence is to be secured during the different construction phases.

The analyses show the competence needed to execute the activities and the need for competence development either by further training of existing personnel or by new recruitment. Training programmes are established for individuals and groups when necessary to complement the general introductory training for all new employees.

SKB also has a competence management system for its own personnel and consultants in which competence assurance (documentation of competence and any gaps between requirements and assessed level) is performed. The competence of personnel is developed for example through rotation programmes where employees are given an opportunity to work within different areas and in different roles. SKB also has a competence transfer programme to prepare for generation changes and to reduce the vulnerability to loss of competence.

[18] As noted under Topic 6, Vattenfall AB is a licensee under the Act on Nuclear Activities with regard to the former Ågesta reactor. However, the company is also the owner, or major shareholder, of several of the other licensee organisations, both in Sweden and Germany. Vattenfall has decided to gather all nuclear decommissioning competences within a dedicated business unit (BUND) which provides decommissioning services to the complete fleet of nuclear installations under the company's aegis, including nuclear power plants (Ringhals and Forsmark), as well as the facilities operated by SKB and AB Svafo. Whereas the legal constructs surrounding the nuclear operations within Vattenfall are complex, the creation of synergies within a dedicated business unit for nuclear decommissioning is seen as a means of establishing a "knowledge centre" that not only helps to promote efficiencies in operations but also acts as a means to support the strategic development of necessary competences in the long-term.

Regarding competence management in the very long term, there are two fundamental factors that must be considered:

- SKB's activities are planned to continue up until around 2090.
- SKB is a dominant actor in Sweden when it comes to the management of radioactive waste, but substantial tasks also need to be carried out by the owner companies, suppliers and regulatory authorities.

The first point is an advantage as competence development and competence management can be planned in the long term. SKB has developed strategic competence management plans and analysed the risks and problems that may arise when it comes to competence management in the long term. SKB considers potential problems to be manageable.

Knowledge management at Cyclife Sweden AB

As per 2021, Cyclife had 121 employees, with the majority (94) being men. The average age was 46 years. During 2021, the total staff turnover rate was 13.9%, which was an increase from 2020 (11.1%). The staff include operators at the production facilities (metal treatment, incineration, pyrolysis), project managers, support functions and specialists spanning several areas such as health physics, radiochemistry and waste treatment. A person can have several functions.

The education level of the specialists is mainly high, e.g. Master of Science in Engineering and/or PhD. When recruiting new staff, Cyclife currently mainly uses external recruitment companies that carry out competence-based recruitment.

Competence assurance and knowledge transfer

Cyclife's management system defines how competence assurance is managed as part of the Human Resources process. An introduction programme for new recruits is established and managed by the responsible manager. For all functions, functional descriptions are established where knowledge requirements are defined.

In order to maintain systematically and quality-assure training of new employees, competence cards for a diverse number of tasks are defined in the functional descriptions. Competence cards consists of a theoretical and a practical part respectively for different tasks. The practical part is executed under the supervision of a supervisor and authorization to perform a task is confirmed by the responsible manager and documented. For employees in a management position, it is specified to be responsible for ensuring that employees at Cyclife receive the support, education and training needed to solve the tasks.

Change of function within the company is described in the HR-process in the management system. The manager is responsible for the employee handing over his/her tasks to the next employee and that this is executed in structured and documented way. For this, a supporting document is part of the process. The manager ensures that the employee of the function has sufficient prerequisites and competence for the required tasks and has received sufficient information about other tasks. If this is not the case, an action plan including time plan must be defined.

Assessment of employee suitability

In conjunction with recruitment or hiring of temporary staff, an assessment is made of whether the person who is to perform the duties in question is suitable, both regarding competence and suitability in general. In the recruitment specification the criteria are identified and documented for each recruitment. General suitability is based on interviews, security clearance, medical checks and drug testing. Passing a drug test and obtaining security clearance are requirements before a person can be considered suitable to perform duties. Staff suitability is evaluated annually in conjunction with personal development review (PDR) meetings. It is each employee's obligation to report to their line manager or supervisor if he or she suspects that any employee is not functioning in a safe manner, whether regarding their own safety or that of others, or is a threat to the safety of the facility.

Competence development

Cyclife has recurring training for all employees. Required educations are defined in each functional description. There are mandatory one-off trainings, one-off skills development trainings and refresher trainings.

For each function, there are identified competency, education and training requirements documented in the relevant function description. Every employee's competence and level of training is analysed at PDR meetings or whenever major changes are made to a function. If the requirements are not met, development targets are established. Temporary staff who perform duties within standard processes will be evaluated for competence in the same way as employees.

