

Status: February 4, 2020

The control of safety of radioactive waste management and decommissioning in Switzerland

(“Country Report”)

1. NATIONAL FRAMEWORK FOR MANAGEMENT AND REGULATION OF RADIOACTIVE WASTE AND DECOMMISSIONING

1.1 NATIONAL framework

1.1.1 OVERVIEW of national policy

Nuclear fuel cycle

Currently, five nuclear power reactors (3 pressurized water reactors PWR, 2 boiling water reactor BWR) are operated at four sites (Beznau, Mühleberg, Gösgen and Leibstadt), totalling around 3'200 MWe in Switzerland. A total of around 3,575 tonnes HM of spent fuel is expected from the five reactors currently in operation, assuming a 50-year operating lifetime. In December 2019, the reactor in Mühleberg was shut down and will be decommissioned for economic reasons.

In 2003, the Swiss parliament decided to introduce a 10-year moratorium on the export of spent fuel for reprocessing which started in July 2006. Prior to the moratorium, the utilities were free to choose between reprocessing and direct disposal of the spent fuel. The Nuclear Energy Act stated a series of conditions, which had to be fulfilled for an authorisation of the export of spent fuel for reprocessing to be granted. The conditions included an international agreement with the country of destination, the existence in that country of an adequate facility corresponding to the international standards and the fact that the country of destination has ratified the Convention on Nuclear Safety and the Joint Convention¹. The reprocessing took place in France and UK. Plutonium and uranium gained from reprocessing was used for fuel fabrication and recycled in Swiss NPPs.

During the moratorium, no spent fuel was exported for reprocessing and spent fuel had to be managed as radioactive waste. Under new legislation, which entered into force in 2018, the export of spent fuel for reprocessing was banned indefinitely. The last radioactive waste arising from reprocessing was returned to Switzerland in 2016.

Following the reactor accident in Fukushima (Japan), Federal Councilor Doris Leuthard announced in mid-March 2011 that the pending application procedures for general licenses for new nuclear power plants were suspended. In the course of the same year, the Federal Council and Parliament laid the foundation for a new energy policy (Energy Strategy 2050), which included the phase out of nuclear energy. The new legislation prohibits the construction of new power plants. The existing nuclear power plants may remain in operation for as long as they are declared safe by the Federal Nuclear Safety Inspectorate (ENSI). In 2016,

¹ Switzerland ratified the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

the operators jointly decided to withdraw the general license applications for replacement nuclear power plants that were submitted in 2008 and suspended in 2011.

Dry storage buildings at Beznau NPP (ZWIBEZ) and at the Central Storage Facility (ZZL, operated by ZWILAG) were built for the interim storage of spent fuel and of radioactive waste returned from reprocessing abroad. In addition, a building for the wet storage of spent fuel at Gösgen NPP was commissioned in 2008.

Radioactive waste management

The management (handling and storage) of radioactive waste is governed by the provisions of the Nuclear Energy Act and the Nuclear Energy Ordinance, both of which entered into force on 1 February 2005.

The management of radioactive waste originating from medicine, industry and research is governed by the Radiological Protection Act and the Radiological Protection Ordinance both of which became effective on 1 October 2004.

Responsibility for radioactive waste management lies with the waste producers. Legislation requires in principle the disposal of Swiss radioactive waste in Switzerland. The option for the disposal of radioactive waste within the framework of a bilateral or multilateral project is possible under very stringent conditions, but is not pursued.

Nuclear energy legislation and the corresponding regulations require the volume of raw waste to be minimised and conditioned as soon as possible.

Concerning radioactive waste disposal, the long-term safety of human beings and protection of the environment are of highest priority. All radioactive waste is to undergo disposal in repositories located in suitable geological formations. Near-surface disposal is not allowed. Either a combined repository or two repositories are foreseen, one for mostly short-lived low and intermediate level waste (“L/ILW”) and the other for high level waste and spent fuel as well as long-lived intermediate level waste (“HLW”) mainly from reprocessing. The site selection process has to follow a so-called “sectoral plan” procedure within the framework of the spatial planning legislation. Stringent requirements in terms of geological stability, host rock barrier performance and local geological conditions (depth, thickness and lateral extent of host rock are therefore a decisive factor in the site selection procedure. In addition to safety criteria, the site selection procedure additionally has to take account of socioeconomic and spatial planning aspects. These vary from region to region, and can only be developed with the participation of the involved regions.

Since no repository is yet available, all radioactive waste is currently stored in interim storage facilities. Each nuclear power plant has the interim storage capacity for its own operational waste. The radioactive waste from medicine, industry and research is stored at the Federal Storage Facility. Radioactive waste returning from reprocessing abroad is stored at the Central Storage Facility (ZZL).

Decommissioning

The Nuclear Energy Act requires that basic considerations for decommissioning are made at the stage of the general licence application. Applications for construction and operation licences can only be made once the general licence has been issued. Licensees must present a decommissioning plan with the application documents for the construction licence. They also have to regularly update the decommissioning plan during the operation period. At the end of the operational lifetime of the facility, they must submit a decommissioning project. After this project has been reviewed and approved by the authorities, a

decommissioning order is issued by the licensing authority (DETEC). Legislation therefore addresses all aspects of decommissioning at the appropriate stage of facility development.

Earlier nuclear legislation did not contain detailed provisions regarding the decommissioning of nuclear facilities. The concepts for the decommissioning of the four commercial nuclear facilities (see section 4.2) were accepted on a case by case basis; they describe the decommissioning and dismantling steps and the obligations of the operators. The new legislation on nuclear energy now specifies the obligations and procedures for decommissioning in detail.

The first decommissioning order based on the new legislation was issued on 2 July 2014 regarding the pilot incinerator plant at the Paul Scherer Institute. The project for the decommissioning of this plant, which ceased operations at the end of 2002, was submitted to the Swiss Federal Office of Energy (SFOE) in July 2011.

BKW Energy Ltd announced in late 2013 that Mühleberg NPP will be permanently shut down at the end of 2019. The single 372 MWe boiling water reactor began operating in 1972. Apart from the experimental plant of Lucens it will be the first Swiss nuclear power plant to be decommissioned.

On 18 December 2015, BKW submitted the application documents according to Article 28 of the Nuclear Energy Act (NEA) to decommission its NPP (the final decommissioning project) to the SFOE.

During the preparation of the legal procedure leading to the decommissioning order of the Mühleberg NPP, the Swiss Confederation established an inter-institutional monitoring group. There were three subgroups on technical aspects, legal procedure and communication. In March 2015, April 2016, June 2017 and September 2018 the subgroup of communication organized nine public events around the Mühleberg NPP. In total more than 2000 people visited these events and showed much interest in the decommissioning plan, the funding, the costs, the waste treatment and disposal.

The requirements for the final decommissioning plan are described in the Nuclear Energy Act, the Nuclear Energy Ordinance and in ENSI's technical guideline G17. The decommissioning guideline ENSI-G17 is in accordance with the WENRA Safety Reference Levels and the respecting IAEA Safety Standards on decommissioning.

The documents of the final decommissioning plan were reviewed by the relevant authorities: the Federal Nuclear Safety Inspectorate (ENSI), the Federal Office for the Environment (FOEN), the Cantonal Environmental Protection Agencies, the Federal Office of Public Health (FOPH), the State Secretariat for Economic Affairs (SECO) for conventional occupational health and safety (SUVA) and last but not least for a second opinion by the Federal Nuclear Safety Commission (NSC). Based on the authorities advisory opinions DETEC issued the decommissioning licence in June 2018 that regulates the decommissioning process - in schedule within 2.5 years - including the public participation process – more than one year before final shutdown – in a first of a kind project in Switzerland. There were no complaints against the licence to the Federal Administrative Court. The decommissioning licence is legally binding. This ensures that any necessary preparation can be finalized before the plant's planned shutdown on 20 December 2019.

