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Technical Report 21-01E

Waste Management Programme 2021 of the Waste Producers

December 2021

National Cooperative for the Disposal of Radioactive Waste

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The present document is a translation of NTB 21-01 for information purposes only. For formal purposes please refer to the original German version.

The Waste Management Programme was discussed in depth with the waste producers and was approved by them at the meeting of Nagra's Board of Directors on 03rd December 2021.

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Executive summary

This report documents the Waste Management Programme prepared by the Swiss waste producers in line with legal requirements. From the perspective of the waste producers, the objective of the Waste Management Programme is to provide a comprehensive presentation of the work required for disposing of all radioactive waste in Switzerland (strategic work programme), to identify the conceptual requirements and assumptions and to outline how these will be implemented in the design of the facilities and their stepwise construction.

The Waste Management Programme 2021 (WMP21) was prepared by Nagra on behalf of the waste producers; it is directed mainly to the authorities but also outlines how the waste producers have responded to conditions specified by the Federal Council and to further recommendations made by the authorities in relation to the Waste Management Programme 2016 (WMP16).

WMP21 is composed in such a way as to also be informative for the wider public. One important component is documenting the progress made in the Sectoral Plan for Deep Geological Repositories (SGT) since the previous version (WMP16) was published. Particular attention is drawn to the following:

- In concluding Stage 2 of the Sectoral Plan in November 2018, the Federal Council approved the decision to focus on the Opalinus Clay as the host rock for all repository types. Therefore, based on the suitability of this host rock from a safety perspective, it can be assumed for future project planning that the alpha-toxic waste (ATW) will be emplaced in the same repository as the low- and intermediate-level waste (L/ILW).
- At the same time, the Federal Council decided that the Jura Ost (JO), Nördlich Lägern (NL) and Zürich Nordost (ZNO) siting regions were to be investigated in more detail. Based on very close collaboration with the siting regions and cantons, the Federal Council also identified areas for locating the surface facilities and documented these in object sheets for Stage 2.
- Extensive field investigations (2D and 3D seismics, Quaternary boreholes, deep boreholes) have been conducted within the framework of the ongoing Stage 3 of the Sectoral Plan, and preliminary results from these investigations confirm the fundamental suitability of all three siting regions.
- In many countries (such as France, Spain, the UK and the USA), L/ILW is disposed of in near-surface and comparatively cost-efficient repositories. In contrast, Switzerland has decided to pursue the more costly and complex option of deep geological disposal also for this waste category. With the focus on the Opalinus Clay as the host rock for all waste types, it is essentially possible to dispose of all waste in a so-called combined repository, which consists of both HLW and L/ILW repository sections. The results of the advanced field investigations confirm that all three siting regions provide sufficient space for a combined repository layout. This fulfils the same safety requirements regarding operational and long-term safety as two individual repositories, but also has clear advantages regarding construction-related risks, resource consumption and the emission of greenhouse gases as fewer facilities have to be constructed and operated at the surface and underground. Compared to two individual repositories, realising a combined repository is thus associated with operational, safety-related, ecological and economic advantages. For this reason, and if the conclusive overall safety-based assessment allows, the general licence application will be submitted for a combined repository.

- Nagra demonstrated in Stage 3 of the Sectoral Plan process that the areas at the Zwilag interim storage facility and the surface facility at the site of the deep geological repository are the only suitable and reasonable siting options for a spent fuel (SF) encapsulation plant; this position is also supported by a transregional working group.
- The time schedule has not changed since the beginning of Stage 3 of the Sectoral Plan process. The permitting procedure for the deep boreholes did not result in any legal delays that could have impacted the realisation plan and the underground investigations could therefore be carried out as planned. Nagra's announcement of the site(s) for which it will prepare a general licence application for a combined repository or two general licence applications for separate repositories (in line with the Sectoral Plan) is therefore expected for 2022. At the same time, Nagra must specify where it plans to locate the surface infrastructure (including the site of the encapsulation plants).
- As in the past, the cost estimates for the repositories were developed in collaboration with external specialists and companies with extensive experience in the realisation of nuclear facilities and underground construction. The methodology used for the 2021 Cost Study (CS21) was based on the same methodology as that used for the 2016 Cost Study (CS16). Based on the results of CS21, the current cost estimate for the deep geological disposal is slightly lower than in CS16.

Detailed summary

Many important steps in the management of radioactive waste have already been implemented in Switzerland, and there is now wide experience in carrying out the associated activities. This applies in particular to the treatment and packaging of radioactive waste, its characterisation and inventorying as well as interim storage and associated transports.

Legal regulations (Nuclear Energy Act, KEG 2003 and Nuclear Energy Ordinance, KEV 2004) and guidelines are in place for the realisation of a deep geological repository. ENSI's revised G03 Guideline (ENSI 2020b) provides additional, important guidance. The Sectoral Plan for Deep Geological Repositories (SGT) approved by the Federal Council in 2008 regulates the current siting procedure, which is conducted in three stages (BFE 2008). Clarifications on the safety-related specifications for Stage 3 of the Sectoral Plan (ENSI 2018c) also provide concrete requirements for the ongoing, final stage of the site selection process.

This report documents the Waste Management Programme prepared by the waste producers in line with legal requirements (Art. 32 KEG, Art. 52 KEV). The requirements for the Waste Management Programme (WMP) are anchored in Art. 52 Par. 1 KEV. The following summarises the most important information contained in Chapters 2 to 8 of the WMP21 in line with Art. 52 Par. 1 KEV:

- **Origin, types and volumes of radioactive waste (Chapter 2)**: The origin, types and volumes of radioactive waste to be disposed of in Switzerland are known and, in line with Art. 51 KEV, this waste is categorised into high-level waste (HLW), alpha-toxic waste (ATW) and low- and intermediate-level waste (L/ILW). The current Waste Management Programme is based on the "60-year operating lifetime of the nuclear power plants (NPPs)" scenario. This assumes an operating lifetime of 47 years for the Mühleberg NPP (shut down in 2019) and 60 years for the Beznau, Gösgen and Leibstadt NPPs and represents a more conservative assumption regarding the waste volumes than is the case for the "50-year NPP operating lifetime" scenario. For the radioactive waste and materials from applications in medicine, industry and research (MIR), a collection period up to the end of 2064, i.e. the end of L/ILW waste emplacement operations, is assumed. There is still the option to emplace additionally produced L/ILW MIR waste in the repository prior to its final closure (Agneb 2019), which would have to be considered in the general licence application. The entire waste inventory in WMP21 was determined based on the nuclide-specific exemption limits specified in the revised Radiological Protection Ordinance 2017 (StSV 2017). While the volumes of the delivered and conditioned waste remained practically unchanged compared to WMP16 (total approx. 45,000 m^3), the packaged volume (total approx. 82,500 m^3) decreased by around 10% compared to WMP16 (see Section 2.1). To ensure a consistent presentation of the details on waste management in WMP21 and CS21, as well as the comparability of the information in these two reports with that in the previous reports, WMP21 also includes a scenario assuming a 50-year operating lifetime for the Beznau, Gösgen and Leibstadt NPPs and 47 years for the Mühleberg NPP. The waste is continuously conditioned, characterised and inventoried. Before the start of conditioning of a waste stream, the proposed conditioning process must be evaluated by Nagra in terms of the suitability for disposal of the final waste packages. This is a prerequisite for the regulatory approval of routine conditioning. Besides information on existing waste, there is also a model inventory of waste that will arise in the future. This provides a reliable basis for planning and realising the geological repositories and managing the available interim storage capacity.

- **Deep geological repositories (Chapter 3)**: In Switzerland, deep geological disposal is stipulated as the **waste management concept** (Section 3.1.1) in the Nuclear Energy Act (KEG) for all radioactive waste, with the exception of the waste mentioned in Art. 51a KEV. The Swiss waste management concept is based on two repository types: one for L/ILW and one for HLW (information on the allocation of these wastes to the L/ILW and HLW repository types can be found in Section 4.1). The two repositories can be located together as a so-called combined repository in the same siting area. Realising a combined repository is associated with operational, safety-related, ecological and economic advantages (Section 3.1.1). The combined repository is an overall facility, and many elements of the surface infrastructure and some of the underground structures (access structures and central area) can be jointly used. Compared to two individual repositories, realising a combined repository thus leads to important simplifications in terms of construction and operation. Further advantages arise with regard to the licensing procedure and the support and collaboration effort for the project required on site. Results of the field investigations to date confirm that, in principle, all three siting regions provide sufficient space for a combined repository layout. Based on the advantages outlined above, and if the conclusive overall safety-based assessment allows, the general licence application will be submitted for a combined repository.

  In Switzerland, the **safety concept** (Section 3.1.2) is based on a multi-barrier system consisting of staged, passively functioning engineered and natural barriers that are optimised in terms of ensuring long-term safety. These barriers consist of the waste matrix, disposal containers and backfilling and sealing as engineered barriers and the containment-providing rock zone as the geological barrier.

  Even if the **technology for the construction, operation and closure** (Section 3.1.3) will continue to develop until construction begins, the technical feasibility of disposal has already been demonstrated for L/ILW and HLW as part of the so-called *Entsorgungsnachweis* projects (see Section 1.3). The Swiss disposal programme foresees **monitoring and retrievability** as integral components of the repository concepts (Section 3.1.4). Corresponding technical concepts are available and are periodically adapted to reflect the state of the art.

  Geology (Section 3.1.5) as a natural barrier plays a key role: besides isolating the waste from the human environment, i.e. the biosphere, and ensuring long-term stability, it also makes a significant contribution to the barrier function. Following the decision of the Federal Council in 2011, six proposals for potential siting regions for an L/ILW repository and three for an HLW repository were confirmed for further investigation in Stage 2 of the Sectoral Plan. Based on complementary geological investigations and a systematic and safety-oriented narrowing-down process, the Federal Council agreed in 2018 to focus on the Opalinus Clay as the host rock and decided that the Jura Ost (JO), Nördlich Lägern (NL) and Zürich Nordost (ZNO) geological siting regions were to be further investigated in Stage 3 of the Sectoral Plan process.

  In Stage 3, extensive geoscientific investigations were conducted in the three remaining siting regions. By October 2021, eight deep boreholes had been completed and one deep borehole was still ongoing, but drilling is expected to be concluded shortly[1]. Further field investigations include 3D seismics, high-resolution 2D seismics and 11 Quaternary boreholes (see Figs. 3.1-2 and 3.1-3). Together with further studies on the geological and hydrogeological properties of the siting regions, the ongoing evaluation and integration of the field investigations form an important basis for the safety-based comparison of the siting regions and for the justification of the site selection.

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[1] WMP21 was compiled based on the information available as of 31st October 2021.

The next safety demonstrations (Section 3.1.6) for the deep geological repository will be required for the general licence application; the corresponding stipulations can be found in ENSI (2018c). However, safety demonstrations for the operational phase as well as for the post-closure phase of the repository (safety case) are also required for all subsequent licensing steps up till the final closure of the deep geological repository (ENSI 2020b).

Within the framework of Swiss legislation, aspects pertaining to **land use and environmental compatibility** (Section 3.1.7) are clearly regulated; these regulations also apply to the repository project. Stage 1 of an Environmental Impact Assessment (EIA) will be carried out in the course of the general licence procedure. A further component of the general licence application is a report on compliance with spatial planning.

The **repository conceptual design** (Section 3.2) is based on the safety concept for HLW and L/ILW and is a concretisation of the repository concept that is applicable for all siting regions included in Stage 3 of the Sectoral Plan. It considers stage-appropriate requirements on safety, engineering feasibility and the handling of available resources as well as the need for optimisation. The present conceptual design includes stage-appropriate repository concepts as well as concepts for construction, operation and closure. To maintain the required flexibility to consider potential future developments, different variants are considered for elements of the repository conceptual design.

- Following the decision of the Federal Council on Stage 2 of the Sectoral Plan, only geological siting regions (JO, NL and ZNO) remain in Stage 3 that are fundamentally suited for hosting both individual repositories and a combined repository. In WMP21, the repository conceptual design is based on the model of a combined repository. The design of the individual repositories is addressed insofar as to identify which specific components of a combined repository will not be required for the corresponding individual repository (Sections 3.3 and 3.4).

  The facility elements and structures required to operate the repository can be broadly split into three categories:

  – *Surface infrastructure* (see Figs. 3.2-3 and 3.2-4): The surface facility constitutes the core of the surface infrastructure. The radioactive waste must be prepared for emplacement, i.e. packaged for disposal, and this takes place in the encapsulation plants. For practical reasons, these plants will either be realised at the surface facility at the repository site or at the interim storage facility in Würenlingen (Zwilag). In both cases, the packaged disposal containers will be transported below ground through the main access from the surface facility. Auxiliary access facilities mainly provide the infrastructure for repository construction (through the auxiliary access for operations) and a supply of fresh air for the facility elements and the structures at disposal level (through the auxiliary access facility for ventilation).

  – *Underground accesses* (see Figs. 3.2-1 and 3.2-2): These access structures ensure the connection between structures located at the surface and at the disposal level in the form of shafts and tunnels.

  – *Facility components and structures at disposal level* (see Figs. 3.2-1 and 3.2-2): The endpoints of all access structures as well as the accesses to the HLW and L/ILW main and pilot repositories connect to the so-called main underground connection area; this mainly includes the elements of the so-called central area and the test areas. At the disposal level, the combined repository includes a main repository and a pilot repository with observation drifts for both the HLW and L/ILW repository sections.

- **Allocation of the waste to the deep geological repositories (Chapter 4)**: The waste types have not changed since WMP16. As the Federal Council approved focusing on the Opalinus Clay as the host rock for all repository types in conclusion of Stage 2 of the Sectoral Plan, it can be assumed that, for future planning, based on the suitability of the host rock from a safety perspective, the alpha-toxic waste (ATW) will be emplaced in the L/ILW repository or in the L/ILW repository section of a combined repository. The definitive allocation of the waste to the different repositories will be carried out in a stepwise manner as part of the various nuclear licensing procedures. This allows optimisation of the waste allocation or the requirements on the waste to be emplaced based on conditions actually encountered.

- **Realisation plan for construction of the deep geological repositories (Chapter 5)**: The time schedule has remained unchanged since the beginning of Stage 3 of the Sectoral Plan process and is as follows. In the ongoing Stage 3, the announcement of the site(s) for the preparation of the general licence application (around 2022), the submission of the application (around 2024) as well as expert opinions and reports surrounding the decision-making process up till the granting of the general licence are important communication milestones. Although the announcement of the site for which the general licence application will be prepared does not represent a licensing step in the realisation of a deep geological repository, the public could perceive it as "the site selection" due to its media impact. At the same time, and considering the final regional position statements on the surface infrastructure and the transregional position on the site for an encapsulation plant for spent fuel assemblies, Nagra will announce where the surface infrastructure (including the site of the encapsulation plants) will be placed. A legally valid general licence is expected for 2031. The realisation plans in WMP21 include the new phase "preparation for underground geological investigations (EUU)". During this phase, and once the general licence enters into force, construction work will be carried out to prepare for the underground geological investigations. Once the licence for the EUU has been granted, the EUU access structures down to the disposal level and the facilities for the EUU will be constructed. The purpose of the EUU is to verify the potential disposal zone, confirm safety-relevant properties and test safety-relevant techniques as well as to demonstrate their functionality. Following the EUU and the granting of the construction licence, construction will begin, and the operating licence application will be submitted. The current Waste Management Programme foresees the start of operation of the combined repository and L/ILW repository in 2050 and of the HLW repository in 2060. The monitoring phase will begin with the completion of emplacement operations for L/ILW (end of 2064) and HLW (end of 2074). For planning purposes, the monitoring phase is expected to last 50 years. Long-term monitoring begins after final closure.