The responsible manager evaluates the training needs of individual employees in annual PDR meetings. Competence analysis is carried out according to the HR process. Each employee must have an individual training plan that is updated annually. All personnel complete a training programme according to regulatory requirements, including the courses SoS (Skydd och Säkerhet/*Protection and safety*) and SiP (Strålskydd i praktiken/*Radiation protection in practice*), as well as required retraining every three years. Exceptions can be made by radiation protection supervisors for the requirement for to complete the SiP training. All employees and hired workers who constantly work in a controlled area (category A) as well as own and hired personnel in a supervisory position complete in-depth radiation protection training according to regulatory requirements, as well as required retraining at least every five years.

Cyclife's ambition is to be an employer where it is possible to grow and develop. Vacancies are advertised internally within the company as a first step to promote internal development. It contributes to internal competence development within the company and is a way to attract and retain competence.

Requisite knowledge to drive the processes is obtained through several channels:

- Experience – documented in protocols/minutes, reports, investigations and post job-debriefings.
- Knowledge from incidents/deviations.
- Learning from one another through internal training courses – carried out by various individuals within the organization.

- Mandatory internal training.
- Trade fairs, Conferences, etc.
- Collaboration in internal and external forums such as the Health & Safety Committee as well as industry-wide initiatives relating to harmonisation of clearance measurements and the management of low and intermediate level waste.
- Study visits to other facilities or suppliers.

In case of changing conditions in processes or new products/services, the need for new knowledge within the organisation is the subject of risk assessment. The need for new knowledge for individual employees is discussed in PDR meetings.

Cyclife also accepts interns from EDF in order to exchange knowledge within the EDF group.

Attracting and retaining competence

Cyclife's policy and core values are an important part of being an attractive employer. Cyclife's goal is to be a workplace where employees enjoy and are proud to work. The core values have been developed in collaboration with Cyclife's employees.

Cyclife has recently started actively working to develop the company's brand to attract and retain existing staff. Cyclife has recently recruited a communicator who works with Employer branding. The work is starting up and Cyclife has e.g. initiated the work of producing shorter films that will show and promote Cyclife as an employer at the market and will be used for marketing purposes to attract staff. Planning for next year regarding participation in fairs and visibility in schools is ongoing. E.g. Cyclife's long-term responsibility for the environment is used for advertising purposes to attract staff.

In order to increase local recruitment of operators for metal treatment, Cyclife has initiated a training program together with a local municipal adult training school. The training was created by Cyclife and covers the basic skills required for the practical work as an operator in Cyclife's metal treatment facility. During their studies, the students will also have an internship at Cyclife.

Since 2020, Cyclife has had a trainee program for the training of radiation protection technicians. This was initiated based on the identification of lack of resources of health physics competence on the market.

Evaluation

Annually, an employee survey managed within the EDF group is carried out that all employees have the opportunity to answer. The analysis of the survey gives Cyclife a basis for improvements and follow up, in order to strengthen the strive for being an attractive employer. Also, EDF and Cyclife have the confidential "whistle blowing" channel which gives each the opportunity and obligation to raise the alarm when required.

Knowledge management at Svafo

Training at Svafo

There are currently 65 employees employed at Svafo: 45 men and 20 women. The average age of the staff is 49 years. The level of educational background is relatively high, approximately 60 % have a university degree.

Svafo is part of the Vattenfall Group and management training follows Vattenfall´s leadership programme. Besides that, Svafo work with two programs called Clear Leadership and Clear Partnership, which is aimed especially at managers but also involves all employees and in summary focus on what it takes to collaboratively organize and sustain healthy relationships at work.

For each member of the staff there is an individual competence development plan. The company's staff participates in national and international networks to share knowledge and experience from other actors.

Attracting and retaining competence at Svafo

Svafo is located quite far from any major city. Therefore the most important thing for Svafo is to be a flexible employer and offer the employee to choose which office to be stationed at, the possibility to work from home and to influence the job description.

By offering interesting work where new techniques and methods are to be developed – sometimes in collaboration with a university – highly qualified staff with solid experience can be attracted.

The company is now producing a communication material with the aim of becoming more visible/transparent in order to both retain and attract competence. Svafo collaborate with different universities for the same purpose.

Svafo works continuously with competence planning; what competence exists and what is needed within 5-10 years' time and how can knowledge transfer be carried out in order to handle employee turnover. The competence planning also aims at identifying competences that could be hard to replace or hard to attract. One strategy is to collaborate with other entities within the Vattenfall Group, which gives bigger power to act.