Immediately after final shutdown, BKW Energy Ltd will begin with preparatory dismantling activities with spent fuel on site. In the first phase the planned activities include the clearing out of the turbine building and the installation of decontamination facilities as well as the removal of the RPV internals. According to the plans of BKW, decommissioning will be completed within 11 years.

1.1.2 OVERVIEW of relevant institutions

Implementing bodies

Responsibility for conditioning and interim storage of radioactive waste from nuclear power plants (NPPs) remains with the operators who are also responsible for the decommissioning of their nuclear facilities. The federal government is responsible for the management of radioactive waste generated by the use of radioisotopes in medicine, industry and research. The operators of nuclear power plants and the federal government set up the National Co-operative for the Disposal of Radioactive Waste (Nagra). It is responsible for the implementation of permanent and safe disposal of all types of radioactive waste.

The ZWILAG (Zwischenlager Würenlingen AG) operates the Central Storage Facility (ZZL) in Würenlingen.

Regulatory bodies

The Swiss Confederation is responsible for providing the legal framework, and its supervisory authorities are responsible for the supervision of nuclear power plants and the management and eventual disposal of radioactive waste.

The SFOE is responsible for the implementation of the various licensing procedures, and prepares the decision-making process of the relevant federal department and the Federal Council. Licences and permits required for the construction of nuclear facilities and deep geological repositories, as well as for carrying out geological studies, are issued by the federal authorities. The SFOE is also responsible for the Site Selection Procedure for Deep Geological Repositories according to the Sectoral Plan.

The general licence, which is initially needed for each nuclear facility, is granted by the Federal Council (federal government). The general licence has to be approved by Parliament and is subject to an optional national referendum. The Federal Council also issues the closure order for disposal facilities. The licensing authority for the subsequent licences for nuclear facilities (construction and operation) is the Federal Department of the Environment, Transport, Energy and Communications (DETEC). DETEC also issues the decommissioning order.

The Swiss Federal Nuclear Safety Inspectorate (ENSI) is the competent authority for supervising nuclear facilities with respect to radiation protection and nuclear safety at all stages of the life cycle. Since 2008, ENSI is also the competent authority with regard to physical protection. It has three main functions: ENSI (a) specifies the detailed safety requirements in regulatory guidelines, (b) reviews licence applications, and (c) supervises the nuclear facilities, the preparations for the disposal of radioactive waste, and the transport of radioactive material from and to nuclear facilities. ENSI also has certain licensing competences according to the radiation protection legislation.

The Federal Office of Public Health (FOPH) is the main licensing authority for the handling of radioactive material which does not fall under the Nuclear Energy Act. The FOPH also supervises the handling of radioactive material in medical and research institutions and in situations where the protection of the general public is the primary concern. It is also responsible for monitoring radioactivity in the environment. Since 1980, the FOPH organises annual collection campaigns for radioactive waste from medicine, industry and research that is subject to the legal provisions governing radioactive waste disposal. Radioactive waste originating from medicine, industry and research collected during the annual collection campaigns is conditioned at the Paul Scherrer Institute (PSI) and stored at the Federal Storage Facility on the same site.

In accordance with applicable legislation, all radioactive waste producers from medicine, industry and research must make provision for the temporary storage of waste at the site of production, and submit details of their proposal for approval to the Swiss Accident Insurance Institute in the case of enterprises subject to the Federal Accident Insurance Act, or to the Federal Office of Public Health in all other cases. This procedure is necessary before the Federal Accident Insurance Institute or the Federal Office of Public Health can take a decision as to the licences for the possession and use of radioactive substances, and equipment containing such substances.

The Federal Nuclear Safety Commission (NSC) examines fundamental issues relating to nuclear safety, and may submit position statements to the Federal Council and the DETEC concerning safety assessments of the Swiss Federal Nuclear Safety Inspectorate (ENSI).

A federal government working group on radioactive waste management (AGNEB) was set up by the Federal Council on 15 February 1978. This Group is responsible for following up the work carried out in this sector by other bodies, and for preparing the technical elements necessary for making an evaluation and which will serve as a guidance to the Federal Council and the DETEC when taking decisions in this field. It reports to the DETEC annually.

As part of the sectoral plan procedure for deep geological repositories, the Expert group Geological Disposal (EGT) supports the Federal Nuclear Safety Inspectorate (ENSI) and takes a position on earth science and construction issues. The expert group supports ENSI in the safety assessment in the sectoral plan procedure by reviewing scientific reports of the National Co-operative for the Disposal of Radioactive Waste (Nagra). EGT also advises ENSI on the geological assessment of siting regions and sites, on the construction feasibility of deep geological repositories and on applications for earth science investigations.

1.2 NATIONAL, technical regulatory organisation

1.2.1 REGULATORY function

The Swiss Federal Nuclear Safety Inspectorate (ENSI) is the government's supervisory authority for nuclear safety and radiation protection in the field of nuclear energy, including radioactive waste management. According to the institutional framework described in 1.1.2 above, ENSI is not the licensing authority, but has the mission to supervise and assess Swiss nuclear facilities right through from the planning stage, to construction, operation, and decommissioning or closure. ENSI also supervises the transport of radioactive material to and from nuclear facilities and the geological investigations in view of radioactive waste disposal.

Formulation of safety requirements

ENSI takes part in drawing up legislation concerning nuclear safety and radiological protection. It defines the safety requirements to be met by nuclear facilities, specifies the body of regulations (standards and rules) to be applied and issues its own guidelines. In the field of radioactive waste management, four specific guidelines exist: ENSI-B05 on the conditioning of radioactive waste, ENSI-G03 on the requirements for geological disposal, ENSI-G04 on requirements for the interim storage of radioactive waste, and ENSI-G05 on the requirements for transport and storage casks.

Assessment of projects

ENSI prepares the review reports at each stage of the licensing process for nuclear facilities and for geological investigations in view of radioactive waste disposal. The review reports make recommendations concerning the granting of licences and propose licence obligations.

Supervision of nuclear facilities

In its role as supervisory body, ENSI verifies compliance with the legal requirements, as well as with the obligations laid down by the licensing authority and issues permits for operations within the framework of the licence. For instance, each type of conditioned waste package requires ENSI approval prior to routine production. Such an approval is issued on the basis of a detailed specification characterising the waste package and after Nagra has certified the suitability of this type of waste package for disposal in one of the repositories foreseen.

Information

ENSI answers questions posed by Parliament, political authorities and the general public relating to the safety of the nuclear facilities and to possible radiological implications for human health and the environment. ENSI strives to serve as the people's expert advisor on these subjects. It has made it a duty to respond to events of public concern by providing quick, complete and understandable information.

1.2.2 ORGANISATION and resources

ENSI currently employs around 140 staff: physicists, mechanical, electrical and civil engineers, geologists, chemists, biologists and psychologists, in addition to technical and administrative personnel. Its organisation is shown in figure 1. For particular tasks, ENSI enlists the aid of experts from external organisations.

ENSI is divided into four technical divisions: Nuclear Power Plants (NPP), Waste Management, Safety Analyses and Radio Protection.