- **Duration and required capacity of centralised and decentralised interim storage facilities (Chapter 6)**: The information on the origin, types and volumes of the waste to be disposed of in Switzerland provides a reliable basis for planning and implementing the deep geological repository and for managing the available interim storage capacities. Even for the conservative scenario with higher waste volumes ("60-year NPP operating lifetime" scenario), sufficient capacity will be available in the Zwilag interim storage facility in Würenlingen and at the Beznau NPP (ZWIBEZ) for all the waste arising from the operation and decommissioning of the nuclear power plants. Until emplacement in a deep geological repository, sufficient interim storage capacity for MIR waste expected to arise up to the end of 2064 can be assured, for example, with an expansion of the Swiss Federal Interim Storage Facility at the Paul Scherrer Institute (PSI). Extending operations at the interim storage facilities is essentially possible. Proven technology for transporting the waste is already in place, and concepts have been developed for the infrastructure that will be required in the future.

- **Financing plan for waste management activities up to the shutdown of the nuclear installations (Chapter 7)**: Within the framework of cost studies, the costs of decommissioning and disposal are calculated periodically to fix the contributions to be made by the owners of the nuclear installations to the Decommissioning and Waste Disposal Funds as well as the financial reserves to be put aside. With a view to coordinated and consistent presentation of this information, the 2021 Cost Study (CS21) and WMP21 are submitted together, as previous versions have been. CS21 thus forms the basis for the costs specified in the WMP21. Future costs are financed on the one hand directly by the owners (costs before shutdown of the nuclear power plants) and on the other via the Decommissioning and Waste Disposal Funds for the decommissioning and disposal tasks after shutdown of the nuclear power plants. The owners of the installations are obliged to make annual contributions to the Funds. However, this does not free the owners of the obligation to bear costs, which is anchored in the Nuclear Energy Act (Art. 31 KEG). The Funds are more in the nature of securing the financial means for decommissioning and waste disposal after shutdown of the nuclear installations. The two Funds are supervised by the Federal Council. To review the underlying cost studies, it has established STENFO, the Decommissioning Fund that specifies the costs of decommissioning the nuclear installations, and the Waste Disposal Fund that specifies the costs of disposal arising after the shutdown of the nuclear power plants. In addition to the obligation of the owners to make payments into the Funds and to set aside internal reserves, the Nuclear Energy Act foresees further security measures and an obligation to make additional payments. As in the past, the costs were calculated in collaboration with external specialists and companies with extensive experience in the realisation and dismantling of nuclear facilities and underground structures. Based on the results of CS21, the current cost estimate for the deep geological repository is slightly lower than in CS16, which is due to optimisation measures. By the end of 2020, the assets of the Decommissioning and the Waste Disposal Funds were 7.55% and 12.49%, respectively, above the target amount (swissnuclear 2021c).

- **Information concept (Chapter 8)**: Decisive factors for the implementation of the geological disposal projects are active dialogue with interested parties and providing comprehensive information to the public on all questions relating to waste disposal. The public should be in a position to understand the different roles assumed by the actors in the process. For the Sectoral Plan process, the lead, and hence the responsibility for providing information, lies with the Swiss Federal Office of Energy (BFE), which must ensure the effective participation of the public in the site selection process. The BFE can call for the regulatory authorities and, if necessary, Nagra to bring their technical know-how into the process. Nagra communicates actively and in a timely manner with all stakeholders, both through Sectoral Plan bodies and directly. It also supports the authorities in carrying out their legal mandate to inform and to communicate and addresses its communication directly and indirectly to politicians, the siting regions and the broader public. The aim of Nagra's public outreach approach is to ensure that its activities, results and proposals in the Sectoral Plan process and beyond can be understood by the respective stakeholders. In addition, it seeks to acknowledge and discuss the concerns and questions of the actors, especially the affected regions, and to include these actors in the process whenever possible. With this approach, Nagra aims to contribute to an objective discussion with politicians and the regions in the narrower sense and the public in the broader sense. The aim is to strengthen the joint sense of responsibility for the safe disposal of radioactive waste in Switzerland.

Kurzzusammenfassung

Der vorliegende Bericht dokumentiert das Entsorgungsprogramm der Entsorgungspflichtigen, wie es gesetzlich verlangt wird. Gegenstand und Ziel des Entsorgungsprogramms ist es, eine gesamtheitliche übergeordnete Darstellung der für die Entsorgung aller radioaktiven Abfälle der Schweiz notwendigen Arbeiten zu geben (strategisches Arbeitsprogramm) und die konzeptuellen Vorgaben, Annahmen und deren Umsetzung für die Auslegung der Anlagen und deren schrittweise Realisierung aufzuzeigen.

Das Entsorgungsprogramm 2021 (EP21) wurde von der Nagra im Auftrag der Entsorgungspflichtigen erstellt; es richtet sich primär an die Behörden und zeigt auch auf, wie die Entsorgungspflichtigen auf spezifische Auflagen des Bundesrats sowie weitere Empfehlungen der Behörden zum Entsorgungsprogramm 2016 (EP16) eingetreten sind.

Das EP21 ist so abgefasst, dass es auch der breiteren Öffentlichkeit zur Information dienen kann. Als wichtiger Bestandteil hält es den Fortschritt im Verfahren des Sachplans geologische Tiefenlager (SGT) seit seiner Vorgängerversion (EP16) fest. Speziell hervorzuheben sind:

- Der Bundesrat hat im November 2018 als Abschluss von SGT Etappe 2 der Fokussierung auf Opalinuston (OPA) als Wirtgestein für alle Lagertypen zugestimmt; somit kann aufgrund der sicherheitstechnischen Eignung dieses Wirtgesteins für die weitere Projektierung davon ausgegangen werden, dass die alphatoxischen Abfälle (ATA) zusammen mit den schwach- und mittelaktiven Abfällen (SMA) im gleichen Lager eingelagert werden.
- Gleichzeitig hat der Bundesrat entschieden, dass die geologischen Standortgebiete Jura Ost (JO), Nördlich Lägern (NL) und Zürich Nordost (ZNO) in SGT Etappe 3 weiter zu untersuchen sind. Des Weiteren wurden vom Bundesrat, gestützt auf eine intensive Zusammenarbeit mit den Standortregionen und -kantonen, Standortareale für die Oberflächenanlagen festgelegt und diese in Objektblättern zu Etappe 2 festgehalten.
- Im Rahmen der laufenden Etappe 3 des Sachplans wurden vertiefte Feldarbeiten durchgeführt (2D-/3D-Seismik, Quartärbohrungen, Tiefbohrungen). Die bisherigen Ergebnisse der Feldarbeiten bestätigen die grundsätzliche Eignung aller drei Standortgebiete.
- In vielen Ländern (u.a. Frankreich, Spanien, Grossbritannien, USA) werden SMA in oberflächennahen und vergleichsweise kostengünstigen Endlagern entsorgt. Die Schweiz hat sich für die aufwendigere Tiefenlagerung auch dieser Abfallkategorie entschieden. Mit der Fokussierung auf den Opalinuston für alle Abfallarten besteht die grundsätzliche Möglichkeit, alle Abfälle in einem sogenannten Kombilager bestehend aus einem HAA- und einem SMA-Lagerteil zu entsorgen. Die Ergebnisse der weit fortgeschrittenen Feldarbeiten bestätigen, dass in allen drei Standortgebieten genügend Platz für die Anordnung eines Kombilagers vorhanden ist. Ein solches erfüllt die gleichen sicherheitstechnischen Anforderungen bezüglich Betriebs- und Langzeitsicherheit wie zwei Einzellager, hat aber klare Vorteile im Hinblick auf Gefahren beim Bau, den Ressourcenverbrauch und die Emission von Treibhausgasen, da eine geringere Anzahl von Anlagen sowohl an der Oberfläche als auch untertag gebaut und betrieben werden muss. Die Realisierung eines Kombilagers ist somit im Vergleich zu zwei Einzellagern mit betrieblichen, sicherheitstechnischen, ökologischen und ökonomischen Vorteilen verbunden. Deshalb wird, falls es die abschliessende sicherheitstechnische Gesamtbewertung erlaubt, mit dem Rahmenbewilligungsgesuch ein Kombilager beantragt.

- Die Nagra hat in SGT Etappe 3 aufgezeigt, dass für die Platzierung der «Brennelement-verpackungsanlage» (BEVA) der Raum beim Zwilag sowie auch die Areale für die Oberflächenanlage beim geologischen Tiefenlager geeignet sind und die einzigen sinnvollen Standortvarianten darstellen; diese Erkenntnis wird auch von einer überregionalen Arbeitsgruppe getragen.
- Der Zeitplan ist seit Beginn von SGT Etappe 3 unverändert. Das Bewilligungsverfahren für die Tiefbohrungen hat zu keinen rechtlich bedingten Verzögerungen mit Auswirkungen auf den Realisierungsplan geführt. Die erdwissenschaftlichen Untersuchungen konnten deshalb wie geplant durchgeführt werden. Die Ankündigung der Nagra, für welchen Standort oder welche Standorte sie ein Rahmenbewilligungsgesuch (RBG) für ein Kombilager respektive zwei RBG für die Einzellager ausarbeiten wird (Auswahl der Standorte für die Vorbereitung der Rahmenbewilligungsgesuche gemäss Konzept SGT) steht deshalb bevor (voraussichtlich 2022). Zudem sollen gleichzeitig die Areale zur Platzierung der Oberflächeninfrastruktur (inkl. Standort der Verpackungsanlagen) bezeichnet werden.
- Die Kosten wurden wie schon in der Vergangenheit in Zusammenarbeit mit externen Fachleuten und spezialisierten Firmen erarbeitet, die grosse Erfahrung in der Realisierung von Nuklearanlagen und Tunnelbauten haben. Die Kostenberechnung 2021 (KS21) wurde mit der gleichen Methodik wie bei der Kostenstudie 2016 (KS16) durchgeführt. Die aktuelle Kostenermittlung für das geologische Tiefenlager liegt gemäss den Resultaten der KS21 leicht tiefer als bei KS16.

Ausführliche Zusammenfassung

Viele wichtige Schritte zur Entsorgung der radioaktiven Abfälle in der Schweiz sind heute realisiert, und für die damit verbundenen Aktivitäten besteht mittlerweile eine grosse Erfahrung. Diese betreffen die Behandlung und Verpackung der radioaktiven Abfälle, ihre Charakterisierung und Inventarisierung sowie die Zwischenlagerung und die dazugehörigen Transporte.

Für die Realisierung der geologischen Tiefenlager sind die gesetzlichen Regelungen KEG 2003, KEV 2004 und Richtlinien vorhanden. Ebenso ist die revidierte ENSI-Richtlinie ENSI-G03 (ENSI 2020b) für das Vorhaben von Bedeutung. Das vom Bundesrat 2008 genehmigte Konzept Sachplan geologische Tiefenlager (SGT) (BFE 2008) regelt zudem das laufende Standortwahlverfahren; dieses erfolgt in drei Etappen. Mit den Präzisierungen der sicherheitstechnischen Vorgaben für SGT Etappe 3 (ENSI 2018c) liegen auch für die derzeit laufende letzte Etappe konkrete Vorgaben vor.

Der vorliegende Bericht dokumentiert das Entsorgungsprogramm der Entsorgungspflichtigen, wie es gesetzlich verlangt wird (Art. 32 KEG, Art. 52 KEV). Die geforderten Angaben für das Entsorgungsprogramm sind in Art. 52 Abs. 1 KEV vorgegeben. Nachfolgend sind die wichtigsten Angaben aus Kap. 2 bis 8 des EP21 gemäss den Aspekten in Art. 52 Abs. 1 KEV zusammengefasst:

- **Herkunft, Art und Menge der radioaktiven Abfälle (Kap. 2)**: Die Herkunft, Art und Menge der in der Schweiz zu entsorgenden radioaktiven Abfälle sind bekannt und die Abfälle werden gemäss Art. 51 KEV in die Kategorien hochaktive Abfälle (HAA), alphatoxische Abfälle (ATA) und schwach- und mittelaktive Abfälle (SMA) eingeteilt. Dem aktuellen Entsorgungsprogramm wird ein Szenario «60 Jahre Betrieb KKW» zugrunde gelegt. Dieses geht von einer Betriebszeit von 47 Jahren für das KKM (Einstellung des Leistungsbetriebs von KKM erfolgte im Jahr 2019) und 60 Jahren für KKB, KKG und KKL aus und stellt bzgl. der Abfallmengen eine konservativere Annahme dar, als dies beim Szenario «50 Jahre Betrieb KKW» der Fall ist. Bei den radioaktiven Abfällen und Materialien aus Medizin, Industrie und Forschung (MIF) wird von einer Sammelperiode bis Ende 2064, dem Ende des Einlagerungsbetriebs für SMA-Abfälle, ausgegangen. Zudem stellt die Einlagerung von zusätzlichen MIF-SMA-Abfällen ins geologische Tiefenlager vor Verschluss eine denkbare Option dar (Agneb 2019), die im Rahmenbewilligungsgesuch zu berücksichtigen wäre. Die Abfallmengen im EP21 wurden allesamt auf Basis der nuklidspezifischen Freigrenzen gemäss Revision der Strahlenschutzverordnung 2017 (StSV 2017) ermittelt. Während das Volumen der angelieferten bzw. konditionierten Abfälle im Vergleich zum EP16 praktisch unverändert ist (total ca. 45'000 m^3), ist das verpackte Volumen (total ca. 82'500 m^3) im Vergleich zum EP16 ca. 10 % kleiner (s. Kap. 2.1). Um eine konsistente Darstellung der Informationen zur Entsorgung im EP21 und in der KS21 zu gewährleisten und die Vergleichbarkeit der Angaben zur Kostenstudie im EP21 und in der KS21 mit denen in früheren Entsorgungsprogrammen und Kostenstudien sicherzustellen, beinhaltet das EP21 auch ein Szenario, welches von einem 50-jährigen Betrieb der KKW (KKB, KKG, KKL) sowie 47 Jahre Betrieb für KKM ausgeht (sog. Szenario «50 Jahre Betrieb KKW»). Die entstehenden Abfälle werden laufend konditioniert, charakterisiert und inventarisiert. Vor Beginn der Konditionierung eines Abfallstroms wird das vorgeschlagene Konditionierverfahren durch die Nagra bezüglich der Endlagerfähigkeit der fertigen Abfallgebinde beurteilt. Dies ist Voraussetzung für die behördliche Genehmigung der routinemässigen Konditionierung. Neben den Informationen über die vorhandenen Abfälle besteht auch für die erst in Zukunft anfallenden Abfälle ein modellhaftes Inventar. Damit ist eine zuverlässige Basis für die Planung und Realisierung der geologischen Tiefenlager und für die Bewirtschaftung der bestehenden Zwischenlager vorhanden.