Knowledge management at SSM

In 2021, 297 employees were employed at SSM: 168 men and 139 women. Their average age was 49. The staff turnover rate, including retirements, was 13 per cent. Compared with many other Swedish authorities, the staff of SSM have a relatively high level of educational background. This is a result of the many specialist areas covered by the Authority. In an international comparison, the number of regulatory staff in Sweden is relatively small for the size of the nuclear programme. Many staff members have historically typically been involved in several tasks. SSM applies a competence supply model. The objective of the model is to provide an overview of the methods and other measures that SSM uses in order to acquire and maintain the competence needed by the Authority.

SSM systematically analyses prospective skills needed by the Authority in the short and long term in order to perform its current and future tasks. Working strategically with staffing and competence, and thereby developing the organisation and its work is a critical requirement for SSM's capability to achieve its goals and effectively conduct its activities.

Competence supply model

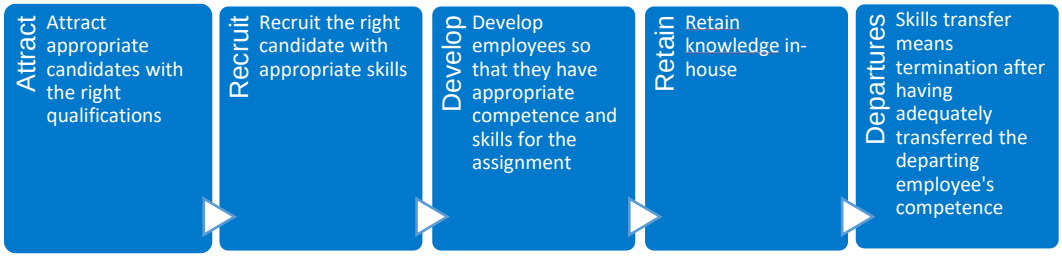

Figure 7 - SSM competence supply model.

The purpose of SSM's competence supply model (Figure 7) is to provide an overview of the methods and other assumptions that SSM applies in order to optimally meet its needs for staffing and competence. The overall objective of the model is to create the necessary conditions for performing effective knowledge management in order to develop the operations of SSM. The supply model includes the following steps:

- To attract the right candidates with appropriate qualifications, SSM uses its employee value proposition and markets it, for example at job fairs.
- In order to recruit the right candidates, SSM applies competence-based recruitment, and ensures that employees once recruited are committed to SSM's introduction programme, which also includes a mentor for the first six months.
- In order to retain its employees, SSM has several programmes in the areas of supervision and leadership. Employee departures are subject to a tailored skills transfer programme for the purpose of retaining knowledge in-house at SSM.

Employee value proposition

An important prerequisite for the Authority's staffing and competence is that the Authority succeeds in attracting and recruiting staff who have the education, experience and skills needed, together with the qualities that make the employees contribute optimally to the organisation. What the Authority offers as an employer and workplace should be attractive to those who it wishes to recruit.

Training at SSM

Management training

A basic competence profile and performance expectations for all staff at SSM, including managers, are defined the Authority's Employee policy. The policy has a clear starting point in the public administration values and has a clear link to the Authority´s model for

training of leaders, “Developing Leadership”. A specific internal training programme for future leaders has been set up in order to foster good leadership and secure a consistent management of the Authority´s regulatory functions.

Competent supervision

A continuous professional training programme named “Competent Supervision” is compulsory for all employees involved in SSM’s regulatory supervision activities. The objective is for all inspectors to have the same basic skills for performing consistent supervisory work in accordance with SSM’s internal processes and procedures, regardless of the facilities or activities that are the focus of one’s supervision.

Attracting and retaining competence at SSM

Actions to attract and keep competence

SSM has continued to work on developing the Authority’s brand in order to attract and keep employees. Shorter videos have been produced that highlight the professional profile of some employees; ads have been designed with new images from the Authority’s brand. SSM has also participated in student fairs with the aim of promoting the Authority as an attractive employer.

Skills transfer program

SSM has developed a skills transfer concept (known as KÖK) in order to manage transfer of skills possessed by only one or a few employees. It is important to have a structured and systematic approach to maintaining competence and skills in the organisation. The programme can also be seen as a professional development opportunity for both mentors and mentees. Mentorship pairs are identified in connection with annual professional development interviews.

SSM has continued working on a structured programme for transfer of competence. A leadership Competence programme has been established to enable backup functions among the Authority's employees possessing critical competence, as well as to carry out professional development. The KÖK programme defines different roles: the mentee ensures that objectives and goals are met, while the mentor transfers his or her skills and helps the mentee achieve the defined objectives and goals. A supervisor performs follow-ups and ensures that the competency transfer takes place.