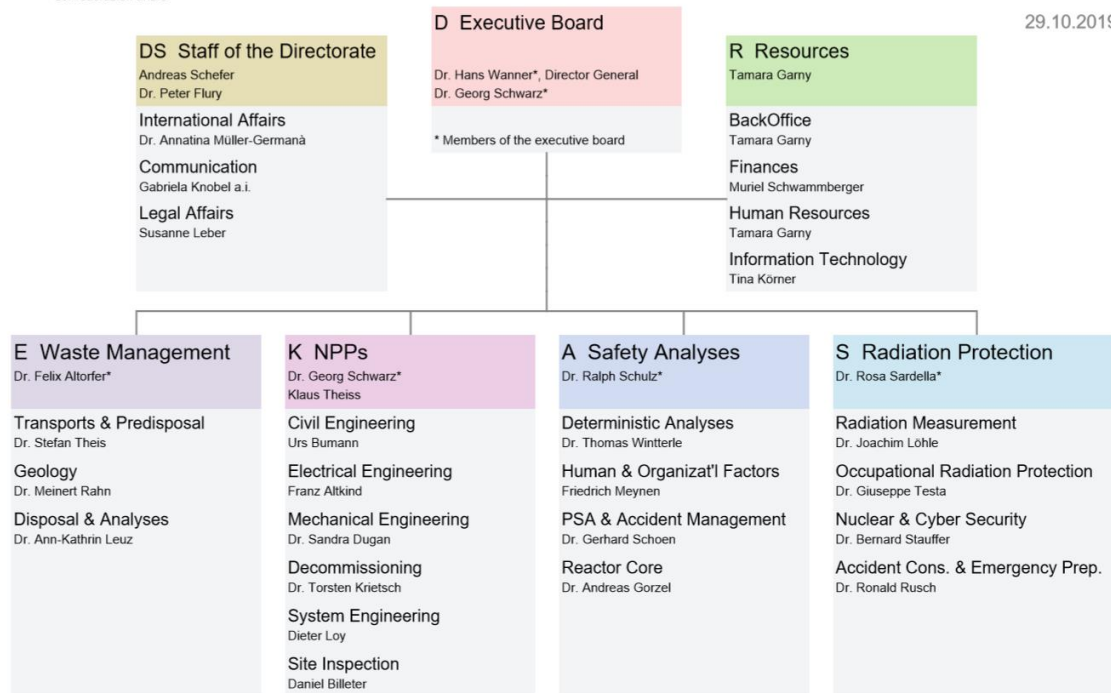


Figure 1: Organisation of ENSI as of 29 October 2019

The Waste Management division has a staff of 20 people. It supervises the transport of radioactive materials, conditioning, storage and disposal of radioactive waste, and decommissioning of nuclear facilities. It evaluates the proposed methods for conditioning radioactive waste, issues the necessary execution permits and supervises the operation of the corresponding facilities. It has a leading function in ENSI's review on the safety of facilities for storage and disposal of spent fuel and radioactive waste. It supervises the construction and operation of such facilities. It follows and appraises geological investigations in preparation of radioactive waste disposal. In its role as the Swiss competent authority, it also issues the package and shipment approval certificates for the transport of radioactive material in Switzerland and supervises such transports to and from nuclear facilities.

ENSI's annual budget is in the order of CHF 60 million (i.e. about EUR 54.5 million). Most of the organisations costs are covered by fees which licence holders have to pay to the federal government.

1.3 NATIONAL implementing organisations

1.3.1 SCOPE of responsibility

According to nuclear energy legislation, the producers of radioactive waste, i.e. the NPP operators and the federal government (for the waste from medicine, industry and research) must ensure that the waste is managed in a safe and permanent manner. To plan and implement final disposal, they established the National Cooperative for the Disposal of Radioactive Waste (Nagra) in 1972. Nagra is responsible for the disposal of all types of radioactive waste, including the preparation of proposals and license applications as well as the operation of the repositories. Furthermore, its tasks include the following:

- Characterisation and maintaining the inventory of radioactive wastes as a basis for planning disposal projects; checking waste specifications as part of the waste disposal certification procedures and as a service to the members of the Nagra Cooperative.
- Acquisition and evaluation of geological data required for site selection, safety assessment and disposal projects.
- Project studies providing input for designing repository installations and engineered barriers, and for planning operating procedures.
- Ongoing analysis of results and data within the context of performance assessment and evaluation of information with a view to licensing procedure requirements.
- Development of databases and fine-tuning of the methods used to evaluate disposal system behaviour; verification and validation of the data and models used in performance assessment.
- Active participation in international collaborative projects, with the aim of coordinating and optimising planning and development activities.
- Fulfilling responsibilities in terms of communication and information dissemination, in particular keeping the public informed on the current status of disposal programmes and proposals for management solutions.
- Providing expert services to third parties.

Every five years, Nagra compiles the Waste Management Programme on behalf of the waste producers as stipulated by the nuclear energy legislation. Nagra also periodically updates the cost estimates for final disposal that serve as a basis for the annual contributions paid by the NPP operators to the Waste Management Fund (see below, chapter 3.5).

1.3.2 ORGANISATION and resources

At present, around 120 members of staff (or 100 full-time positions) – in particular geologists, physicists, engineers and chemists in addition to technical and administrative staff – are employed at Nagra headquarters in Wetingen (Canton of Aargau). Nagra is divided into five divisions:

- Geology, Safety & Radioactive Waste Materials
- Planning & Construction of Deep Geological Repositories
- Collaboration Sectoral Plan & Public Outreach
- Finance, Personnel and Administration
- International Services and Projects

In addition, two major, cross-division projects group activities are related to the Sectoral Plan & General Licence process as well as Research & Development.

To carry out its research programme, Nagra can rely on a broad network of experts, both in Switzerland and abroad. Its work is performed in close collaboration with the Paul Scherrer Institute (PSI, Villigen) and various universities and research institutes. Furthermore, a regular exchange of information between Nagra and partner organisations at an international level takes place within the framework of formal bilateral agreements. Nagra also conducts joint projects with many of its international partners. These projects can be multilateral (for example projects in the rock laboratories) or in cooperation with international organisations (for example the OECD Nuclear Energy Agency and the EU). Participation in European Commission research projects has become a particularly important aspect of Nagra's research and development activities (see also chapter 3.4)

Nagra's annual performance is in the order of CHF 60 million (i.e. about EUR 55 million).

2. LEGAL FRAMEWORK

2.1 PRIMARY legislation and general regulation

Swiss legislation concerning radioactive waste management and decommissioning currently consists of the following acts (issued by Parliament) and ordinances (issued by the Federal Council, i.e. the federal government, or Departments, i.e. ministries):

- Nuclear Liability Act, 18 March 1983 (revised in 2008).
- Radiological Protection Act, 1 October 2004.
- Radiological Protection Ordinance, 1 October 2004.
- Ordinance on the Collection of Radioactive Waste, 3 September 2002
- Nuclear Energy Act, 21 March 2003 (revised in 2018).
- Nuclear Energy Ordinance, 10 December 2004 (revised in 2019).
- Ordinance on the Decommissioning Fund and the Nuclear Waste Management Fund, 7 December 2007.

The legislation on nuclear energy (Nuclear Energy Act and Nuclear Energy Ordinance) entered into force on 1 February 2005. The main features of this legislation concerning radioactive waste management and decommissioning are as follows:

- The generation of radioactive waste must be minimised.
- Radioactive waste generated in Switzerland must be disposed of domestically.
- Export or import of radioactive waste for disposal is allowed only under strict conditions and requires an international agreement.
- The producers of radioactive waste are responsible for its safe management, including permanent disposal.
- The Confederation assumes responsibility for the collection, conditioning, storage and disposal of radioactive waste generated by the use of radioisotopes in medicine, industry and research.
- Radioactive waste shall be disposed of in deep geological repositories; the final closure of a repository is preceded by a monitoring phase; retrievability must be ensured “with reasonable effort” until closure of the repository.
- The owners of NPPs in operation must demonstrate the feasibility of permanent and safe disposal of all radioactive waste within ten years. Similarly, the demonstration of disposal feasibility is required when applying for a general licence for a new nuclear facility².
- The operators of nuclear power plants must submit a Waste Management Programme, which describes the steps for treatment, interim storage and disposal of all radioactive waste and evaluates the costs; the disposal programme must be approved by the Federal Council. The waste producers must update the programme every 5 years.
- The operators of nuclear power plants have to pay annual contributions to the Decommissioning Fund and to the Radioactive Waste Management Fund, which are administrated by an independent Commission.