- **Die geologischen Tiefenlager (Kap. 3)**: In der Schweiz ist die geologische Tiefenlagerung als **Entsorgungskonzept** (Kap. 3.1.1) für alle radioaktiven Abfälle im Kernenergiegesetz vorgegeben, mit Ausnahme der in Art. 51a KEV erwähnten Abfälle. Das schweizerische Entsorgungskonzept geht von zwei Lagertypen aus: einem für SMA und einem für HAA (Informationen zur Abfallzuteilung zu den Lagertypen SMA und HAA finden sich in Kap. 4.1). Beide Lager können als ein sogenanntes Kombilager im gleichen Standortgebiet platziert werden. Die Realisierung eines Kombilagers ist mit betrieblichen, sicherheitstechnischen, ökologischen und ökonomischen Vorteilen verbunden (s. Kap. 3.1.1). Das Kombilager stellt eine Gesamtanlage dar und es können viele Elemente der Oberflächeninfrastruktur und ein Teil der Bauten untertag (Zugangsbauwerke und zentraler Bereich) gemeinsam genutzt werden. Daraus ergeben sich beim Kombilager im Vergleich zu zwei Einzellagern wesentliche Vereinfachungen beim Bau und Betrieb. Ebenso ergeben sich bewilligungstechnische Vorteile und auch Vorteile beim Aufwand der Begleitung des Projekts und der Zusammenarbeit vor Ort. Die bisherigen Ergebnisse der Feldarbeiten bestätigen, dass in den drei Standortgebieten grundsätzlich genügend Platz für die Anordnung eines Kombilagers vorhanden ist. Deshalb wird, falls es die abschliessende sicherheitstechnische Gesamtbewertung erlaubt, gestützt auf die oben dargelegten Vorteile mit dem Rahmenbewilligungsgesuch ein Kombilager beantragt.

  In der Schweiz beruht das **Sicherheitskonzept** (Kap. 3.1.2) auf einem bezüglich Langzeitsicherheit optimierten Mehrfachbarrierensystem bestehend aus gestaffelten, passiv wirkenden technischen und natürlichen Barrieren. Dies sind Abfallmatrix, Endlagerbehälter, Verfüllung und Versiegelung als technische Barrieren sowie der einschlusswirksame Gebirgsbereich als natürliche Barriere.

  Auch wenn sich die **Technologie für den Bau, Betrieb und Verschluss** (Kap. 3.1.3) bis Baubeginn weiterentwickeln wird, konnte bereits im Rahmen des Entsorgungsnachweises für SMA und HAA (s. Kap. 1.3) die technische Machbarkeit der geologischen Tiefenlagerung aufgezeigt werden. Die **Überwachung und Rückholbarkeit** sind im schweizerischen Programm als integrale Bestandteile der Tiefenlagerkonzepte vorgesehen (Kap. 3.1.4). Es bestehen hierzu technische Konzepte, die periodisch an die neuesten Erkenntnisse angepasst werden.

  Der **Geologie** (Kap. 3.1.5) als natürliche Barriere kommt eine wichtige Bedeutung zu; neben der Isolation der Abfälle vom menschlichen Lebensraum bzw. der Biosphäre und der Gewährleistung der langfristigen Stabilität leistet sie einen wichtigen Beitrag zur Barrierewirkung. Mit dem Bundesratsentscheid von 2011 wurden sechs Vorschläge für Standortgebiete für ein SMA-Lager und drei Vorschläge für ein HAA-Lager für die weitere Untersuchung in SGT Etappe 2 festgehalten. Basierend auf ergänzenden geologischen Untersuchungen und einer systematischen und sicherheitsgerichteten Einengung hat der Bundesrat 2018 der Fokussierung auf Opalinuston (OPA) als Wirtgestein zugestimmt und entschieden, dass die geologischen Standortgebiete Jura Ost, Nördlich Lägern sowie Zürich Nordost in SGT Etappe 3 weiter zu untersuchen sind.

  In der laufenden Etappe 3 wurden für die drei verbliebenen Gebiete umfangreiche erdwissenschaftliche Untersuchungen durchgeführt. Bis Oktober 2021 wurden 8 Tiefbohrungen abgeschlossen, eine voraussichtlich abschliessende Tiefbohrung befindet sich in Ausführung[2]. Weitere Feldarbeiten umfassen u.a. 3D-Seismik, hochauflösende 2D-Seismik sowie 11 Quartärbohrungen (s. Fig. 3.1-2 und 3.1-3). Die laufende Auswertung und Integration der Felduntersuchungen bilden zusammen mit weiteren Studien zu geologischen und hydrogeologischen Eigenschaften der Standortgebiete eine wichtige Basis für den sicherheitstechnischen Vergleich der Standortgebiete und für die Begründung der Standortwahl.

[2] Das EP21 wurde auf Grundlage des Informationsstands per 31. Oktober 2021 erstellt.

Die nächsten Sicherheitsnachweise (Kap. 3.1.6) für das geologische Tiefenlager werden für das Rahmenbewilligungsgesuche gefordert; diesbezügliche Vorgaben finden sich in ENSI (2018c). Sicherheitsnachweise für die Betriebsphase sowie für die Nachverschlussphase des Tiefenlagers (Langzeitsicherheitsnachweis) sind aber auch für alle anschliessenden Bewilligungsschritte bis zum definitiven Verschluss des geologischen Tiefenlagers erforderlich (ENSI 2020b).

Im Rahmen der schweizerischen Gesetzgebung sind Aspekte zur **Raumnutzung und Umweltverträglichkeit** (Kap. 3.1.7) klar geregelt; diese Vorgaben gelten auch für das Vorhaben geologische Tiefenlager. Die Umweltverträglichkeitsprüfung (UVP) der 1. Stufe erfolgt im Zuge des Rahmenbewilligungsverfahrens. Einen weiteren Bestandteil des Rahmenbewilligungsgesuchs stellt der Bericht über die Abstimmung mit der Raumplanung dar.

Die **Auslegung der geologischen Tiefenlager** (Kap. 3.2) basiert auf dem Sicherheitskonzept für HAA und SMA und ist eine für alle Standortgebiete in SGT Etappe 3 anwendbare Konkretisierung des Lagerkonzepts. Sie berücksichtigt stufengerecht Anforderungen an die Sicherheit, technische Machbarkeit und den Umgang mit vorhandenen Ressourcen sowie das Gebot der Optimierung. Die derzeitige Lagerauslegung umfasst stufengerecht Anlagenkonzepte sowie Konzepte zum Bau, Betrieb und Verschluss. Um die erforderliche Flexibilität zur Berücksichtigung möglicher zukünftiger Entwicklungen zu erhalten, werden dabei für Elemente der Lagerauslegung verschiedene Varianten betrachtet.

- Nach dem Entscheid des Bundesrats zu SGT Etappe 2 verbleiben in Etappe 3 ausschliesslich geologische Standortgebiete (JO, NL und ZNO), welche grundsätzlich für Einzellager und für ein Kombilager geeignet sind. Im EP21 wird die Lagerauslegung am Beispiel des Kombilagers modellhaft erläutert. Auf die Auslegung der Einzellager wird insofern eingetreten, als dass aufgezeigt wird, welche spezifischen Lagerteile aus dem Kombilager für das jeweilige Einzellager hinfällig werden (Kap. 3.3 und 3.4).

  Die Anlagenelemente und Bauten, welche für den Betrieb eines Lagers benötigt werden, lassen sich vereinfacht in drei Kategorien einteilen:

  - *Oberflächeninfrastruktur (OFI)* (s. Fig. 3.2-3 und 3.2-4): Die Oberflächenanlage (OFA) stellt das Kernstück der OFI dar. Die radioaktiven Abfälle müssen für die Einlagerung vorbereitet, d.h. endlagergerecht verpackt werden. Die Verpackung erfolgt in den Verpackungsanlagen (VA). Diese werden zweckmässigerweise entweder bei der OFA am Ort des geologischen Tiefenlagers oder beim Zwischenlager in Würenlingen (Zwilag) realisiert. In beiden Fällen werden ausgehend von der OFA die verpackten Endlagerbehälter über den Hauptzugang nach untertag transportiert. Über die Nebenzugangsanlagen erfolgen schwerpunktmässig der Bau des Tiefenlagers (Betriebszugang) sowie die Frischluftversorgung der Anlagenelemente und Bauten auf Lagerebene (Lüftungszugang).

  - *Zugänge nach untertag* (s. Fig. 3.2-1 und 3.2-2): Diese Zugangsbauwerke stellen in Form von Schächten und Tunnels die Verbindung zwischen der Oberfläche und den Bauten auf Lagerebene sicher.

  - *Anlagenelemente und Bauten auf Lagerebene* (s. Fig. 3.2-1 und 3.2-2): Die Endpunkte aller Zugangsbauwerke sowie die Zugänge zu den HAA- und SMA-Haupt- und Pilotlagern schliessen an den sogenannten Haupterschliessungsbereich (HEB) an; dieser umfasst im Wesentlichen die Anlagenelemente des sogenannten zentralen Bereichs und die Testbereiche. Das Kombilager enthält auf Lagerebene sowohl für den HAA- als auch den SMA-Lagerteil je ein Hauptlager und ein Pilotlager mit Kontrollstollen.

- **Zuteilung der Abfälle zu den geologischen Tiefenlagern (Kap. 4)**: Die Art der Abfälle hat sich gegenüber dem EP16 nicht geändert. Da der Bundesrat indes als Abschluss von SGT Etappe 2 der Fokussierung auf Opalinuston (OPA) als Wirtgestein für alle Lagertypen zugestimmt hat, kann aufgrund der sicherheitstechnischen Eignung dieses Wirtgesteins für die weitere Projektierung davon ausgegangen werden, dass die alphatoxischen Abfälle (ATA) im SMA-Lager respektive SMA-Lagerteil des Kombilagers eingelagert werden. Die definitive Abfallzuteilung auf die verschiedenen geologischen Tiefenlager erfolgt schrittweise im Rahmen der verschiedenen nuklearen Bewilligungsverfahren. Dieses Vorgehen ermöglicht auf Basis der effektiv vorgefundenen Verhältnisse, die Abfallzuteilung bzw. die Anforderungen an die einzulagernden Abfälle entsprechend dem Optimierungsgebot zu regeln.

- **Realisierungsplan für die Erstellung der geologischen Tiefenlager (Kap. 5):** Der Zeitplan seit Beginn von SGT Etappe 3 ist unverändert und sieht wie folgt aus. In der laufenden dritten Etappe des Sachplanverfahrens sind namentlich die Ankündigung des Standorts oder der Standorte zur Ausarbeitung des Rahmenbewilligungsgesuchs (ca. 2022), die Einreichung des Gesuchs (ca. 2024) sowie Stellungnahmen und Gutachten rund um die Entscheidungssequenz bis zur Erteilung der Rahmenbewilligung wichtige kommunikative Meilensteine. Obwohl die Ankündigung der Standorte zur Ausarbeitung der Rahmenbewilligungsgesuche kein Bewilligungsschritt in der Realisierung des geologischen Tiefenlagers darstellt, dürfte sie aufgrund ihrer medialen Wirkung von der Öffentlichkeit als "Standortwahl" wahrgenommen werden. Zeitgleich erfolgt unter Berücksichtigung der definitiven regionalen Stellungnahmen zur Oberflächeninfrastruktur und der überregionalen Stellungnahme zum Standort der BEVA die Bezeichnung der Areale zur Platzierung der Oberflächeninfrastruktur (inkl. Standort der Verpackungsanlagen) durch die Nagra. Mit dem Vorliegen einer rechtskräftigen Rahmenbewilligung wird 2031 gerechnet. Die Realisierungspläne für das EP21 beinhalten danach neu eine Phase "Vorbereitung EUU". In dieser Phase erfolgt nach Rechtskraft der Rahmenbewilligung die Bauvorbereitung für die erdwissenschaftlichen Untersuchungen untertag (EUU). Mit Erteilung der Bewilligung EUU folgt der Bau der Zugangsbauwerke EUU bis auf die Lagerebene und die Erstellung von Bauten für erdwissenschaftliche Untersuchungen untertag. Die EUU dienen der Überprüfung der Lagerzone, der Bestätigung sicherheitsrelevanter Eigenschaften und der Erprobung sicherheitsrelevanter Techniken respektive dem Nachweis deren Funktionstüchtigkeit. Im Anschluss an die EUU und die Erteilung der Baubewilligung erfolgt der Bau, und das Betriebsbewilligungsgesuch wird eingereicht. Das aktuelle Entsorgungsprogramm sieht die Inbetriebnahme des Kombilagers und SMA-Lagers 2050 resp. des HAA-Lagers 2060 vor. Mit Ende des Einlagerungsbetriebs SMA (Ende 2064) und HAA (Ende 2074) beginnt die Beobachtungsphase. Für Planungszwecke wird von einer Beobachtungsphase von 50 Jahren ausgegangen. Nach dem Gesamtverschluss beginnt die Langzeitüberwachung.

- **Dauer und benötigte Kapazität der zentralen und der dezentralen Zwischenlagerung (Kap. 6)**: Die Angaben zur Herkunft, Art und Menge der in der Schweiz zu entsorgenden radioaktiven Abfälle stellen eine zuverlässige Basis für die Planung und Realisierung der geologischen Tiefenlager und für die Bewirtschaftung der vorhandenen Zwischenlager dar. Auch im konservativeren Szenario, welches zu höheren Abfallvolumina führt (Szenario «60 Jahre Betrieb KKW»), ist mit den bestehenden Zwischenlagern Zwilag und Zwischenlager des Kernkraftwerks Beznau (ZWIBEZ) eine ausreichende Zwischenlagerkapazität für sämtliche Abfälle aus dem Betrieb und der Stilllegung der Kernkraftwerke vorhanden. Für die bis Ende 2064 erwarteten MIF-Abfälle kann u.a. aufgrund der Erweiterung des Bundeszwischenlagers am Paul Scherrer Institut (PSI) genügend Zwischenlagerkapazität zur Verfügung gestellt werden, um die anfallenden Abfälle bis zu ihrer Einlagerung in die geologischen Tiefenlager sicher zwischenzulagern. Grundsätzlich besteht die Möglichkeit, die Zwischenlager auch länger zu betreiben. Die für den Transport der Abfälle erforderliche Technologie ist vorhanden und für die zukünftig notwendige Infrastruktur liegen Konzepte vor.

- **Finanzplan für die Entsorgungsarbeiten bis zur Ausserbetriebnahme der Kernanlagen (Kap. 7)**: Zur Festlegung der Beiträge für den Stilllegungs- und Entsorgungsfonds und der durch die Eigentümer der Kernanlagen zu tätigenden Rückstellungen sind die Kosten der Entsorgung und der Stilllegung im Rahmen der Kostenstudie periodisch zu ermitteln. Im Hinblick auf eine aufeinander abgestimmte und konsistente Darstellung der Informationen werden die KS21 und das EP21 wie ihre Vorgängerversionen zeitlich koordiniert eingereicht. Die KS21 stellt somit die Basis für die im EP21 aufgeführten Kosten dar. Die Finanzierung der zukünftigen Kosten erfolgt einerseits direkt durch die Eigentümer (Kosten vor Ausserbetriebnahme der Kernkraftwerke) und andererseits über die Stilllegungs- und Entsorgungsfonds für die Kosten der Stilllegungs- und Entsorgungsaufgaben nach Ausserbetriebnahme der Kernkraftwerke. Die Eigentümer sind verpflichtet, dafür jährliche Beiträge an die Fonds zu leisten. Die Fonds entbinden die Eigentümer jedoch nicht von der im Kernenergiegesetz verankerten Kostentragungspflicht (Art. 31 KEG). Sie dienen vielmehr der Sicherstellung der Geldmittel für die Stilllegungs- und Entsorgungskosten nach Ausserbetriebnahme der Kernanlagen. Die beiden Fonds stehen unter der Aufsicht des Bundesrats. Er hat für die Prüfung der zugrundeliegenden Kostenstudien den Stilllegungsfonds für Kernanlagen und Entsorgungsfonds für Kernkraftwerke (STENFO) eingesetzt, der jeweils die voraussichtliche Höhe der Stilllegungs- und Entsorgungskosten festlegt. Zusätzlich zur Einzahlungspflicht in die Fonds und Bildung von internen Rückstellungen sieht das Kernenergiegesetz weitere Sicherungsmassnahmen und eine Nachschusspflicht der Eigentümer vor. Die Kosten wurden wie schon in der Vergangenheit in Zusammenarbeit mit externen Fachleuten und spezialisierten Firmen erarbeitet, die grosse Erfahrung in der Realisierung/Rückbau von Nuklearanlagen und Tunnelbauten haben. Die aktuelle Kostenermittlung für das geologische Tiefenlager liegt gemäss den Resultaten der KS21 aufgrund von Projektoptimierungen leicht tiefer als bei der KS16. Per Ende 2020 liegt das Vermögen des Stilllegungs- bzw. des Entsorgungsfonds 7.55 % bzw. 12.49 % über dem Soll-Betrag (swissnuclear 2021c).