National arrangements to obtain, maintain and further develop necessary expertise and skills

Financing knowledge and skills development

SSM’s receives an annual financial appropriation from the Government for research, which may be used for both basic and applied research, as well as for the development of methods and processes. The overall aim is to enhance national competence within the Authority’s area of activity and to support and develop the Authority’s supervision activities. Such research activities are primarily carried out by experts and researchers outside the Authority, thereby helping to maintain and develop national competence of importance for work with radiation safety.

SSM funds a number of research projects and research positions at Swedish universities to develop and maintain competence and teaching ability. Key areas are reactor physics, severe accidents and non-proliferation. SSM also funds higher research positions within e.g. radiation biology, radioecology and dosimetry. Research grants are also announced through open proposals for applications in the areas of radiation protection and waste management.

In addition to the programme for research, demonstration and development conducted by SKB (see Topic 4), SSM also commissions research in the field of disposal of spent nuclear fuel and decommissioning of nuclear facilities, financed by the Nuclear Waste Fund. Support has been awarded to research projects on canister corrosion, biosphere processes, bentonite and backfill, geosphere processes, fuel processes, radiological consequence assessment and others. The purpose of the research is to provide support for both ongoing and upcoming regulatory reviews supporting authorisation processes in relation to the development of disposal facilities. Support for research also aims to maintain knowledge, competence and continuity over the longer term in areas relevant to the disposal of radioactive waste. Support is therefore sometimes provided in the form of support for post-doctoral research projects at universities and colleges.

Over the past three decades, SSM and its predecessors have implemented extensive research programs with the aim of developing independent competence and tools in geological disposal. The research has been carried out by the Authority's own staff and through a network of external experts through several international initiatives in the fields of hydrogeology (Intracoin and Hydrocoin), model validation (e.g. Intraval), radionuclide transport, rock mechanics modelling (Decovalex), biosphere modelling (Biomovs and Bioprota) and environmental protection (Erica). Two comprehensive independent evaluations of the long-term radiation safety when disposing of spent nuclear fuel according to the KBS-3 method were carried out in the 1990s (Project-90 and SKI Site-94).

In addition to the technical research, a research programme (partly co-financed by SKB and undertaken within the scope of the EU research framework) on stakeholder dialogue was carried out together with environmental organisations, other non-governmental organisations and municipalities that were affected by SKB's repository siting programme. This research programme work has contributed to the development of methods and forums for dialogue with stakeholders and for a better understanding of the roles and needs of different actors.

Special funding arrangements have provided support for non-profit organisations to participate actively in the consultation process in accordance with the Environmental Code for licensing a repository for spent nuclear fuel. Over time, these organisations have also built up a competence and capacity to follow the development of final disposal methods.

Supply of competence at a national level

In December 2016, SSM received a government assignment on long-term competence supply in relation to radiation protection and nuclear safety. In that work, six areas were identified as vulnerable where national competence is critical for society:

- Nuclear power technology, including reactor physics, thermal hydraulics and nuclear data
- Severe accidents and nuclear chemistry
- Nuclear control and non-proliferation
- Radiation biology
- Radioecology
- Radiation protection dosimetry

It was found that these areas are either underfunded, or that the Authority is the sole financier. The list did not include issues related to radioactive waste management, principally because of the extensive research and related training programmes undertaken by the nuclear industry through SKB.

In 2020, SSM on its own initiative followed up the previous assignment with a study aimed at describing and specifying the research needed for Sweden to maintain a national competence supply within the Authority's competence areas against the background of EU directives, conventions and IAEA standards.

These two studies, the original government assignment and the subsequent follow-up, have formed the basis for the development of a proposal for a national strategic focus on competence for radiation safety (including safety of waste management), which was submitted to the Government in March 2022. The proposal contains a total of 21 priority initiatives to satisfy the national competence needs in the field of radiation safety during the coming ten-year period. The priority initiatives are grouped in the following five strategic focus areas: national coordination, research policy for viable research environments, international research collaborations, education for society's competence needs, and attractiveness of the radiation safety field. The proposal has been broadly anchored through consultation with national stakeholders in the field of radiation safety (universities, industry, authorities and others). These stakeholders have been part of a collaboration platform that has been used for several years in the Authority's strategic work with national competence supply.

During second half of 2022 a survey of the national competence supply was performed in the area of radiation safety by Oxford Research of behalf of SSM. The survey results identified that the need for nuclear waste expertise appears to be increasing.

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The Swedish Radiation Safety Authority works proactively and preventively with nuclear safety, radiation protection and nuclear non-proliferation in order to protect people and the environment from the harmful effects of radiation, now and in the future.

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