² The demonstration of feasibility for the disposal of low- and intermediate-level waste was formally accepted by the federal government in 1988. For the disposal of spent fuel, HLW and long-lived ILW, the demonstration of feasibility (*Entsorgungsnachweis*) was approved by the federal government in June 2006.

- A general licence, stating the site and the purpose of the facility, is required prior to further licences for a nuclear facility. The general licence is granted by the Federal Council, has to be approved by Parliament and is subject to an optional national referendum.
- Licences are required for construction and operation of radioactive waste management facilities, as for other nuclear facilities. The licensing authority is the DETEC.
- Basic commitments regarding decommissioning and closure of a disposal facility, i.e. a basic concept must be stated with the application for the general licence. The licensee has then to present a decommissioning and a closure plan with the application for the construction licence. Both of them have to be periodically updated during the operation of the facility.
- Decommissioning of a nuclear facility is required after final shutdown. DETEC orders the owner to carry out the decommissioning project, which has to be approved by the supervisory authority.
- After the end of waste emplacement in a disposal facility, the evolution of the system has to be monitored during an observation phase. The closure of the disposal facility is ordered by the Federal Council based on a project, which has to be approved by the supervisory authority. After closure, the Federal Council can take further measures like an environmental monitoring of the site.
- Geological investigations (e.g. deep boreholes) in view of disposal of radioactive waste require a licence issued by DETEC.
- Domestic transport, import, export and transit of nuclear fuel and radioactive waste are subject to licence issued by the SFOE.
- Shipment of spent fuel for reprocessing abroad are prohibited since the revision of the Nuclear Energy Act in 2018
- In the nuclear area, the supervisory authority with respect to nuclear safety and radiation protection is ENSI. In the non-nuclear area, the supervisory authorities are the Federal Office of Public Health (FOPH) and the Swiss National Accident Insurance Office. FOPH manages the licensing procedures in the non-nuclear area.

The licensing process for nuclear facilities is conducted by the SFOE and consists of the following main steps:

1. Submission of the application with a description of the project and a safety analysis report.
2. Review of the project by the nuclear safety authorities.
3. Consultation of federal offices and cantonal governments.
4. Public consultation (licence application and review reports).
5. Compilation by the SFOE of the feedback collected from the public consultation and preparation of the decision.
6. Decision by the DETEC or the Federal Council, generally along with a list of licence obligations. Appeals against the decision may be filed with a board of appeals (this does not apply in the case of decisions by the Federal Council).

The detailed procedure for the site selection of disposal facilities prior to the application for the general license is not prescribed by the current legislation. The Nuclear Energy Ordinance however states that the site selection process must be defined in a so-called “sectoral plan”. Sectoral plans are spatial planning instruments typically used at the federal level to implement major infrastructure projects of national importance such as airports or high voltage transmission lines. The conceptual part of the “Sectoral plan for deep geological repositories” (sectoral plan), defining the various steps of the procedure, the selection criteria as well as the respective role of the stakeholders, was prepared by the federal authorities under the lead of the SFOE. Following a broad consultation process, it was approved by the Federal Council on 2 April 2008.

The focus of the site selection process is on safety-based criteria, but land use and socio-economic aspects must also be taken into account. The conceptual part of the sectoral plan specifies a three-stage site selection process. It regulates the collaboration between the Federal Council, the relevant federal offices, the implementer, the cantons, communes and neighbouring countries. It also outlines how spatial planning activities are coordinated with one another and how development can be supported in siting regions that are influenced by the repository projects.

2.2 REGULATIONS concerning specific activities or facilities

2.2.1 RADIOACTIVE waste management

Specific regulations are implemented in the licences granted by the licensing authority. In the field of radioactive waste management, licences have up to now been granted for various geological investigations and for the construction and operation of conditioning and storage facilities. The licences generally contain a series of obligations which also define the steps or activities which are subject to a permit by ENSI.

All licences for geological investigations require the formation of a supervisory commission constituted with representatives of the federal, cantonal and local authorities involved at the particular site, generally also including persons from groups opposing the project.

The operation licences for conditioning and storage facilities specify in detail the limits for effluent discharges from the facility. They also set the criteria for the acceptance of waste for conditioning or storage. The licence for the Central Storage Facility specifies the reference requirements which shall be met by the transport and storage casks foreseen for spent fuel and vitrified high level waste.

2.2.2 DECOMMISSIONING

The Nuclear Energy Act requires the operator of a nuclear facility to apply for a general licence as a first step. Applications for construction and operation licences can only be made once the general licence has been issued. Licensees must state the basic commitments with respect to decommissioning in the application documents for the general licence and present a decommissioning plan with the application documents for the construction licence. They have to regularly update the decommissioning plan during the operation period. At the end of the operational lifetime of the facility, they must submit a decommissioning project. After this project has been reviewed and approved by the authorities, a decommissioning order is issued by the licensing authority (DETEC). The legislation thus addresses all aspects of decommissioning at the appropriate stage of facility development.

2.3 GUIDANCE on implementation

The guidelines issued by ENSI state in detail how the Swiss nuclear safety authorities intend to carry out their legal tasks. The intent is to give advice to designers, constructors and operators of nuclear facilities regarding the criteria by which the nuclear safety authorities assess formal licence applications and supervise the facilities. The guidelines are not legally binding, but the fulfilment of the requirements set forth in the guidelines is a prerequisite for a positive assessment of a project by ENSI.

2.3.1 RADIOACTIVE waste management

Four guidelines issued by ENSI concern specifically radioactive waste management: ENSI-B05 on the conditioning of radioactive waste, ENSI-G03 on the requirements for geological disposal, ENSI-B17 on requirements for the interim storage of radioactive waste), and ENSI-G05 on the requirements for transport and storage casks.

Guideline ENSI-B05: Requirements on the Conditioning of Radioactive Waste

Conditioning represents the first step on the way to the disposal of radioactive waste. Although disposal facilities do not yet exist in Switzerland, the conditioned waste packages must be suitable for interim storage as well as for disposal.

Radioactive waste should be conditioned in such a way that the resulting waste package can be subjected as a unit to the waste management stages of transport, storage and disposal. Subsequent packaging procedures (e.g., over-packing for transport or disposal) are admissible. To achieve this objective, requirements concerning the waste form, the packaging, the waste package, the data acquisition and the quality assurance are set. The procedure for obtaining the permit for the production of waste packages is fixed. A prerequisite for granting the permit is that Nagra, the organisation responsible for disposal, certifies the suitability of the type of waste package to be disposed of in one of the repositories foreseen.

A series of technical measures are indicated, which are regarded as acceptable means for fulfilling the protection objectives.

Guideline ENSI-G03: Protection Objectives for the Disposal of Radioactive Waste

The guideline ENSI-G03 defines specific design principles for deep geological repositories and requirements for the safety case. It applies to all methods of geological disposal and to all categories of radioactive waste. It is planned to implement a revised version of guideline G03 in 2020.