  Informationskonzept (Kap. 8): Im Hinblick auf die Realisierung der benötigten Tiefenlager sind ein aktiver Dialog mit den Interessierten und eine umfassende Information der Öffentlichkeit zu allen Fragen der nuklearen Entsorgung wichtig. Die Bevölkerung soll die unterschiedlichen Rollen der beteiligten Akteure wahrnehmen und verstehen. Im Rahmen des SGT liegt die Federführung und damit die Verfahrensinformation beim Bundesamt für Energie (BFE), welches dafür zuständig ist, der Bevölkerung in geeigneter Weise die Mitwirkung an den Verfahren zu ermöglichen. Es kann dazu die Aufsichtsbehörden und fallweise die Nagra mit ihrem Fachwissen beiziehen. Die Nagra kommuniziert aktiv und zeitgerecht mit allen Anspruchsgruppen über die Gremien des Sachplans und direkt, sie unterstützt die Behörden in ihrem gesetzlichen Auftrag zur Information und Kommunikation und richtet sich in ihrer Kommunikation auch direkt und indirekt an die Politik, die Standortregionen und eine breitere Öffentlichkeit. Die Öffentlichkeitsarbeit der Nagra soll dazu beitragen, dass die Arbeiten, Resultate und Vorschläge der Nagra im Sachplanverfahren und darüber hinaus anspruchsgruppengerecht nachvollzogen werden können. Zudem sollen die Anliegen und Fragen der Akteure – insbesondere auch der betroffenen Regionen – aufgenommen, diskutiert und soweit möglich einbezogen werden. Damit möchte die Nagra zu einer sachlichen Auseinandersetzung von Politik und Regionen im engeren sowie der Öffentlichkeit im weiteren Sinn beitragen. Dies soll die gemeinsame Übernahme der Verantwortung für eine sichere Entsorgung der radioaktiven Abfälle in der Schweiz stärken.

L’essentiel en bref (*Résumé*)

Le présent rapport documente le programme de gestion élaboré par les producteurs de déchets, comme l’exige la législation en vigueur. Le programme de gestion a pour objet et but de décrire, du point de vue des producteurs de déchets, l’ensemble des travaux nécessaires à la gestion de tous les déchets radioactifs en Suisse (programme de travail stratégique) et de présenter les exigences conceptuelles, les hypothèses et leur mise en œuvre pour la conception des installations de stockage et leur réalisation par étapes.

Le programme de gestion des déchets 2021 (EP21) a été élaboré par la Nagra sur mandat des producteurs de déchets ; il est en premier lieu destiné aux autorités. Il montre en particulier comment les producteurs de déchets ont répondu aux exigences spécifiques émises par le Conseil fédéral et aux autres recommandations formulées par les autorités à l’issue de l’examen du programme de gestion des déchets 2016 (EP16).

L’EP21 est rédigé de telle manière qu'il puisse également être un support d'information pour le grand public. Une partie importante du document est consacrée aux progrès effectués dans le cadre de la procédure du plan sectoriel « Dépôt en couches géologiques profondes » depuis la précédente édition du programme de gestion des déchets (EP16). Les événements les plus marquants sont énumérés ci-dessous :

- En novembre 2018, à l’issue de l'étape 2 du plan sectoriel, le Conseil fédéral a approuvé le choix de l’Argile à Opalinus comme roche d'accueil pour tous les types de déchets ; du fait des caractéristiques de cette roche au regard de la sûreté, on pourra dorénavant, pour les besoins de la planification, postuler que les déchets alpha-toxiques (DAT) seront stockés dans le même dépôt que les déchets de faible et de moyenne activité (DFMA).
- Dans le même temps, le Conseil fédéral a décidé que les domaines d’implantation géologiques Jura Est (JO), Nord des Lägern (NL) et Zurich Nord-Est (ZNO) devraient faire l’objet d’un examen plus approfondi à l’étape 3 du plan sectoriel. Par ailleurs, grâce à une collaboration intensive avec les régions et les cantons d’implantation, le Conseil fédéral a défini des aires d’implantation pour les installations de surface et les a inscrites dans des fiches d’objet pour l’étape 2.
- Au cours de l’étape 3 du plan sectoriel, actuellement en cours, des investigations de terrain approfondies ont été réalisées (sismique 2D et 3D, forages quaternaires, forages profonds). A ce jour, les résultats de ces travaux confirment que les trois domaines d'implantation sont adaptés à la construction d’un dépôt géologique.
- Dans de nombreux pays (dont la France, l’Espagne, le Royaume-Uni et les États-Unis), les DFMA sont stockés dans des dépôts proches de la surface, relativement peu coûteux. Pour cette catégorie de déchets, la Suisse a opté, comme pour les déchets de haute activité (DHA) en faveur du stockage en profondeur, plus onéreux. Du fait du choix de l’Argile à Opalinus comme roche d’accueil pour tous les types de déchets, il est en principe possible de construire un dépôt dit combiné, où les DHA et les DFMA seront stockés dans des secteurs séparés. Les résultats des investigations de terrain obtenus à ce jour confirment qu’il y a suffisamment d’espace dans chacun des trois domaines d’implantation pour accueillir un dépôt combiné. Un dépôt combiné répond aux mêmes exigences en termes de sûreté en exploitation et de sûreté à long terme que deux dépôts individuels, mais présente de nets avantages si l’on considère les difficultés liées à la construction, la consommation des ressources et les émissions de gaz à effet de serre : en effet, un tel dépôt nécessite la construction et l’exploitation de moins d’installations, aussi bien en surface que sous terre. Par rapport à deux

dépôts individuels, cette solution présente par conséquent des atouts sur les plans de l'exploitation et de la sûreté ainsi que des avantages écologiques et économiques. De ce fait, si les résultats finals de l'évaluation de sûreté globale le permettent, la demande d'autorisation générale portera sur un dépôt combiné.

- A l'étape 3 du plan sectoriel, la Nagra a démontré que l'« installation de conditionnement des éléments combustibles » (« BEVA ») pouvait être implantée soit à proximité du dépôt intermédiaire centralisé Zwilag, soit sur l'aire d'implantation de l'installation de surface du dépôt en couches géologiques profondes. Il s'agit là des seules variantes raisonnablement envisageables – un avis du reste partagé par un groupe de travail suprarégional.

- Le calendrier de réalisation est resté inchangé depuis le début de l'étape 3 du plan sectoriel. La procédure d'autorisation des forages profonds n'a pas donné lieu à des recours juridiques qui auraient entrainé des retards. Les investigations géologiques ont donc pu être réalisées comme prévu. L'annonce par la Nagra du ou des sites pour lesquels elle préparera une demande d'autorisation générale pour un dépôt combiné, ou deux autorisations générales pour des dépôts séparés (« sélection des sites pour la préparation des demandes d'autorisation générale selon le concept du plan sectoriel »), est donc imminente (probablement en 2022). Par ailleurs, il reste à déterminer les aires d'implantation pour l'infrastructure de surface (y compris l'emplacement de l'installation de conditionnement).

- Comme par le passé, les coûts de la gestion des déchets ont été calculés en collaboration avec des experts externes et des entreprises spécialisées ayant une grande expérience dans la construction d'installations nucléaires et de tunnels. L'étude des coûts 2021 (KS21) a été réalisée selon la même méthodologie que l'étude des coûts 2016 (KS16). Selon les résultats de la KS21, l'estimation actuelle des coûts du dépôt en couches géologiques profondes est légèrement inférieure à celle de la KS16.

Résumé détaillé

De nombreuses étapes importantes ont été franchies en matière de gestion à long terme des déchets radioactifs en Suisse et l'on dispose aujourd'hui d'une expérience considérable relative aux activités nécessaires, à savoir le traitement et le conditionnement des déchets radioactifs, leur caractérisation et leur inventaire, ainsi que leur entreposage (ou « stockage intermédiaire ») et leur transport.

La réalisation de dépôts en couches géologiques profondes est désormais bien encadrée au niveau légal, avec la loi sur l'énergie nucléaire (KEG 2003) et l'ordonnance sur l'énergie nucléaire (KEV 2004) de même que plusieurs directives, dont notamment la directive révisée de l'IFSN ENSI-G03. Le concept du plan sectoriel « Dépôt en couches géologiques profondes », approuvé par le Conseil fédéral en 2008, régit par ailleurs la procédure de sélection des sites d'implantation, qui se déroule en trois étapes (BFE 2008). Pour la troisième et dernière étape, actuellement en cours, des exigences concrètes concernant la sûreté ont également été spécifiées (ENSI 2018c).

Ce rapport documente le programme de gestion 2021 (EP21) élaboré par les producteurs de déchets, comme l'exige la loi (Art. 32 KEG, Art. 52 KEV). Art. 52 al. 1 KEV précise les aspects qui doivent être abordés par le programme de gestion des déchets. Le contenu des chapitres 2 à 8 de l'EP21 est résumé ci-dessous, en suivant les indications de Art. 52 al. 1 KEV:

- **Origine, typologie et volumes de déchets radioactifs** (chap. 2) : La provenance, la typologie et le volume des déchets radioactifs produits en Suisse sont connus. Conformément à Art. 51 KEV, les déchets sont divisés en trois catégories : déchets de haute activité (DHA), déchets alpha-toxiques (DAT) et déchets de faible et de moyenne activité (DMFA). Le programme de gestion actuel est basé sur le scénario « 60 ans d'exploitation des centrales nucléaires », qui postule une durée d'exploitation de 47 ans pour la centrale de Mühleberg (mise hors service fin 2019) et de 60 ans pour les centrales de Beznau, Gösgen et Leibstadt. Concernant les volumes de déchets, il s'agit là d'une hypothèse plus prudente que ce que prévoit le scénario « 50 ans d'exploitation des centrales nucléaires ». Pour les déchets et matériaux radioactifs issus du secteur médical, de l'industrie et de la recherche (MIR), les calculs intègrent une période de collecte s'étendant jusqu'à fin 2064, ce qui correspond à la fin du stockage des déchets DFMA. Passé cette date et jusqu'à la fermeture du dépôt, le stockage de quantités supplémentaires de déchets MIR / DFMA demeure possible (Agneb 2019) ; cette variante devrait le cas échéant être prise en compte dans la demande d'autorisation générale. Les volumes de déchets mentionnés dans l'EP21 ont tous été déterminés sur la base des limites d'exemption spécifiques aux différents radionucléides, conformément à la révision 2017 de l'ordonnance sur la radioprotection (StSV 2017). Alors que le volume de déchets proprement dit, le cas échéant après traitement, est resté pratiquement inchangé par rapport à l'édition 2016 du programme de gestion (environ 45 000 m3 au total), le volume de déchets conditionnés dans leur emballage de stockage (environ 82 500 m3 au total) est inférieur d'environ 10 % aux chiffres de 2016 (*cf.* chap. 2.1). Afin d'harmoniser les données figurant dans le programme de gestion des déchets (EP21) et l'étude des coûts (KS21), mais aussi pour permettre une comparaison des informations sur les études de coûts présentées dans l'EP21 et la KS21 avec celles des éditions précédentes, l'EP21 comprend également un scénario qui postule une durée d'exploitation de 50 ans pour les centrales de Beznau, Gösgen et Leibstadt et de 47 ans pour Mühleberg (scénario intitulé « 50 ans d'exploitation des centrales nucléaires »). Les déchets produits sont conditionnés, caractérisés et inventoriés au fur et à mesure. Avant le début du conditionnement d'un flux de déchets, la Nagra détermine si les colis produits à l'aide de ce procédé sont adaptés au stockage final. Il s'agit d'une condition préalable à l'approbation réglementaire du procédé, avant qu'il ne soit plus largement mis en œuvre. Outre les informations sur les déchets existants, un inventaire-type est également disponible pour les déchets qui ne seront produits que dans le futur. Ceci fournit une base fiable pour la planification et la réalisation de dépôts en couches géologiques profondes et pour la gestion des dépôts intermédiaires existants.

- **Les dépôts en couches géologiques profondes (chap. 3)** : En Suisse, selon le **modèle de gestion** ancré dans la loi sur l'énergie nucléaire, l'ensemble des déchets radioactifs devra être stocké dans un dépôt en couches géologiques profondes (chap. 3.1.1), à l'exception des déchets mentionnés à Art. 51a KEV. Le modèle suisse de gestion des déchets prévoit deux types de dépôts : l'un pour les DFMA, l'autre pour les DHA (pour des précisions concernant la répartition des déchets entre les dépôts DFMA et DHA, se reporter au chap. 4.1). Il est possible de construire les deux dépôts dans le même domaine d'implantation. La réalisation d'un tel dépôt, dit «combiné» présente des atouts sur les plans de l'exploitation et de la sûreté ainsi que des avantages écologiques et économiques (chap. 3.1.1). Il s'agit en effet d'une installation globale dont certains composants peuvent être utilisés conjointement par les deux dépôts, notamment en surface et pour une moindre part sous terre (ouvrages d'accès et zone centrale). Ceci permet de simplifier de manière non négligeable la construction et l'exploitation d'un dépôt combiné ; par rapport à deux dépôts séparés, une telle solution est en outre plus judicieuse lorsqu'il s'agit de préparer les demandes d'autorisation ou de collaborer avec les régions concernées. Les résultats des investigations de terrain obtenus à ce jour confirment qu'il y a suffisamment d'espace dans chacun des trois domaines d'implantation pour accueillir un dépôt combiné. En conséquence, si les résultats finals de l'évaluation de sûreté globale le permettent, la demande d'autorisation générale, s'appuyant sur les avantages énumérés ci-dessus, portera sur un dépôt combiné. En Suisse, le **concept de sûreté** (chap. 3.1.2) est basé sur un système de barrières multiples optimisé pour la sûreté à long terme et composé de barrières techniques et naturelles échelonnées et à action passive. Il s'agit en l'occurrence de la matrice de déchets, du conteneur de stockage, du remblayage et du scellement, qui constituent les barrières techniques, et de la zone de confinement géologique, qui constitue la barrière naturelle.

  Même si la **technologie** mise en œuvre pour **la construction, l'exploitation** et **la fermeture** du dépôt (chap. 3.1.3) va continuer d'évoluer jusqu'au début de la construction, la faisabilité technique du stockage en couches géologiques profondes a déjà été démontrée dans le cadre de la démonstration de la faisabilité du stockage pour les DFMA et les DHA (chap. 1.3). Le programme suisse prévoit que les notions de **surveillance** et de **récupérabilité** fassent partie intégrante des concepts de dépôt en couches géologiques profondes (chap. 3.1.4). Les concepts techniques correspondants ont été élaborés et font l'objet d'une mise à jour périodique en fonction de l'évolution des connaissances.