The overall objective of radioactive waste disposal and the principles to be observed, which are stated in the guideline ENSI-G03, are in agreement with the internationally agreed IAEA requirements. The safety requirements, derived from the overall objective and associated principles, are expressed in the form of protection objectives:

1. *Protection of human*: The geological disposal of radioactive waste may result in only low additional radiation exposure to individual members of the population.
2. *Protection of the environment*: As the natural basis for the existence of man and other living beings, the environment must be protected. Biodiversity may not be put at risk by geological disposal.
3. *Transboundary protection*: The risks resulting from geological disposal of radioactive waste in Switzerland may not be higher in other countries than is permissible in Switzerland.
4. *Future protection*: Risks arising in the future from geological disposal of radioactive waste may not be greater than those permissible in Switzerland today.
5. *Long-term safety*: A geological repository has to be designed in such a way that, after its closure, no further measures are required to ensure long-term safety.
6. *Safety barriers*: The long-term safety of a geological repository is to be assured by staged, passively functioning natural and engineered barriers (multiple barrier system, Article 11, paragraph 2b of the Nuclear Energy Ordinance).
7. *Monitoring and retrieval*: Any measures that would facilitate monitoring and maintenance of a geological repository or retrieval of the waste may not compromise the functioning of the passive safety barriers (Article 11, paragraph 2c of the Nuclear Energy Ordinance).
8. *Freedom from burdens*: The responsibility for geological disposal lies with the generation enjoying the benefits of the energy production. No undue burdens should be placed on future generations.

9. *Natural resources*: The foreseeable future use of natural resources may not be unnecessarily restricted by the presence of a geological repository.
10. *Optimisation*: For decisions that form part of planning, construction and operation (including closure) of a repository, alternatives are to be considered with a view to optimising operational and long-term safety.

Quantitative protection criteria are used to determine whether the protection objective has been fulfilled, taking the guiding principles for implementation into consideration. Compliance with the protection criteria has to be shown in a safety demonstration.

The variants for the future evolution of a sealed repository that are realistically conceivable are to be classified into likely and less likely and the selected classification has to be justified. Based on this classification, there are two protection criteria for the post-closure phase:

Protection criterion 1: For each future evolution classified as likely, the release of radionuclides may not lead to an individual dose exceeding 0.1 mSv per year.

Protection criterion 2: Future evolutions classified as less likely and not considered under protection criterion 1 may not, taken together, constitute an individual radiological risk of fatality exceeding one in a million per year.

Guideline ENSI-G04: Requirements for interim Storage of Radioactive Waste

The interim storage system comprising the store and the waste packages must equally fulfil two goals: (1) the protection of human health and the environment against emissions from the waste packages and (2) the protection of the waste packages against harmful effects.

Guideline ENSI-G05: Requirements for Transport and Storage Casks

The transport and storage casks have to resist static and dynamic impacts in both normal operation and in accident situations. For each new transport and storage cask type a safety report has to be prepared, which will be reviewed by the supervisory authority ENSI. The safety report must address the requirements listed in the guideline. These include requirements concerning the following issues:

- density of the casks
- subcriticality
- resistance to ageing
- protection against airplane crash
- behaviour in case of an earthquake
- limitation of dose rate
- limitation of the temperature of the casks and their contents
- limitation of the temperature at the cask surfaces and in the storage facility
- validity of transport licence for dangerous goods
- possibility to retrieve the contents of the casks

2.3.2. DECOMMISSIONING

The guideline ENSI G-17 stipulates the requirements for the decommissioning of nuclear installations. It also specifies the detailed requirements for the application documents regarding decommissioning. The guideline was published in 2015.

3. WASTE MANAGEMENT STRATEGY AND CURRENT PRACTICE

3.1 WASTE classification and quantities

The Radiological Protection Ordinance defines when material or waste is considered to be radioactive and falls within the scope of application of the legislation on radiological protection. In addition, the Nuclear Energy Act applies to:

- nuclear materials;
- nuclear facilities;
- radioactive waste:
 1. that is generated in nuclear facilities, or
 2. that has been delivered in accordance with article 27, paragraph 1 of the Radiation Protection Act

The following waste categories are defined in the Nuclear Energy Ordinance:

- High level radioactive waste
 - spent fuel elements that are no longer used;
 - vitrified fission product solutions
- Alpha-toxic waste: waste in which the content of alpha emitters exceeds 20'000 becquerels per gram of conditioned waste. It includes reprocessing as well as MIR waste.
- Low and intermediate level waste: all other radioactive waste.

The main producers of radioactive waste in Switzerland are the nuclear power plants. There are 4 reactors in operation - 3 PWR (Beznau 1 and 2 and Gösgen) and 1 BWR (Leibstadt) at 3 sites totalling around 2800 MWe. The BWR reactor at Mühleberg was shut down in December 2019.

This gives or eventually will give rise to following waste streams:

- Spent fuel
- Vitrified waste from spent fuel reprocessing (now banned by the nuclear energy legislation)
- Operational waste.
- Decommissioning waste.

Further radioactive waste arises from the use of radionuclides in medicine, industry and research. Switzerland has no uranium mines and no enrichment, fuel fabrication or reprocessing plants.

At present, the following spent fuel and radioactive waste management facilities exist in Switzerland:

- Nuclear power plants:

All Swiss nuclear power plants have on-site installations for the conditioning and storage of their own operational waste.
- Central Storage Facility:

This facility operated by the ZWILAG company in Würenlingen features storage buildings for spent fuel and all kinds of radioactive waste, conditioning installations and a plasma furnace for melting and incineration of low-level waste.
- Separate storage facility ZWIBEZ at Beznau nuclear power plant:

It consists of a hall for low level operational waste and a hall for the dry storage of spent fuel.

- Wet storage facility at Gösgen nuclear power plant:
An additional spent fuel pond on the site of the Gösgen nuclear power plant. It is intended to be also independently operational over several years after the future shutdown of the Gösgen nuclear power plant.
- National Collection Centre and Federal Storage Facility:
These installations for radioactive waste from medicine, industry and research are operated by the Paul Scherrer Institute (PSI) in Würenlingen.

There are yet no deep geological repositories in Switzerland, site selection is ongoing.

An overview of the waste arisings is provided below. These figures are based on the model inventory of all radioactive wastes estimated to arise from an operating lifetime of 47 years for NPP Mühleberg and 60 years for the other four NPPs and from their subsequent decommissioning. The volume of waste from medicine, industry and research (MIR) is based on the end of operation of the L/ILW repository. The values indicated are for the wastes packaged in disposal containers ready for placement in the repositories; the values in brackets are the volumes of conditioned wastes, as delivered to the disposal facility, before packaging into disposal containers.

According to current estimates, the total volume (rounded) of waste for the L/ILW repository will amount to 82,000 m³ (42,500 m³) for the existing NPPs and waste from medicine, industry and research. Of this, 19,000 m³ (14,000 m³) is operational and decommissioning waste from medicine, industry and research, 35,500 m³ (9,500 m³) represent operational waste from the NPPs (including exchangeable reactor internals such as control rods, etc.) and from the future SF/HLW encapsulation plant and repository surface facilities. Furthermore, 27,500 m³ (19,000 m³) are expected from the decommissioning of the five existing NPPs and the waste treatment installations (e.g. plasma incinerator) at the ZWILAG centralised interim storage facility.

A total of around 4,100 tonnes HM of spent fuel is expected from the five reactors currently in operation, assuming an operating lifetime of 47 years for NPP Mühleberg and 60 years for the other four NPPs. Around 1,140 tonnes IHM of spent fuel have been reprocessed in France and the United Kingdom. Following the latest revision of the nuclear energy legislation, reprocessing is now prohibited. The expected volumes thus amount to 9,000 m³ (1,365 m³) of spent fuel elements (encapsulated in disposal containers) and 400 m³ (115 m³) of vitrified high-level waste to be disposed of in the HLW-repository.

Alpha-toxic waste includes reprocessing as well as MIR waste. The expected volumes amount to approximately 1,100 m³ (290 m³).

Finally, the following table shows the volumes and activities of waste prepared for geological disposal as of the end of 2018. The table does not contain pre-conditioned raw wastes and waste packages prepared for processing in the Zwilag plasma furnace, for example.

Conditioned waste (31st December 2018, figures rounded)	Volume (m3)	Activity (Bq)
Nuclear power plants	3 532	$2.5 \cdot 10^{15}$
Zwilag	2 366	$7.5 \cdot 10^{18}$

Federal Government's interim storage facility (MIR)	1 578	$1.2 \cdot 10^{16}$
---	-------	---------------------

The Zwilag waste consists of waste packages delivered to the interim storage facility from the power plants, waste packages from the plasma furnace and steel flasks with vitrified high-level waste from reprocessing.

3.2 WASTE management strategy and issues at national level

Radioactive waste arising from the use of radioisotopes in medicine, non-nuclear industry and research is collected by the Paul Scherrer Institute (PSI) on behalf of the Federal Office of Public Health. It is then conditioned and stored until disposal at the Federal Storage Facility at the PSI.

Radioactive waste arising from the operation of the nuclear power plants is conditioned and stored mostly on-site. Some low-level operational waste has been conditioned (e.g. incinerated) at PSI in the past. This kind of waste is now transferred to the Central Storage Facility operated by ZWILAG for incineration and melting in the new plasma furnace. This installation was commissioned in 2001 and started its operation in the same year.

Until 1 July 2006, spent fuel was sent for reprocessing to France (AREVA NC) and the United Kingdom (Sellafield Ltd), until a moratorium prohibited the export of spent fuel for reprocessing until 30 June 2016. Before the start of the moratorium, about 1'139 t of spent fuel were shipped from the Swiss NPPs to the reprocessing facilities. All Swiss fuel was reprocessed. The waste arising from reprocessing was returned to Switzerland and is stored at the Central Storage Facility.

Spent fuel is now stored in transport and storage casks at the Central Storage Facility. At the end of 2018, the storage hall contained 41 casks with spent fuel elements from the nuclear power plants Gösgen, Leibstadt and Mühleberg and one cask with spent fuel elements from the research reactor "Diorit" from PSI.

ZWIBEZ, an interim storage facility located at the Beznau NPP, can accommodate 48 storage casks for HLW and spent fuel. ZWIBEZ contained 11 casks at the end of 2018. In addition to that, a separate building for the wet storage of spent fuel elements was commissioned at Gösgen nuclear power plant in 2008, with a storage capacity for 1056 spent fuel assemblies.

A combined repository (L/ILW and HLW) or two deep geological repositories are foreseen for the disposal of all Swiss radioactive waste. For low and intermediate level waste, the demonstration of feasibility was formally accepted by the Federal Council in 1988. Acceptance was based on a study of the technical feasibility and safety of the disposal concept, entitled "Project Gewähr" ("Guarantee"), which was prepared by Nagra and reviewed by the regulatory authorities. Nagra's site selection procedure for a L/ILW repository began in the 1970s. In 1993, Nagra proposed Wellenberg in Canton Nidwalden as the repository site and in 1994, an application for a general licence was submitted. The review of the licence application by the federal nuclear safety authorities came to a positive conclusion, but the granting of the mining concession required by cantonal legislation was rejected by the voters of Canton Nidwalden in a cantonal referendum (the siting commune of Wolfenschiessen voted in favour of the concession). A gradual approach was subsequently proposed and an application for an exploratory shaft only (for a modified repository project) was submitted in 2001. The population of Canton Nidwalden rejected the concession application in September 2002, with the commune of Wolfenschiessen voting again in favour of the project. Consequently, the project was abandoned.

For high-level waste disposal, Nagra initially pursued the option of the crystalline basement as a first priority and in 1979, an application was submitted for a licence to construct a rock laboratory in the crystalline formations of the Grimsel region (canton Bern). The following considerations favoured the selection of crystalline as a host rock:

- knowledge available from foreign projects (particularly Sweden);
- favourable properties with regard to rock mechanics (e.g. strength) that would facilitate the construction and operation of a repository;
- based on available knowledge, it was assumed that large-scale undisturbed blocks of rock with low permeability exist in the crystalline basement of northern Switzerland;
- no conflict with natural resources.

The selection of the crystalline basement as a host rock served as the basis to identify the investigation area for potential sites: the area to be investigated had to be tectonically quiet and stable in the long term. The Alps and the areas of north and north-west Switzerland influenced by the Rhine valley rift (“Oberrheingraben”) did not meet these requirements and were therefore excluded. Due to the risk of erosion, the repository also had to be located at least 400 m below the earth’s surface, yet for reasons of engineering feasibility and temperature, no deeper than 1200 m below the surface. Since crystalline formations satisfying these criteria could only be found in northern Switzerland, the investigation area was limited to a relatively small area covering the cantons of Solothurn, Aargau, Zurich and Schaffhausen. In June 1980, Nagra submitted applications to drill twelve deep boreholes in the crystalline basement of northern Switzerland and performed a reflection seismic campaign in the region of interest. Between October 1982 and February 1985, Nagra drilled exploratory boreholes at Böttstein, Weiach, Riniken, Schafisheim, Kaisten and Leuggern under the supervision of the responsible authorities. The seventh borehole, in Siblingen, was drilled between September 1988 and April 1989. The investigations delivered some surprising results: it was found that the crystalline basement of northern Switzerland is intersected by a large sedimentary trough (the so-called Permo-Carboniferous Trough). The notion that there was a large body of non-fractured crystalline rock in northern Switzerland therefore had to be abandoned and Nagra decided not to drill the remaining boreholes.

Project Gewähr (“Guarantee”), which was submitted to the authorities by Nagra in 1985 was based on the crystalline option for HLW disposal. Following a review by the responsible authorities, the Federal Council decided in June 1988 that it was feasible to construct a repository in crystalline rock with the required level of long-term safety. However, it found that there was insufficient proof that the site was satisfactory, i.e. that sufficiently extensive bodies of rock with the required properties could be found, and requested the waste producers to expand their investigations to include sedimentary rocks.

The phase of regional investigations in the crystalline basement of northern Switzerland was concluded by Nagra in 1995 with the „Kristallin-I“ safety analysis. Following a review of this project, HSK³ concluded in 2004 that the safety of a geological repository for vitrified HLW could be assured if a sufficiently large body of rock with the properties described in Kristallin-I could be found. In HSK’s opinion, however, the prospects of finding such a body of rock and demonstrating conclusively that it had the required properties had not improved since Project Guarantee.

For sediments, Nagra initially presented a selection of seven potential host rocks. Based on existing information on safety-relevant properties and the distribution of these rock formations in Switzerland, Nagra then selected two options (Lower Freshwater Molasse (LFM) and Opalinus Clay) for further investigation. The next steps were to carry out field investigations in the Opalinus Clay, evaluate existing data on the Lower

³ Swiss Federal Nuclear Safety Inspectorate (now ENSI)

Freshwater Molasse and to participate in investigations of the LFM being carried out in various boreholes and tunnels. In 1996, an international research project was initiated in the Opalinus Clay of the Mont Terri Rock Laboratory (canton Jura). Nagra, the Confederation and other partner organizations are still involved in this project today. As is the case for the Grimsel Test Site, the Laboratory is purely for research purposes.

The results of the sediment investigations showed that, at least for a HLW repository, the Opalinus Clay has clear advantages in terms of safety over the Lower Freshwater Molasse. As a result, and as part of the work to demonstrate the feasibility of disposal, Nagra proposed exploring the Opalinus Clay option with spatially restricted site investigations and keeping the LFM as a reserve option. The responsible federal authorities (ENSI, CRW, NSC) agreed to this proposal in 1995.

Defining the investigation region for Opalinus Clay was based on safety-oriented criteria and finally led to extensive geological investigations being carried out in the Weinland region of canton Zurich. Nagra submitted an application for a borehole at Benken, which was granted by the Federal Council in 1996. The results from the borehole and the 3D seismic campaign were analysed and documented in several reports. They confirmed the tectonically undisturbed bedding of the Opalinus Clay in the Benken-Trüllikon-Oerlingen-Marthalen area and the long-term isolation capacity of the Opalinus Clay rock formation.