  La **géologie** (chap. 3.1.5) a une grande importance en tant que barrière naturelle ; en plus d'isoler les déchets de l'environnement humain et de la biosphère et d'assurer la stabilité à long terme du système de dépôt, elle joue également un rôle dans le système de confinement. Suivant la décision du Conseil fédéral fin 2011, six propositions de domaines d'implantation pour un dépôt de DFMA et trois propositions pour un dépôt de DHA ont été retenues pour la suite des investigations au cours de l'étape 2 du plan sectoriel. Après des investigations géologiques supplémentaires et à l'issue d'un processus systématique fonctionnant par éliminations successives sur la base de critères de sûreté, le Conseil fédéral a approuvé en 2018 le choix de l'Argile à Opalinus en tant que roche d'accueil. Il a en outre décidé que les domaines d'implantation géologiques de Jura-est, Nord des Lägern et Zurich nord-est devaient faire l'objet d'investigations supplémentaires dans le cadre de l'étape 3 du plan sectoriel.

- Au cours de l'étape 3 actuellement en cours, des études géologiques approfondies ont été réalisées dans les trois domaines restants. En octobre 2021, huit forages profonds avaient été réalisés et un forage profond, qui devrait être le dernier, est encore en cours[3]. D'autres investigations de terrain ont été effectuées afin de mieux appréhender l'évolution géologique à long terme. Il s'agit notamment de sismique-3D, de sismique-2D à haute résolution et de 11 forages quaternaires (voir fig. 3.1-2 et 3.1-3). L'analyse des résultats et la mise en relation des études de terrain, ainsi que les analyses du système géologique et les autres études sur les propriétés géologiques et hydrogéologiques des domaines d'implantation, constituent l'une des bases sur lesquelles reposeront la comparaison des domaines d'implantation sous l'angle de la sûreté et la justification du choix du site.

  Les prochaines démonstrations de sûreté (chap. 3.1.6) pour le dépôt en couches géologiques profondes seront effectuées dans le cadre des demandes d'autorisation générale ; les exigences de l'IFSN sont compilées dans ENSI (2018c). La démonstration de la sûreté en exploitation et de la sûreté post-fermeture (démonstration de la sûreté à long terme) est également requise à chacune des étapes d'autorisation ultérieures, jusqu'à la fermeture définitive du dépôt.

  Dans la législation suisse, l'**aménagement du territoire** et l'**impact sur l'environnement** (chap. 3.1.7) font l'objet de dispositions précises ; celle-ci sont également applicables au projet de dépôt profond. La première étape de l'étude d'impact sur l'environnement (EIE) est prévue dans le cadre de la procédure d'autorisation générale ; la demande d'autorisation générale comprendra également le rapport sur la coordination avec l'aménagement du territoire.

  La **conception des dépôts en couches géologiques profondes** (chap. 3.2) est basée sur le concept de sûreté pour les DHA et les DFMA. Il s'agit d'une concrétisation du concept de stockage, valable pour tous les domaines d'implantation retenus à l'étape 3 du plan sectoriel. Elle tient compte des exigences en matière de sûreté, de faisabilité technique et d'utilisation des ressources existantes, ainsi que des possibilités d'optimisation. La conception actuelle du dépôt comprend les concepts pour les installations ainsi que des concepts de construction, d'exploitation et de fermeture, à un niveau de détail suffisant pour la phase en cours. Afin de conserver la flexibilité nécessaire pour intégrer d'éventuels développements futurs, différentes variantes sont envisagées.

- Suite à la décision du Conseil fédéral concernant l'étape 2 du plan sectoriel, tous les domaines d'implantation géologiques retenus (Jura Ost, Nördlich Lägern et Zürich Nordost) conviennent en principe aussi bien pour des dépôts individuels que pour un dépôt combiné. Dans l'EP21, la conception du dépôt est illustrée à l'aide d'un modèle de dépôt combiné. La conception des dépôts individuels est évoquée dans la mesure où l'on indique quelles zones spécifiques du dépôt combiné n'ont pas d'utilité pour le dépôt individuel respectif (chap. 3.3 et 3.4).

  Les installations spécifiques et les bâtiments nécessaires au fonctionnement du dépôt peuvent être globalement répartis en trois catégories :

  – *Infrastructure de surface* (*cf.* Fig. 3.2-3 et 3.2-4) : L'installation de surface est le cœur de l'infrastructure de surface. A leur réception, les déchets radioactifs sont contrôlés, puis préparés pour le stockage géologique, c'est-à-dire placés dans un conteneur adéquat. Cette opération se déroule dans une installation de conditionnement, qui sera construite – pour des raisons logistiques – soit sur le site du dépôt profond, soit à proximité du dépôt intermédiaire centralisé de Würenlingen (Zwilag). Depuis l'installation de surface du

[3] Le programme de gestion des déchets 2021 reflète l'état des activités et des connaissances au 31 octobre 2021.

dépôt, les conteneurs de dépôt géologique sont ensuite acheminés, par l'accès principal, vers les structures souterraines. Les installations d'accès secondaires servent principalement à la construction du dépôt (accès pour l'exploitation) et à l'alimentation en air frais des parties de l'installation situées au niveau de la zone de stockage (accès pour la ventilation).

- *Accès souterrains* (*cf.* Fig. 3.2-1 et 3.2-2) : ces ouvrages d'accès (puits et tunnels) assurent la liaison entre la surface et le « fond », c'est-à-dire les ouvrages situés au niveau de la zone de stockage.
- *Installations et ouvrages au niveau de la zone de stockage* (voir fig. 3.2-1 et 3.2-2) : L'extrémité inférieure de tous les ouvrages d'accès et les accès aux dépôts principaux et aux dépôts pilotes respectifs des DHA et des DFMA débouchent sur ce qu'on appelle la zone principale de connexion souterraine ; celle-ci comprend essentiellement les installations de la zone dite centrale et les zones expérimentales. Dans un dépôt combiné, le niveau dit « de stockage » comprend, pour chacun des secteurs dédiés aux DHA et aux DFMA, un dépôt principal et un dépôt pilote ainsi que des galeries d'observation.

- **Répartition des déchets entre les dépôts en couches géologiques profondes** (chap. 4) : la typologie des déchets est restée inchangée depuis la précédente édition du programme de gestion (EP16). A l'issue de l'étape 2 du plan sectoriel, le Conseil fédéral a approuvé le choix de l'Argile à Opalinus en tant que roche d'accueil pour tous les types de déchets. Pour la suite de la planification du projet, en raison des caractéristiques de cette roche d'accueil, on part donc du principe que les déchets alpha-toxiques (ATA) et les DFMA seront stockés ensemble, soit dans le dépôt pour DFMA, soit dans le secteur pour DFMA du dépôt combiné. L'affectation définitive des déchets aux différents dépôts profonds sera affinée au fur et à mesure, à l'occasion des différentes procédures d'autorisation nucléaire. Cette façon de faire permettra de tenir compte des conditions réelles rencontrées afin d'optimiser la répartition des déchets et les exigences à respecter quant à leurs caractéristiques.

- **Plan de mise en œuvre pour la construction des dépôts en couches géologiques profondes** (chap. 5) : Le calendrier de l'étape 3 du plan sectoriel, inchangé depuis le début de cette étape, est structuré autour de plusieurs jalons importants en termes de communication: annonce du ou des sites pour l'élaboration de la demande d'autorisation générale (env. 2022), dépôt de la demande d'autorisation (env. 2024), puis prises de position et expertises en rapport avec la série de décisions qui précéderont l'octroi de l'autorisation générale. Bien que l'annonce des sites pour l'élaboration de la demande d'autorisation générale ne constitue pas une étape d'autorisation officielle dans la réalisation du dépôt en couches géologiques profondes, elle est susceptible d'être perçue par le public comme une "sélection de sites" en raison de son impact médiatique. Dans le même temps, la Nagra désignera les aires d'implantation de l'infrastructure de surface (y compris l'emplacement de l'installation de conditionnement), en tenant compte des prises de position définitives des régions sur l'infrastructure de surface ainsi que de l'avis du groupe de travail suprarégional sur l'emplacement de l'installation de conditionnement. Selon le calendrier actuel, l'entrée en vigueur de l'autorisation générale devrait intervenir en 2031. Pour la suite du programme de gestion, une nouvelle phase de planification, la "préparation des investigations géologiques souterraines" a été ajoutée. Cette phase comprend, après l'entrée en vigueur de l'autorisation générale, les préparatifs en vue des investigations géologiques souterraines. Une fois que celles-ci auront reçu l'autorisation nécessaire, on procédera à la construction des ouvrages d'accès correspondants jusqu'au niveau du dépôt, puis des installations d'investigation proprement dites. Les investigations géologiques souterraines visent à examiner la zone prévue pour le stockage, confirmer les propriétés du site pertinentes pour la sûreté et enfin tester différentes technologies, importantes pour la sûreté du dépôt, afin de démontrer leur capacité fonctionnelle. A l'issue des investigations géologiques souterraines interviendront l'autorisation de construire, la construction du dépôt, puis l'autorisation d'exploitation. Le programme actuel de gestion des déchets prévoit la mise en service du dépôt combiné et du dépôt pour DFMA en 2050 et du dépôt pour DHA en 2060. La phase de surveillance commencera à la fin des opérations de mise en place, respectivement fin 2064 pour les DFMA et fin 2074 pour les DHA. À des fins de planification, on postule une phase de surveillance de 50 ans. Après la fermeture générale du dépôt commencera la surveillance à long terme.

- **Durée et capacité nécessaire du stockage intermédiaire centralisé et décentralisé** (chap. 6) : Les informations disponibles sur l'origine, la typologie et les volumes de déchets radioactifs qui doivent être stockés en Suisse constituent une base fiable pour la planification et la réalisation de dépôts en couches géologiques profondes et pour la gestion des dépôts intermédiaires existants. Même dans le scénario le plus prudent, qui conclut à des volumes de déchets plus élevés (scénario « 60 ans d'exploitation des centrales nucléaires »), les dépôts intermédiaires Zwilag et ZWIBEZ (dépôt intermédiaire de la centrale nucléaire de Beznau) disposent d'une capacité de stockage provisoire suffisante pour tous les déchets provenant de l'exploitation et du démantèlement des centrales nucléaires. Pour les déchets MIR attendus d'ici à fin 2064, l'extension du dépôt intermédiaire fédéral à l'Institut Paul Scherrer (IPS) permettra notamment de disposer d'une capacité d'entreposage suffisante pour accueillir les déchets en toute sécurité jusqu'à leur mise en place dans les dépôts profonds. Si la mise en service des dépôts profonds était retardée, les installations existantes disposeraient aussi de capacités suffisantes pour entreposer l'ensemble des déchets. En principe, il serait également possible de prolonger la durée d'exploitation des dépôts intermédiaires. La technologie nécessaire au transport des déchets est disponible et des concepts existent pour la réalisation des infrastructures qui seront nécessaires à l'avenir.

- **Plan financier pour la gestion des déchets jusqu'à la mise hors service des installations nucléaires** (chap. 7) : Afin de fixer les contributions au fonds de désaffection pour les installations nucléaires et au fonds de gestion des déchets radioactifs ainsi que le montant des provisions à constituer par les exploitants des installations nucléaires, les coûts de la gestion des déchets et du démantèlement des centrales doivent être déterminés à intervalles réguliers dans le cadre de l'estimation des coûts. Pour assurer une présentation coordonnée et cohérente des informations, l'étude des coûts et le programme de gestion 2021 seront transmis aux autorités de façon simultanée, comme ce fut le cas des versions précédentes. Les coûts présentés dans le programme de gestion EP21 reposent par conséquent sur l'étude des coûts KS21. Les coûts futurs seront financés, soit directement par les exploitants des installations nucléaires (coûts survenant avant la mise hors service des centrales nucléaires), soit par les fonds de désaffectation et de gestion des déchets (coûts des opérations de désaffectation et de gestion des déchets après la mise hors service des centrales nucléaires). A cet effet, les exploitants des installations nucléaires sont tenus de verser des contributions annuelles dans les fonds. Toutefois, l'existence de ces derniers ne libère pas les exploitants de leur obligation légale de prendre en charge les coûts (Art. 31 KEG). Ils servent plutôt à garantir les ressources financières pour les activités de démantèlement et de gestion des déchets après la mise hors service des installations nucléaires. Les deux fonds sont placés sous la surveillance du Conseil fédéral. C'est la STENFO (« Fonds de désaffection pour les installations nucléaires et fonds de gestion des déchets radioactifs ») qui examine les études de coût sur mandat du Conseil fédéral et fixe le montant anticipé des coûts de démantèlement et de gestion des déchets. Outre l'obligation d'alimenter les fonds et de constituer des provisions internes, la loi sur l'énergie nucléaire prévoit d'autres mesures visant à assurer le financement, ainsi que l'obligation pour les exploitants de verser le cas échéant des contributions complémentaires. Comme par le passé, l'estimation des coûts a été élaborée en collaboration avec des experts externes et des entreprises spécialisées ayant une grande expérience dans la réalisation et le démantèlement d'installations nucléaires et de tunnels. Selon les résultats de la KS21, l'estimation actuelle du coût du dépôt en couches géologiques profondes est légèrement inférieure à celle de la KS16 en raison d'une série de mesures d'optimisation. Fin 2020, les avoirs du fonds de désaffectation et du fonds de gestion des déchets étaient supérieurs respectivement de 7,55 % et 12,49 % au montant cible (swissnuclear 2021c).

- **Concept d'information** (chap. 8) : Dans le cadre de la réalisation des dépôts en couches géologiques profondes, il est important d'entretenir un dialogue actif avec les parties intéressées et d'informer le public de manière détaillée sur toutes les questions ayant trait à la gestion des déchets nucléaires. La population doit connaître les différents acteurs impliqués et comprendre leurs rôles respectifs. La responsabilité générale pour le plan sectoriel «Dépôts en couches géologiques profondes» incombe à l'Office fédéral de l'énergie (OFEN), qui est par conséquent aussi chargé d'informer la population et de lui garantir une participation adéquate. L'OFEN peut consulter les autorités de surveillance, ou dans certains cas la Nagra, pour des questions spécifiques. La Nagra communique activement et sans retard avec toutes les parties prenantes, soit par le biais des commissions établies dans le cadre du plan sectoriel, soit directement ; elle soutient les autorités dans leur mandat légal d'information et de communication, et s'adresse également directement et indirectement à la classe politique, aux régions d'implantation et au grand public. Le travail de relations publiques de la Nagra vise à assurer que les travaux, les résultats et les propositions qu'elle effectue dans le cadre de la procédure du plan sectoriel et au-delà puissent être compris par tous, quel que soit son niveau d'implication de chacun. En outre, les préoccupations et les interrogations des parties prenantes, en particulier celles des régions concernées, doivent être collectées, discutées et, dans la mesure du possible, prises en compte dans la suite des travaux. La Nagra entend ainsi contribuer à un débat objectif entre la classe politique et les régions d'une part, et le grand public d'autre part, afin de favoriser une prise de responsabilité commune dans la gestion sûre des déchets radioactifs en Suisse.

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1 Introduction and objectives

1.1 Background and requirements for the Waste Management Programme 2021

According to the Nuclear Energy Act (KEG 2003) and the Nuclear Energy Ordinance (KEV 2004), the Federal Government has the lead role in the management of nuclear waste. Aside from regulations in the nuclear energy legislation, additional instruments are available to the Government such as the Sectoral Plan for Deep Geological Repositories (SGT) for repository site selection (Swiss Federal Office of Energy, BFE 2008) and the Waste Management Programme (WMP) in the form of a comprehensive presentation of the work required for disposing of all radioactive waste in Switzerland (strategic work programme). Within the framework of the Cost Study, the decommissioning and waste management costs are determined every five years to fix the contributions to be made to the Decommissioning and Waste Disposal Funds and the financial reserves to be made by the owners of the nuclear installations. The regulations included in the nuclear energy legislation and other instruments provide all the boundary conditions and prerequisites needed to successfully realise waste management.