Based on these results, Nagra submitted the report to demonstrate the feasibility of disposal for HLW to the federal government at the end of 2002. In a so-called "Options Report", Nagra showed which largescale areas would come into consideration for a HLW repository from a geological viewpoint, which host rocks exist in these areas and which are potential siting area. In June 2006, the Federal Council, and its supporting authorities concluded that the legally required demonstration for these wastes was successful. This was not a siting decision, but a demonstration of the general feasibility of constructing a geological repository in Switzerland, as required by the nuclear energy legislation. The demonstration served as a basis for the Federal Council to define future procedure in the waste management programme.

According to the Nuclear Energy Ordinance of 2004, the site selection process for both L/ILW and HLW repositories is defined in a so-called "Sectoral Plan" within the framework of the spatial planning legislation (see chapter 2.1). The Federal Council adopted the Conceptual Part of the "Sectoral Plan for Deep Geological Repositories" in April 2008, thus initiating a three-stage procedure that will result in the designation of suitable sites for deep geological repositories. The procedure is led by the SFOE, whereas Nagra acts as the implementer. ENSI is the safety authority. An overview of milestones and decisions in the Swiss programme is described below.

Stage 1 (2008-2011)

Stage 1 focused on the identification of suitable siting regions using safety and geological criteria. In October 2008, Nagra proposed potential geological siting areas on the basis of safety criteria (see chapter 3.2):

- Südranden (Canton Schaffhausen) with the host rock Opalinus Clay and its confining units
- Zürich Nordost (Cantons of Zurich and Thurgau) with the host rocks Opalinus Clay and the claystone sequence 'Brauner Dogger' with their confining units
- North of Lägern (Cantons Zurich and Aargau) with the host rocks Opalinus Clay and the claystone sequence 'Brauner Dogger' with their confining units
- Jura Ost (Canton Aargau) with the host rock Opalinus Clay and its confining units
- Jura-Südfuss (Cantons Solothurn and Aargau) with the host rocks Opalinus Clay and its confining units and the Effingen Beds

- Wellenberg (Cantons of Nidwalden and Obwalden) with the host rock marl formations of the Helveticum

The siting areas for the HLW repository are:

- Zürich Nordost (Cantons Zurich and Thurgau) with the host rock Opalinus Clay and its confining units
- North of Lägern (Cantons Zurich and Aargau) with the host rock Opalinus Clay and its confining units
- Jura Ost (Canton Aargau) with the host rock Opalinus Clay and its confining units

In the last three siting areas a so-called "combined repository" (L/ILW and HLW) is also envisaged.

ENSI, their experts and the Federal Nuclear Safety Commission reviewed safety-related aspects of the proposed sites. In 2010, they both confirmed that Nagra's analysis of the geological information was technically justified, comprehensive and transparent and therefore agreed to the six proposed siting areas. The proposals by Nagra were also reviewed by an expert group of the cantons (AG SiKa/KES) and by a German expert group (ESchT). In their review reports both agreed with Nagra's proposed siting areas as well. A broad public consultation took place from September to November 2010. 3'700 statements were received, which were compiled by the SFOE. The Federal Council approved the proposed geological siting regions in November 2011 and incorporated them into the Sectoral Plan.

With regional participation being an important component of the site selection procedure, so-called "regional conferences" were set-up in all six siting regions in order to guarantee that the interests and needs of the siting regions are considered. These bodies consist of representatives from the municipalities affected as well as from organisations and the population. This regional participation, set-up and lead by the SFOE, provides the siting regions with the opportunity to represent their region and to express their concerns within the process.

Stage 2 (2011-2018)

Stage 2 aimed at selecting at least two sites each for the L/ILW and the HLW repository. In 2015, Nagra proposed Jura Ost and Zürich Nordost as geological siting areas in which one repository for each waste category of radioactive waste or a combined repository would be feasible. Following its detailed study, ENSI came to the conclusion that, in addition to the two proposed geological siting areas, Nördlich Lägern should also be further examined. This view was shared by the Federal Nuclear Safety Commission. In addition to narrowing down the number of geological siting areas, Nagra collaborated with the regional conferences in the proposed siting regions to identify and designate locations for the placement of the surface facilities. For each siting region, at least one area was designated. Additionally, the siting regions were evaluated on the basis of socio-economic and ecological criteria. The findings were summarised in a socio-economic and ecological impacts study. Following a public consultation in 2017, stage 2 was concluded with the decision by the Federal Council in November 2018. The results were incorporated into the Sectoral Plan.

Stage 3 (2018-ca. 2029)

The goal of stage 3 is site selection. The findings relating to the site-specific geological conditions will be supplemented by geological studies in the three remaining geological siting regions. The surface infrastructure will be finalised in cooperation with the three remaining regional conferences and the social and economic impacts of the repositories will be examined in greater detail. Approximately in

2024, Nagra will submit general licence applications for the construction of a combined repository or two separate repositories. These applications will be reviewed by the relevant authorities. Towards the end of the 2020s, the Federal Council will decide on the applications for general licences, and its decision will have to be approved by Parliament. Parliamentary resolutions are subject to optional national referenda. If a referendum is initiated, the Swiss electorate will decide on the award of the general licence, most likely in the early 2030s. Only once this entire process is concluded, will the sites for the deep geological repositories be definitive.

After the construction and operation of facilities for underground geological investigations applications for a construction license and ultimately for an operating license for each repository will follow, both of which will be granted by the relevant Federal Department. According to the current schedule, the L/ILW repository should be operational around 2050 and the HLW repository around 2060.

Field investigations

Geological investigations in the three siting regions Jura Ost, Zürich Nordost and Nördlich Lägern started in 2019. 3D-seismic campaigns were already performed from 2015 to 2017. Interpretation of the data showed that sufficient space is available in the clay rich host rock formation in all three siting regions. The investigations revealed differences between the siting regions from the point of view of lithology and tectonic setting.

The investigation of the rock properties in the siting regions requires deep boreholes up to 1200 m below surface to recover rock samples and perform in situ testing. A total of 23 applications for drillsites have been submitted by Nagra. By January 2020, 18 licenses have been granted. Drilling was completed at the first site (Bülach, siting region Nördlich Lägern), while operations are nearing completion at Trüllikon (siting region Zürich Nordost). Preparations are ongoing at several other sites.

Furthermore, drilling in shallow boreholes focussing on the recent landscape evolution in the siting regions is currently ongoing.

3.4 RESEARCH and Development

3.4.1 RESEARCH infrastructure

R&D on radioactive waste management is performed at the Paul Scherrer Institute (PSI) and at the underground rock laboratories (Grimsel and Mont Terri), but also at several universities and research institutes in Switzerland and abroad. Several projects are conducted within an international framework (e.g. IGD-TP or EU Framework programmes, now Joint Programming, or bilateral and multi-lateral agreements). The implementer Nagra funds a substantial part of this R&D. The government funds research as well. ENSI, the regulatory body for nuclear energy, initiates and funds safety related regulatory R&D. A small amount of ENSI's R&D budget is devoted to radioactive waste management. ENSI also follows and comments on the work done at the PSI.

The nuclear energy act stipulates that the federal Government may promote applied research into the peaceful use of nuclear energy, especially into the safety of nuclear installations and into nuclear waste disposal. For this purpose, it runs a research programme, covering the needs of the Confederation in this field. The SFOE manages projects in the fields of human and social sciences and ENSI the regulatory safety related research.

3.4.2 CONTENTS of R&D plans

Waste management R&D activities at PSI are mainly performed at the Laboratory for Waste Management. The activities address fundamental repository chemistry, chemistry and physics of radionuclides at geological interfaces and radionuclide transport and retardation in geological media and engineered barriers. The work performed is a balanced combination of experimental activities in dedicated laboratories for handling radioactive isotopes and in the field, and theoretical modelling. The work is directed towards repository projects and the results find their application in comprehensive performance assessments carried out by Nagra.

RD&D activities underpinning the geological characterization of the potential siting areas are conducted in Switzerland at several universities (UniBern, ETHZ, EPFL) contributing to geological characterization methods and process understanding (geophysics, tectonics, stratigraphy, mineralogy, erosion).

A large share of the RD&D activities related to the engineered barriers (canister, bentonite) and their evolution are conducted as part of international collaborations or networks.

At Grimsel Rock Laboratory (granite site) research projects are jointly conducted by partner organisations from 12 countries including Switzerland. Phase VI, ongoing since 2003, has been extended until 2023. The projects relate mainly to the understanding of engineered barrier systems under realistic conditions on a 1:1 scale and to the transport behavior of radionuclides in granitic rocks.

The Mont Terri rock laboratory (clay site) is also an international project with partners from several countries. The experiments at the Mont Terri rock laboratory relate particularly to diffusion and retention of radionuclides in clay, thermo-hydro-mechanical behavior of clay, rock mechanics, gas flowpaths and self-sealing of fissures. Several experiments also address engineered barriers at the 1:1 scale or smaller. ENSI is funding several experiments on rock mechanical issues carried out by the engineering geology unit of the Federal Institute of Technology.

All projects within the research programme of the Confederation must have a solid scientific basis and at the same time focus on practical application. The various project themes should be approached in an open-minded manner and on an interdisciplinary basis. The projects managed by the SFOE cover the priorities listed below:

- Long-term aspects (retention of knowledge and marking)
- Sectoral planning procedure (communication with society)
- Public perception, opinion making and acceptance
- Ethical and legal aspects

3.5 FINANCING of Radioactive Waste Management

3.5.1 FRAMEWORK and responsibilities

In accordance with the polluter-pays principle, producers of radioactive waste in Switzerland are responsible for ensuring its safe management and eventual disposal at their own cost. The various ongoing costs (e.g. for reprocessing, studies carried out by Nagra, construction of interim storage sites) have to be paid as they arise. Decommissioning costs and expenditure associated with the management (including disposal) of radioactive waste after a nuclear power plant has been closed down, are secured through contributions paid into two independent funds by the operator:

- Decommissioning fund for nuclear facilities
- Disposal fund for nuclear power plants

The Nuclear Energy Act and the Federal Ordinance on the Decommissioning Fund and the Waste Management Fund (7 December 2007) form the legal basis for these two funds.

The purpose of the Waste Disposal Fund is to secure the costs for the disposal of nuclear waste resulting from the operation of nuclear installations, and of spent fuel elements following the decommissioning of a nuclear power plant. It was established in 2000.

The aim of the Waste Disposal Fund is to secure the costs for the disposal of nuclear waste and spent fuel elements following the decommissioning of a nuclear power plant. The most important cost components are containers for transport and storage, transport, disposal of spent fuel elements, central waste treatment and interim storage, and disposal of radioactive waste in two deep geological repositories or a combined repository. The owners of the five nuclear power plants in Switzerland (Beznau 1 and 2, Mühleberg, Gösgen and Leibstadt) are obliged to pay annual contributions into this fund.

The purpose of the Decommissioning Fund is to secure the costs for the decommissioning and subsequent dismantling of nuclear installations, and for the disposal of the resulting waste. It was established in 1984.

The aim of the Decommissioning Fund is to secure the costs for the decommissioning and dismantling of nuclear facilities and for the disposal of the resulting waste. The owners of Beznau 1 and 2, Mühleberg, Gösgen and Leibstadt nuclear power plants and of the interim waste storage facility in Würenlingen (ZWILAG) are obliged to pay annual contributions into this fund.

3.5.2 STATUS of financing schemes

The decommissioning and waste disposal funds are supervised by the Federal Council. The SFOE fulfils this supervisory function on behalf of the Federal Council. The annual reports of the funds are approved and published by the Federal Council, which also chooses the members of the Administrative Commission and discharges the Administrative Council. In addition, it chooses the auditors of the funds.

The annual contributions into the funds paid by the operators are based on a mathematical model the key points of which are governed by the Swiss Federal Ordinance on the Decommissioning Fund and the Waste Disposal Fund (SEFV) of 7 December, 2007. The costs of decommissioning and waste disposal are recalculated every five years. Subsequently, a review is carried out by ENSI as well as by cost experts. Then the Federal Department of the Environment, Transport, Energy and Communications (UVEK) determines the costs of decommissioning and waste disposal. The amount arrived at is extrapolated by an assumed increase in the costs and subsequently discounted by an assumed investment rate of return at the time of the final decommissioning. This amount has to be accumulated by the time of the definitive decommissioning.

According to the cost study drawn up in 2016 and the determination of the costs by the UVEK the costs of decommissioning in Switzerland will amount to around 3.8 billion CHF, and those of waste disposal to around 19.5 billion CHF. The costs of decommissioning are to be covered entirely by the decommissioning fund. The costs of waste disposal are to be partially paid directly by the operators and partially by the operators through the waste disposal fund.

The holdings of the decommissioning fund amounted to around 2.4 billion CHF at the end of 2018, and those of the waste disposal fund to around 5.0 billion CHF.

4. DECOMMISSIONING STRATEGY AND CURRENT PRACTICE

4.1 DECOMMISSIONING strategy

The shutdown of the five commercial NPP will be followed by a post-operation phase of 4-5 years with removal of spent fuel and technical as well as administrative work in preparation for the decommissioning. Based on the concept of immediate dismantling, the decommissioning process starts immediately after the post-operation phase with the eventual turning of the sites into a green field.

4.2 STATUS of decommissioning projects

One experimental nuclear power plant was dismantled. This facility at Lucens in the Canton of Vaud, was shut down in 1969 following an accident and subsequently decommissioned. The last part of the site has been released from nuclear regulatory control in 2004. The radioactive waste resulting from the dismantling is stored at the Central Storage Facility.

In 1989 the Federal Council decided that the Department of Nuclear Physics at the University of Geneva had completed the decommissioning of the research reactor and released the site from the former atomic legislation. The fuel elements were transferred to the Paul Scherrer Institute. No radioactive waste resulted from the dismantling of this installation.

Two research reactors at the Paul Scherrer Institute (PSI) are in the process of being decommissioned. The decommissioning activities started in 1994 and 2002, respectively, and they are in their final stage. Many premises of the former nuclear facilities are already used for other purposes. The waste is stored at the Federal Storage Facility.

In July 2014, the DETEC issued PSI an order for the decommissioning of its pilot incinerator plant which ceased operations at the end of 2002. Decommissioning is taking place now and expected to be terminated by 2021 (green field).

4.3 DECOMMISSIONING issues at national level

The operator of Mühleberg NPP applied for a decommissioning order in December 2015, well before the planned shutdown in December 2019. DETEC issued the decommissioning order in June 2018. This order has since become legally binding and the operator's preparations for decommissioning are on schedule. Milestones of decommissioning Mühleberg NPP will be the complete removal of spent fuel by 2024 and conclusion of clearance measurements by 2029.

There are currently no plans for decommissioning of the other Swiss nuclear power plants in the near future. Both the operators and the regulator are following the developments on decommissioning in the international scene.

4.4 RESEARCH and development

4.4.1 RESEARCH Infrastructure

There is currently no R&D programme on decommissioning in Switzerland.

4.4.2 CONTENTS of R&D plans

4.5 FINANCING

4.5.1 FRAMEWORK and responsibilities

See above, Radioactive waste management

4.5.2 STATUS of financing schemes

See above, Radioactive waste management