Under the Nuclear Energy Act and Nuclear Energy Ordinance, the waste producers are obliged to submit a Waste Management Programme to the responsible authorities and to update this every five years (Art. 52 KEV). The waste producers are the nuclear power plant operators and the Swiss Confederation, which is responsible for disposing of the radioactive waste arising from applications in medicine, industry and research (MIR, s. Chapter 2).

The Nuclear Energy Act (Art. 32 KEG) and the Nuclear Energy Ordinance (Art. 52 KEV) contain information on the required content and structure of the Programme; these requirements are shown in Tab. 1.1-1. The Waste Management Programme 2021 (WMP21) was prepared by Nagra on behalf of the waste producers; it is aimed at the authorities but is formulated in such a way as to be informative for the wider public.

In 2013, the Federal Council ruled that the Waste Management Programme must be submitted together with the Cost Study and a Research, Development and Demonstration Plan (RD&D Plan). The Waste Management Programme 2016 (WMP16) (Nagra 2016b) was submitted to the Federal Department of the Environment, Transport, Energy and Communications (DETEC) in December 2016. It was then reviewed by the Swiss Federal Nuclear Safety Inspectorate (ENSI) (ENSI 2018e), the Federal Nuclear Safety Commission (NSC) (KNS 2018) and the Swiss Federal Office of Energy (BFE 2018a).

In its decree of 21st November 2018, the Federal Council confirmed (Bundesrat 2018) that, with the WMP16, Nagra had fulfilled the legal mandate of the waste producers in line with Art. 32 KEG and Art. 52 KEV (Agneb 2014, KEV 2004, BFE 2008) [4].

[4] As the Waste Management Programme (WMP) is not a federal project, the prerequisites for carrying out a compulsory consultation on the Waste Management Programme in accordance with Art. 3a Par. 1 of the Federal Act on the Consultation Procedure (VlG 2005; SR 172.061) are not met. Moreover, as there are no evident reasons for an optional consultation process in line with Art. 3 Par. 2 VlG due to the technical nature of the Waste Management Programme, the Swiss Federal Department of the Environment, Transport, Energy and Communications (DETEC) did not pursue this process for the WMP16 (Bundesrat 2018).

Tab. 1.1-1: Requirements on the Waste Management Programme: taken from KEG (2003) and KEV (2004)

- Those required to manage and dispose of radioactive waste shall draw up a Waste Management Programme, which shall include a financial plan up to the time at which the nuclear installations will be taken out of operation. The Federal Council shall specify a deadline by which the Waste Management Programme is to be submitted (Art. 32 Par. 1 KEG).
- The Waste Management Programme shall be reviewed by an authority designated by the Federal Council, after which it shall be forwarded by the Federal Department of the Environment, Transport, Energy and Communications (DETEC) to the Federal Council for approval (Art. 32 Par. 2 KEG).
- Those required to manage radioactive waste must include the following information in the Waste Management Programme (Art. 52 Par. 1 KEV):
  - a origin, type and quantity of radioactive waste
  - b the required deep geological repositories, including their design concept
  - c allocation of radioactive waste to the deep geological repositories
  - d plan for the realisation of the deep geological repositories
  - e duration and required capacity of centralised and decentralised interim storage
  - f financial plan for the waste management operations through to decommissioning of the nuclear installations, including details concerning:
    1. the activities to be carried out
    2. the associated costs
    3. the type of financing
  - g the information concept.
- The waste producers are obliged to periodically adapt the programme to changing circumstances (Art. 32 Par. 4 KEG).
- The waste producers must update the Waste Management Programme every five years (Art. 52 Par. 2 KEV).
- ENSI and the Swiss Federal Office of Energy are responsible for reviewing and monitoring compliance with the Waste Management Programme (Art. 52 Par. 3 KEV).
- The Federal Council shall provide regular reports on the Programme to the Federal Assembly (Art. 32 Par. 5 KEG).

Moreover, based on the regulatory assessment of the WMP16, the Federal Council formulated specific requirements for the Waste Management Programme 2021 (WMP21) and successive Waste Management Programmes (Bundesrat 2018). All these requirements are addressed in this report. An overview of the rulings and requirements of the Federal Council is provided in Appendix A.7. The Appendix also outlines which chapters of the WMP21 deal with these requirements and which other reports provide more detailed information. These so-called background reports to the WMP21 are not required by the authorities but nonetheless serve to fulfil requirements specified by the Federal Council based on well-founded principles. The background reports address only generic aspects that can be dealt with regardless of the ongoing site selection process in Stage 3 of the Sectoral Plan. Feedback within the framework of the review of WMP21 allows Nagra to incorporate the concerns of the authorities with regard to these generic aspects when preparing the general licence application.

In response to specific requirements of the Federal Council as well as other recommendations by the authorities on WMP16, Appendix A.8 briefly outlines how the waste producers have addressed these. Any corresponding background reports will be referred to. Appendix A.4 addresses the safety optimisation required by ENSI in its revised Guideline ENSI-G03 (ENSI 2020b). In line with this Guideline, the optimisation procedure for decisions related to the safety of planning and realising a repository now must be documented, and updated, if necessary, in the Waste Management Programme.

A Research, Development and Demonstration Plan (RD&D Plan) was submitted as a reference report (Nagra 2016d) for WMP16, documenting the purpose, scope, type and temporal sequence of future RD&D activities.

In connection with its evaluation of RD&D report for WMP16, ENSI prepared a separate memorandum (ENSI 2018b), which includes less significant safety-based aspects. Nagra has taken these aspects into account within the framework of updating the RD&D Plan (Nagra 2021e). Recommendations and instructions regarding Stage 3 of the Sectoral Plan have been included in the clarifications of the safety-based requirements for Stage 3 of the Sectoral Plan for Deep Geological Repositories (ENSI 2018c) and are addressed within the framework of the site selection process or ongoing supervisory activities.

1.2 Overview of the overarching elements of waste management

According to Art. 3b KEG, waste management consists of conditioning (see Section 2.2), interim storage and disposal of radioactive waste in a deep geological repository.

The starting-point for waste management can be summarised as follows:

- Nuclear energy has been used in Switzerland to generate electricity, process heat and district heating since the end of the 1960s (start of operation of the Beznau-I nuclear power plant: 1969, Beznau-II; 1971, Mühleberg: 1972, Gösgen: 1979, Leibstadt: 1984). At the end of 2019, the Mühleberg nuclear power plant ceased power-generating operations. Aside from energy generation, radioactive waste has been produced for decades in the areas of medicine, industry and research.
- The radioactive waste is conditioned on an ongoing basis into a form suitable for further management steps and is held safely in interim storage facilities until such time as it can be delivered to the relevant repository. The required centralised and decentralised interim storage facilities are available (see Chapter 6).
- In line with international practice, the Swiss waste management concept assumes two repository types: one for low- and intermediate-level waste (L/ILW) and alpha-toxic waste (ATW), and one for spent fuel assemblies (SF) and vitrified high-level waste from reprocessing (HLW (WA)). Should the safety-based comparison conducted in line with ENSI (2018c) as part of Stage 3 of the Sectoral Plan process permit, the two repository types will be realised as a so-called combined repository; i.e. the radioactive waste will be disposed of in two separate repository sections (one for L/ILW and one for HLW; see Section 3.2) located at the same site.

Fig. 1.2-1 schematically shows the overarching elements of waste management.

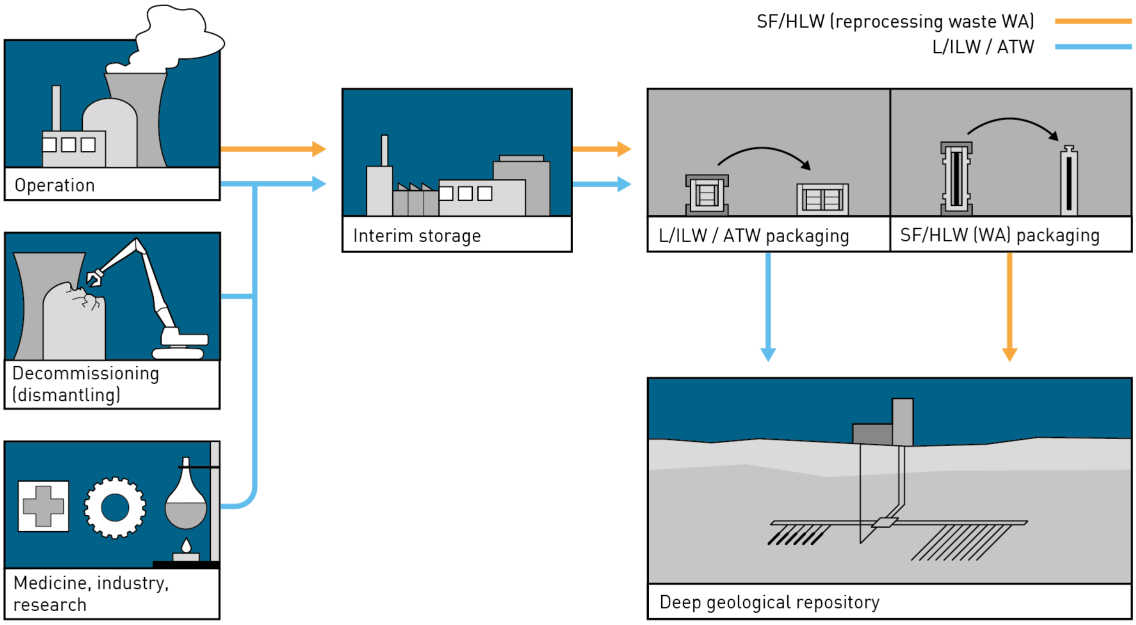

Fig. 1.2-1: Overarching elements of waste management in Switzerland

Model representation of the elements to be addressed within the framework of the Waste Management Programme for a combined repository. This figure illustrates that the radioactive waste arising in Switzerland from nuclear power plant operation, the decommissioning of the nuclear power plants and from applications in medicine, industry and research (MIR) are held in interim storage before being packaged and transferred to a deep geological repository for final disposal. Spent fuel assemblies (SF) and high-level waste from reprocessing (HLW(WA)) are allocated to the HLW repository section and low- and intermediate-level waste (L/ILW) as well as alpha-toxic waste (ATW) are allocated to the L/ILW repository section.

1.3 Status of work

Work on deep geological disposal in Switzerland has been ongoing for around 50 years, resulting in a solid scientific-technical knowledge base. This includes the so-called *Entsorgungsnachweise* demonstrating disposal feasibility for low- and intermediate-level waste (demonstration in 1985 confirmed by the Federal Council in 1988) and for high-level waste (demonstration in 2002 confirmed by the Federal Council in 2006). For the L/ILW repository, the Wellenberg project reached the stage of a general licence application (GNW 1994, Nagra 1994, HSK 1996). The project was withdrawn following two negative votes on a cantonal level.

The conceptual part of the "Sectoral Plan for Deep Geological Repositories" approved by the Federal Council (BFE 2008) specifies the site selection process for deep geological repositories (combined repository or two individual repositories for L/ILW and HLW). The process is divided into three stages, of which Stages 1 and 2 have been completed:

As part of **Stage 1** of the Sectoral Plan process, Nagra proposed six geological siting regions (Jura Ost, Jura-Südfuss, Nördlich Lägern, Südranden, Wellenberg and Zürich Nordost) (Nagra 2008b) that met the safety requirements. In a multi-stage systematic procedure starting from the whole of Switzerland (so-called "blank map of Switzerland"), geological requirements (Nagra 2008a) based on criteria specified in the conceptual part of the Sectoral Plan (BFE 2008) were also incorporated. After an extensive review, the regulatory authorities confirmed the proposal and, in a decision of November 2011, the Federal Council stipulated these six siting regions for further investigation in the Sectoral Plan.

In **Stage 2** of the Sectoral Plan, the siting regions were narrowed down to a minimum of two per repository type (L/ILW and HLW repository, respectively), and the siting areas for the surface facility were also established. To this end, the six siting regions from Stage 1 were investigated in depth and compared with one another from a safety perspective (Nagra 2014o, Nagra 2014n, Nagra 2014m). Based on its investigations and the results of the safety-based comparison, Nagra proposed the Jura Ost and Zürich Nordost siting regions for further investigation in Stage 3 with the Opalinus Clay as the host rock (Nagra 2014o), both for the two repository types or for a combined repository at the same site. At the end of 2018, and based on expert opinions of the authorities, the Federal Council approved focusing on the Opalinus Clay as the remaining host rock and placing the Jura-Südfuss, Südranden and Wellenberg siting regions in reserve. In addition, the Federal Council decided that, aside from the Jura Ost and Zürich Nordost siting regions, the Nördlich Lägern siting region should also be further investigated in Stage 3 (s. Fig. 1.3.1).

In collaboration with the siting regions, siting areas for a surface facility were specified and documented in object sheets for Stage 2, and these were also approved by the Federal Council (see Fig. 1.3-1). In the corresponding planning studies (Nagra 2013f, Nagra 2013d, Nagra 2013c, Nagra 2013a, Nagra 2013b, Nagra 2013e, Nagra 2014l, Nagra 2014j, Nagra 2014k, Nagra 2014f, Nagra 2014d, Nagra 2014e, Nagra 2014i, Nagra 2014g, Nagra 2014h), aspects of land use and environmental compatibility are assessed in detail and the element of flexibility in the design of the surface infrastructure is discussed.

At present, **Stage 3 of the Sectoral Plan** and the **preparation for the general licence application** are ongoing. With a view to the general licence application, Nagra has carried out important field investigations in the three remaining siting regions such as 3D seismic surveys, deep boreholes and Quaternary investigations. The deep boreholes serve, in particular, to calibrate the 3D seismic measurements (especially depth and thickness of the host and confining geological units), as well as to determine relevant rock properties and state parameters. Investigations of unconsolidated Quaternary rocks contribute to assessing the long-term evolution of the geological siting regions. Together with geoscientific system analyses and further studies on process understanding, the ongoing evaluation and integration of the field investigations form the basis for the safety-based comparison of the siting regions and support the justification of the site selection. Results to date confirm that all siting regions are suitable for constructing a deep geological repository and have sufficient space for a combined repository or two individual repositories.

Based on the results of the field investigations and further findings, Nagra's announcement of the site(s) for which it will prepare a general licence application for a combined repository or two general licence applications for individual repositories (site selection in preparation for the general licence in line with the Sectoral Plan Sectoral Plan for Deep Geological Repositories; BFE 2008) is expected for 2022. Based on the final position statements on the surface infrastructure by the regions[5] (RK Jura Ost 2021; RK Nördlich Lägern 2021), the cantons (Kanton SH 2021, Kanton AG 2021a, 2021b, Regierungsrat TG 2021, Kanton ZH 2021) and the three German districts, Waldshut, Schwarzwald-Baar and Konstanz (Hinterseh et al. 2021), as well as the transregional position statement regarding the site for the encapsulation plant for spent fuel

[5] The Waste Management Programme 2021 was compiled based on the information available as of 31st October 2021. To date, the Zürich Nordost regional conference has not yet delivered its final position statement.

assemblies(AG VA-extern 2020), Nagra will also announce the areas for placing the surface infrastructure (including the sites of the encapsulation plants).

According to specifications of the nuclear energy legislation (Art. 62 KEV) and ENSI (2018c), the site selection is documented as part of the general licence application (RBG) and includes a safety-based comparison of the options regarding the safety of the planned repository, an assessment of the properties relevant for site selection and information on the costs.

Additional information on the tasks that must be completed prior to the general licence application can be found in Section 5.4.1.

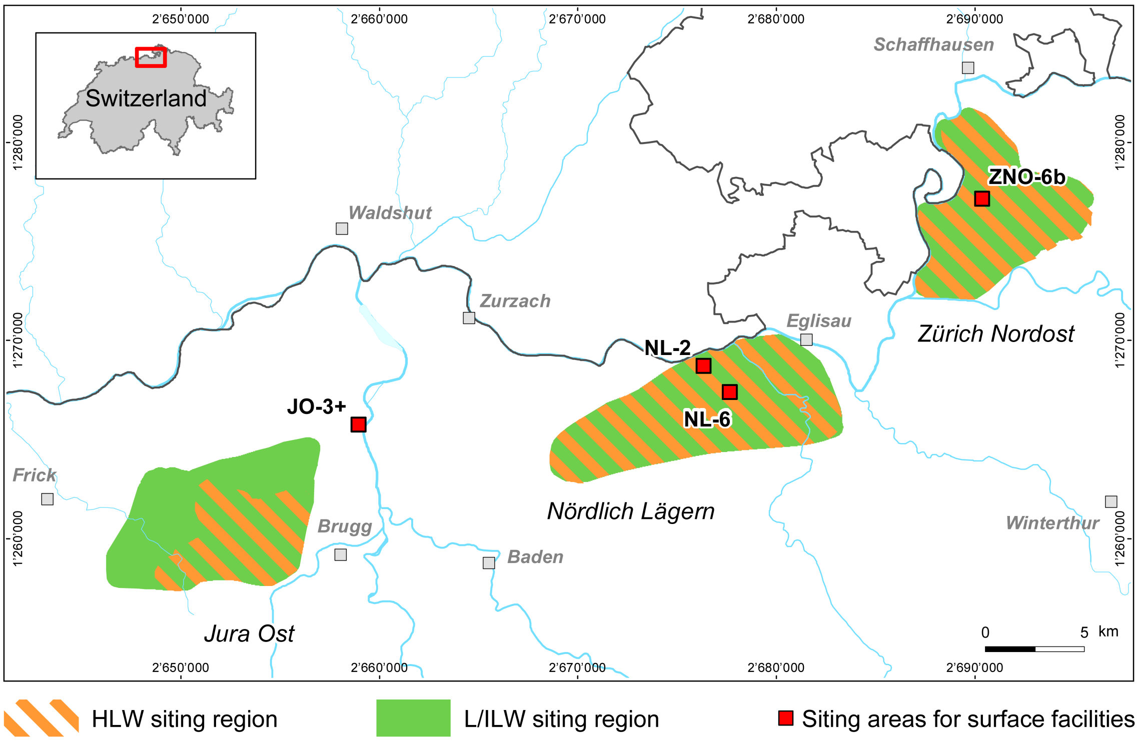

Fig. 1.3-1: The three siting regions as a result of Stage 2 of the Sectoral Plan process including the siting areas for the surface facility outlined in object sheets for Stage 2.

1.4 Objective, content and structure of the Waste Management Programme

WMP21 represents the current status of planning for deep geological disposal; however, it takes into account options for realising the repositories in an open manner, without pre-empting decisions on the sites or on detailed design and technical layout of the deep geological repositories. In contrast, the Cost Study assumes a modelled but concrete base scenario that meets the requirements of the Funds' Administrative Commission with regard to model sites and shows a level of detail that allows the transparent understanding of the cost estimates taking into account chances and risks. For this purpose, the Cost Study makes modelling assumptions that are consistent with the Waste Management Programme but does not make any premature findings on later decisions on the way to realising deep geological disposal.

The work programme and underlying realisation plan documented in the Waste Management Programme (see Chapter 5) also serve as the basis for the periodic updating of the Cost Study.

The most important findings of the Cost Study are summarised in the WMP (see Chapter 7). In addition, the information included in the Cost Study and in the Waste Management Programme is coordinated and consistent. Because of differing requirements and the somewhat different objectives, the WMP is deliberately formulated more broadly than the Cost Study.

The Waste Management Programme shows:

- how the initial position for the different elements of waste management presents itself, what room for manoeuvre exists for optimising the organisation of waste management activities and what flexibility is required to take into account future developments [6]
- what must be realised on what timescale within the framework of what legal and regulatory boundary conditions (realisation plan), how realisation of the elements of waste management that have still not been implemented (particularly deep geological repositories) should be approached (associated work programme), and how the existing flexibility for optimising the facilities and for taking future developments into account can be maintained[7]
- what documentation is required for the different processes
- what overarching activities are required for realising the deep geological repositories and preparing the required documentation and what resources (time, costs) are needed.

In presenting the scientific-technical knowledge base for waste management, the Waste Management Programme refers to the extensive documentation of Nagra's work as part of the *Entsorgungsnachweis* feasibility demonstration projects and the ongoing Sectoral Plan process. However, the Waste Management Programme does not pre-empt any decisions that are to be made in another context.

This particularly applies to:

- the evaluation of potential geological siting regions and sites within the context of the Sectoral Plan process in line with BFE (2008)
- the specification of the main features of the design of the repositories for L/ILW and HLW or a combined repository (site, facility concept, allocated waste categories, maximum disposal capacity) in the general licence according to KEG (2003)
- the detailed conceptual design of the L/ILW and HLW repositories or a combined repository based on the different nuclear licences according to KEG (2003)
- the definition of the field work required in the different phases by the applications and licences for geological investigations according to KEG (2003)

The present report is structured as follows: As explained above, Chapter 1 provides an introduction to the Waste Management Programme (WMP) and describes its objectives and structure. Chapter 2 describes the origin, types and volumes of radioactive waste, as well as its conditioning, characterisation and inventorying. Chapter 3 addresses important principles of deep geological disposal; the design concept is explained based on the combined repository. Chapter 4 discusses the allocation of the waste to the repositories, and Chapter 5 contains the realisation plan for the deep geological repositories. Chapter 6 describes the duration and required capacity of centralised

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[6] The WMP includes variants for the different aspects of waste management to show what flexibility is required for optimisation (taking into account project-related scientific-technical knowledge and advances) and what flexibility is required for accommodating changes in external requirements (e.g. changes in the waste for disposal).

[7] To provide a better overview, the deliberations documented in WMP21 in this respect are also presented in the form of a table in Appendix A.4.2.

and decentralised interim storage. Chapter 7 presents the costs and financing of waste disposal. Chapter 8 documents the information concept.

There is considerable overlap in terms of structure and content between the Waste Management Programmes 2021 and 2016. The reasons for this are:

- The requirements for the Waste Management Programme are anchored in Art. 52 Par. 1 KEV (see Tab. 1.1-1).
- The WMP is understood as a long-term work programme that provides an overall description of the main activities required for managing all radioactive waste arising in Switzerland.
- The conceptual requirements and fundamental assumptions for the design of the facilities and their stepwise realisation have remained largely unchanged since the Waste Management Programme 2016.

For all central topics, Chapters 2 to 8 begin with a brief description of how the assumptions and principles underlying WMP21 have changed compared to WMP16. With the exception of editorial changes and updating of reference information, important topic-specific differences between WMP21 and its predecessor are thus easily identifiable by the reader.

The key differences between WMP21 and WMP16 are:

- The requirements attached by the Federal Council to WMP16 are taken into consideration in WMP21.
- Individual points of the realisation plans have been modified.
- As a result of the 2017 revision of the Radiological Protection Ordinance (StSV; StSV 2017) that specified new exemption limits, the number of scenarios for the waste inventory framework could be reduced compared to WMP16.
- WMP21 outlines the progress made in the Sectoral Plan for Deep Geological Disposal since 2016.

As the Research, Development and Demonstration Plan (RD&D Plan 2021; Nagra 2021e) functions as a reference report for WMP21, WMP21 limits its statements with regard to RD&D activities to a brief description of the topics and otherwise refers to the RD&D Plan.

2 Origin, types and volumes of radioactive waste

Key differences between WMP16 and WMP21

The main commonalities and differences between WMP16 and WMP21 are presented in the following. For detailed information on the reasons for deviations in the arising waste volumes, see Section 2.1.

The basic assumptions for calculating the waste inventory and volumes for WMP21 are mostly identical to those in WMP16. WMP21 is also based on a conservative waste inventory framework assuming a 60-year NPP operating lifetime (Beznau, Gösgen and Leibstadt NPPs). In this scenario, referred to as the "60-year NPP operating lifetime" (also referred to as Scenario 2b in WMP16), a 47-year operating lifetime is assumed for the Mühleberg NPP (shut down at the end of 2019) as was the case in WMP16. In accordance with the requirements of the Administrative Commission of the Decommissioning and Waste Disposal Funds, the base scenario of the 2021 Cost Study assumes a 50-year NPP operating lifetime (Beznau, Gösgen and Leibstadt NPPs) and a 47-year operating lifetime for the Mühleberg NPP. To ensure a consistent presentation of the information on waste management in WMP21 and CS21, as well as the comparability of the information in the cost estimate in these two reports with that in previous Waste Management Programmes and Cost Studies, Appendix A.5 of WMP21 also includes a scenario assuming a 50-year NPP operating lifetime. In WMP16, this was referred to as Scenario 1b.

As in WMP16, the information in WMP21 regarding the arising waste inventory and volumes assumes decay storage of very low-level radioactive materials. In contrast to WMP16, and as a result of the 2017 revision of the Radiological Protection Ordinance (StSV 2017), scenarios listing the waste inventory framework without additional waste inventory/volumes due to the revised exemption limits and without decay storage can be dispensed with (WMP16 scenarios 1a and 2a). The waste inventory and volumes in WMP21 were all determined based on the new nuclide-specific exemption limits according to the revised Radiological Protection Ordinance 2017 (StSV 2017).

Information regarding the conditioning, characterisation and inventorying of radioactive waste has remained largely unchanged since WMP16. Information regarding the conditioning methods was updated and completed (see Tab. 2.2-1). Other changes concern only updates of reference material.

2.1 Description of the radioactive waste

In Switzerland, the categories specified in Art. 51 KEV are used for describing the waste: this categorisation is in line with international practice and is based on the physical properties of the waste arising in Switzerland.

- High-level waste (HLW) includes spent fuel assemblies (SF) not destined for further use and vitrified fission product solutions from the reprocessing of spent fuel assemblies.
- Alpha-toxic waste (ATW) is waste with a content of alpha emitters exceeding a value of 20,000 Becquerels/g of conditioned waste.
- Low- and intermediate-level waste (L/ILW) is all other radioactive waste.

In Switzerland, radioactive waste and materials arise from the use of nuclear energy and the application of radioactive materials in medicine, industry and research (MIR).

The figures on the volumes [8], and the arising of waste over time in WMP21 are based on a "60-year NPP operating lifetime" scenario that results in a higher waste volume than that for the "50-year NPP operating lifetime" scenarios and is therefore more conservative. Boundary conditions for this scenario include:

- 60-year operating lifetime for the Beznau, Gösgen and Leibstadt NPPs, 47-year operating lifetime for the Mühleberg NPP.
- The exemption limits modified as a result of the 2017 revision of the Radiological Protection Ordinance (StSV 2017) were taken into account.
- Consideration of decay storage for activated radioactive substances that, within 30 years after the original material was last used, have decayed to a degree where they could be recycled or considered inactive (Art. 117 StSV).

For a consistent presentation of the information regarding waste management in WMP21 and CS21 as well as for easy comparability of the figures in the Cost Study (Chapter 7) with those in earlier Waste Management Programmes, the WMP21 also includes figures on the waste volumes for the scenario "50-year NPP operating lifetime" (see Appendix A.5).

The inventories and volumes as well as the arising with time of the MIR waste is based on the following assumptions:

- For operational MIR waste, a collection period up to the end of 2064 is assumed. According to the realisation plan, this date corresponds to the end of L/ILW waste emplacement operations (cf. Appendix A.2.1 and Tabs. A.2-1 and A.2-3).
- The figures for the operational waste from the Hotlab research facility of the Paul Scherrer Institute (PSI) are based on the assumption that arising of fuel-containing waste from the Hotlab is coupled with the end of the commercial operation of the Leibstadt NPP (see Tab. A.2-5). With a 60-year operating lifetime of the Leibstadt NPP, the Hotlab will produce waste until 2044.

In the past, around 1,139 t of spent fuel[9] went for reprocessing. All the associated waste was returned to Switzerland and is being held in the Zwilag interim storage facility. WMP21 does not consider any further reprocessing as the Nuclear Energy Act (Art. 9 KEG) has forbidden the reprocessing of spent fuel assemblies since 2018.

The waste inventories and volumes determined based on the "60-year NPP operating lifetime" scenario are listed in Tab. 2.1-1. The table first gives the volume of delivered and conditioned waste. As the waste will be packaged in disposal containers before being emplaced in the emplacement rooms of a repository (see Section 3.2), the volume for waste packaged in disposal containers is given in brackets[10]. The arising of the waste with time (conditioned and also

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[8] For detailed information on the properties of the waste, see Nagra (2014c). The database of the Model Inventory for Radioactive Materials (MIRAM) will be updated for the general licence application.

[9] [tU], tonnes uranium/heavy metal (related to fresh, unspent fuel assemblies).

[10] While the volume of the delivered and conditioned waste corresponds with the waste volume requiring interim storage, the "packaged" volume depends on the container packaging. The figures for these volumes can vary depending on the location of the encapsulation plants. For example, if the L/ILW encapsulation plant is not located at the repository site, planning to date assumes that, for final disposal, specific waste types must be packaged into smaller containers to ensure transport to the repository; this leads to a slight increase in the volume for waste packaged for final disposal. The final decision on how to package and transport the waste takes place in conjunction with the nuclear construction and operating licences.

packaged in disposal containers) is shown in Fig. 2.1-1 (top and bottom) as a cumulative curve divided according to the origin of the waste.

An improved estimate compared to WMP16 with regard to the arising waste volumes and modified assumptions with regard to packaging lead to different figures for the waste inventories and volumes.

The following section systematically outlines the differences for the various waste categories and clarifies the underlying causes. This is based on the figures for the "packaged volumes" as these are relevant for deep geological disposal. The so-called scenario "60-year NPP operating lifetime" (WMP21) and the scenario 2b of WMP16 (Nagra 2016b) form the basis for the comparison. Note that the number of packages assumed for WMP21 has slightly changed compared to WMP16.

- **Spent fuel (SF):** Slight reduction of the packaged volume by 103 m^3 to (new) 8,892 m^3: the key boundary condition of limiting the maximum heat output of the canisters[11] has not changed compared to WMP16. In contrast, the predictions regarding the number of spent fuel assemblies were updated, which led to a slight increase of the unpackaged volume by 10 m^3 to (new) 1,367 m^3. The more significant change results from the revised design of the disposal canisters. This has been updated and their volume has decreased slightly, leading to an overall reduction of the packaged volume.
- **High-level waste from reprocessing (WA-HLW):** Slight reduction of the packaged volume by 21 m^3 to (new) 377 m^3: the high-level waste from reprocessing was conditioned in special steel containers (180-litre flasks). As in WMP16, it is assumed that three 180-l steel flasks can be packaged in a disposal canister to ensure efficient volume utilisation. The reduction is due to a revised design of the disposal canister resulting in a slightly decreased volume; this leads to a slight reduction of the packaged volume.
- **Alpha-toxic waste from reprocessing (WA-ATW):** Slight increase of the packaged volume by 18 m^3 to (new) 432 m^3: The design for the disposal canister foreseen for WA-ATW was concretised; for WMP16, only a design concept was available. Concretising resulted in a slight increase in the volume (0.4 m^3 per disposal canister).
- **Operational waste (BA (NPP)) and reactor waste (RA):** Reduction of the packaged volume by 1,955 m^3 to (new) 31,127 m^3: In WMP16, the packaging for the 200-l package was based on the assumption of a 10.3 m^3 disposal canister that can hold 12 200-l packages. WMP21 goes back to the significantly "tighter" packaging concept of a disposal container with a volume of 26 m^3 assumed in WMP08 for the disposal-ready packaging of 200-l packages. This disposal container can hold 36 200-l packages. Compared to WMP16, the overall packaged volume can be significantly decreased. For the first time, WMP21 fully records the operational waste from the disposal of the transport and storage casks for HLW(WA) and for SF (operational waste) and assigns this to operational waste from NPPs. The packaged volume of this operational waste from the disposal of the transport and storage casks increases by 2,327 m^3 to 2,938 m^3 compared to WMP16: WMP16 was based on the assumption that the baskets for the transport and storage casks would be decontaminated and disposed of conventionally. As it is probably not possible to successfully decontaminate the casks with reasonable cost and effort, WMP21 includes the disposal of the baskets for the transport and storage casks.

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[11] Calculations of the required number of disposal canisters are currently based on a conservative assumption. This states that, at the time of emplacement, a disposal canister for SF/HLW(WA) cannot exceed a maximum thermal output of 1,500 Watt per canister. The result of this conservative assumption is that a small proportion of the SF/HLW(WA) disposal canisters cannot be fully loaded.

- **Decommissioning waste (SA) (NPPs/Zwilag):** Reduction of the packaged volume by 2,414 m^3 to (new) 24,976 m^3: The activated volumes of decommissioning waste were re-calculated in detail. In addition, an optimised packaging concept was developed and, for individual facilities, the arising waste inventory from the controlled zone was re-evaluated. Similar to WMP16, the concept for using low-level contaminated concrete from decommissioning to partially backfill containers filled with metallic waste is considered in WMP21.
- **Medicine, industry and research waste (MIR)[12]:** Reduction of the packaged volume by 3,504 m^3 to (new) 16,148 m^3: WMP16 includes 4,883 m^3 of CERN waste. According to the figures provided by CERN and Nagra's estimates and, based on an agreement between Nagra and the Federal Government of 2018, 2,399 m^3 are now expected. The remaining reduction of around 1,000 m^3 compared to WMP16 results, on the one hand, from a general reduction of the operational waste to arise in the future based on predictions revised in collaboration with PSI, and, on the other hand, from an optimised packaging concept (see Section 'BA(NPP) and RA').
- **Surface facility (OFA):** Reduction of the packaged volume by 1,720 m^3 to (new) 582 m^3: Aside from the operational waste arising from the surface facilities (and the encapsulation plants in particular), the waste from decontaminating the transport and storage casks was also listed under this category in WMP16; in WMP21, this waste is now listed under NPP operational waste (BA(NPP)) and reactor waste (RA). In contrast, the 'OFA' (surface facility) category in WMP21 lists only site-independent operational and decommissioning waste from the encapsulation plants (primarily for spent fuel assemblies); in WMP16, this waste was referred to as SF/HLW(WA) from the encapsulation plant.

The base assumptions regarding the waste inventories or volumes in WMP21 are based on the scenario "60-year NPP operating lifetime", on which the repository conceptual design and the safety case are based. The maximum disposal capacity is only specified with the general licence (Art. 14 Abs. 2 KEG). Considering the time horizon for the realisation and operation of the deep geological repositories, it is necessary to include planning reserves in the maximum disposal capacity. These reserves allow flexibility for future developments. For example, the operating lifetimes of the NPPs have not been fixed yet as, based on legal provisions, they can be operated as long as their safety is assured. In the L/ILW repository, for example, MIR waste can be emplaced beyond the planned end of the emplacement phase[12] (Appendix A.8.8).

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[12] The planning assumption is based on an MIR collection period lasting until the end of 2064 (end of emplacement operations in an L/ILW repository; see Section 5.3 and Appendix A.2.1). Based on a recommendation by the Federal Nuclear Safety Commission, Appendix A.8.8 contains information regarding the handling of MIR waste after 2065. The Federal Government is responsible for its disposal. A disposal-ready waste volume of around 4,000 m^3 must be expected over a period of 90 years. This corresponds to around 5% of the volume of all L/ILW expected until the end of 2064. As the final decision on how to deal with MIR waste does not have to be made for another 50 – 100 years, this waste is not reflected in any of the waste inventory framework listed in the WMPs.

Tab. 2.1-1: Waste volumes in cubic metres (m^3) for a 60-year operating lifetime of the Beznau, Gösgen and Leibstadt NPPs and 47 years for the Mühleberg NPP (scenario "60-year NPP operating lifetime").

Explanation: Volumes of delivered and conditioned waste and the volume "packaged" in disposal containers in brackets. The information is divided according to the categories in the Nuclear Energy Ordinance (KEV 2004) with HLW = high-level waste, ATW = alpha-toxic waste and L/ILW = low- and intermediate-level waste. Additional division according to origin with SF: spent fuel assemblies; WA: waste from reprocessing; BA(NPP): Operational waste from the NPPs (including waste produced at the Zwilag interim storage facility) and operational waste from the disposal of transport and storage casks; RA: reactor waste from the NPPs consisting of exchangeable components from the reactor pressure vessel that arise during operation (no SF); SA: decommissioning waste from the NPPs and Zwilag, including Lucens waste; MIR: waste from medicine, industry and research, including CERN waste; OFA: waste from the operation and decommissioning of the surface facilities.

Spent fuel assemblies (SF) are packaged into disposal canisters without further conditioning before disposal in the HLW emplacement drifts. The first volume given is the non-packaged SF. The number in brackets is the packaged volume, whereby some empty positions in the canisters must be taken into consideration because of the limit on the maximum permissible heat output.

The totals of the exact waste volumes given here may show negligible deviations from the sum of the rounded, individual waste volumes.

		Origin							Total
		SF (NPP)	**WA (NPP)**	**BA (NPP)**	**RA (NPP)**	**SA (NPP)**	**MIR**	**OFA**	
Category acc. to KEV	**HLW**	1367 [1)] (8,892)	114 [2)] (377)				9 [5)] (11)		1,490 (9,280)
	ATW		99 [2)] (432)			25 (25)	165 (524)		289 (981)
	L/ILW			11,100 [4)] (29,691)	407 (1,436)	19,239 (24,951)	11,762 (15,614) [6)]	220 (582)	42,727 (72,274) [6)]
	Total	**1,367** **(8,892)** [3)]	**213** **(809)**	**11,100** **(29,691)**	**407** **(1,436)**	**19,264** **(24,976)**	**11,936** **(16,148)** [6)]	**220** **(582)**	**44,506** **(82,534)** [6)]

1) Corresponds to 2,929 tU.

2) Waste from reprocessing of 1,139 tU.

3) Full loading of disposal canisters (without empty positions) would result in a volume of 7,506 m^3.

4) This includes 2,736 m^3 of conditioned waste from the disposal of transport and storage casks, which is equivalent to a packaged volume of 2,938 m^3.

5) Fuel assemblies from the DIORIT research reactor and compressed drums from PSI's Hotlab facility.

6) These figures also include 2,399 m^3 of CERN waste.

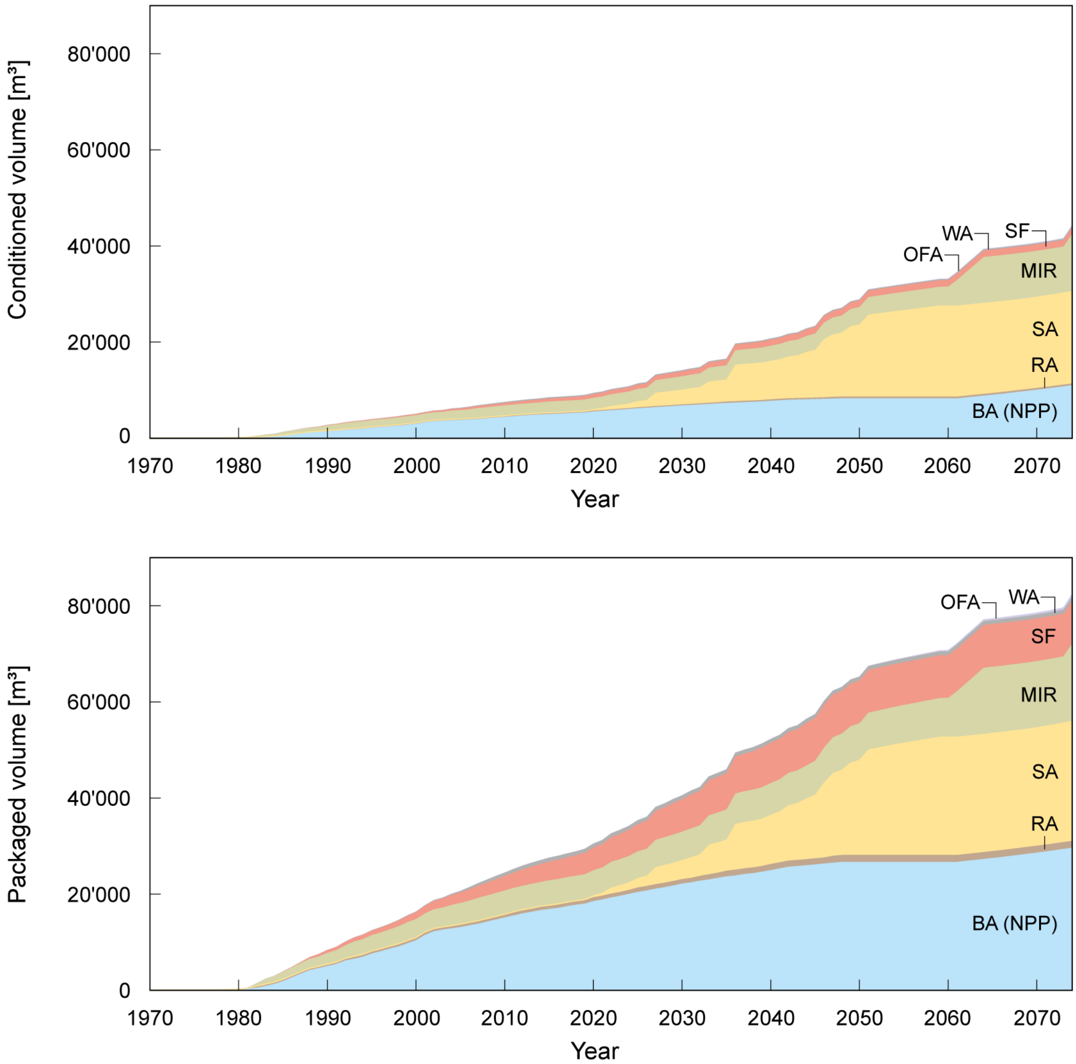

Fig. 2.1-1: Arisings with time of radioactive waste in Switzerland in cubic metres (m^3) for the existing nuclear power plants for a 60-year operating lifetime (for the Beznau, Gösgen and Leibstadt NPPs) as well as 47 years for the Mühleberg NPP and from the MIR area (incl. CERN waste) for a collection period until the end of 2064 ("60-year NPP operating lifetime" scenario)

Timescale from the start of operation of the Beznau NPP (1970 as an approximate average for Beznau I and II) to the end of emplacement in the HLW repository (here, end of 2074).

Waste divided according to origin (for acronyms see Tab. 2.1-1). In addition, BA(NPP) includes waste from the disposal of transport and storage casks.

Above: Volume of conditioned waste requiring interim storage (cumulative curve according to origin, see Tab. 2.1-1).

Below: Volume of waste packaged in disposal containers[13] (cumulative curve according to origin, see Tab. 2.1-1, figures in brackets).

[13] In fact, most of the arising waste is not immediately packaged; packaging in disposal containers is done in the corresponding encapsulation plants once the repositories go into operation (see Sections 3.2 and 5).

2.2 Conditioning, characterisation and inventorying of radioactive waste

The radioactive waste arising today is conditioned[14], characterised and inventoried on an ongoing basis:

- In Switzerland, only spent fuel assemblies without pre-treatment are packaged in transport and storage casks and held in the Zwilag facilities and at the ZWIBEZ interim storage facility at the Beznau NPP once they have cooled sufficiently in the fuel storage pools at the nuclear power plants or the wet storage facility at the Gösgen NPP.
- The waste from reprocessing in England (Sellafield) and France (La Hague) was conditioned into a form that meets Swiss requirements relating to transport, storage and deep geological disposal. The waste was returned to Switzerland and stored in the Zwilag interim storage facility. As the result of a change in the processing procedure in France, part of the ATW waste (see Section 4.1) was returned to Switzerland as so-called CSD-B steel flasks with vitrified waste and not in the form of bituminised waste as originally planned. For waste from reprocessing in England, low- and intermediate-level waste was substituted by a volume of vitrified high-level waste with equivalent radiotoxicity. This significantly reduced the number of transports and the amount of organic substances for disposal.
- For the NPP operational waste (including exchangeable reactor components), conditioning procedures exist for all the waste streams shown. Conditioning of waste is carried out routinely directly on site, and partly also at the centralised Zwilag interim storage facility. The latter applies particularly to waste that is incinerated and melted in the plasma furnace.
- Concepts for the treatment of waste from decommissioning the NPPs have been prepared as part of decommissioning studies, taking into account international know-how, and the waste was characterised by Nagra as part of modelling studies. The decommissioning studies are reviewed periodically (see Chapter 7) and the information on the waste is updated based on new information. For the waste from the decommissioning of the Mühleberg NPP, the specific current dismantling plan forms the basis of the decommissioning study.
- Waste from minor MIR producers is collected on behalf of the Swiss Federal Office of Public Health (FOPH); the Paul Scherrer Institute (PSI) is responsible for conditioning and interim storage (Art. 120 StSV). The waste from large research facilities (PSI, European Organization for Nuclear Research (CERN)) and from decommissioning of the various research installations (technical schools, universities) is conditioned or – if the nuclide inventory is short-lived – placed in decay storage until it is ready for conventional disposal (see Section 6.1), or concepts are available for its disposal or minimisation.

Tab. 2.2-1 provides an overview of the conditioning procedures that are planned or already in use. The figures were updated and completed; they essentially correspond to those of WMP16.

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[14] According to Art. 3 Letter G KEG, conditioning is defined as all operations involved in preparing radioactive waste for interim storage or disposal in a deep geological repository, particularly mechanical shredding, decontamination, compaction, incineration, embedding in waste matrices and packaging.

Tab. 2.2-1: Overview of conditioning methods planned and already in use

Identical conditioning methods are used for comparable MIR waste (e.g. slurries, concentrates, mixed wastes).

Producer	Raw waste	Pre-treatment	Solidification material	Conditioning plant
Beznau NPP	Ion-exchange resins	Draining / suction	Polystyrene	Drying and solidification
	Slurries	Precipitation/ centrifuge/nanofiltration	Cement	In-drum mixer
	Filter cartridges	Drum preparation	Cement	Cementing facility
	Concentrates	Evaporation	Cement	In-drum mixer
Gösgen NPP	Ion-exchange resins	Hot air drying	Bitumen	Extruder
	Concentrates	Concentration by distillation	Bitumen	Extruder
	Filter cartridges	Compaction	Cement	Cementing facility
Leibstadt NPP	Ion-exchange resins and concentrates	Centrifuge and evaporation	Cement	In-drum mixer
	Concentrates	Evaporation	Cement	In-drum mixer
	Fuel assembly channels	Cutting with underwater shears	Cement	Cementing facility
Mühleberg NPP	Ion-exchange resins	Drying and thermolysis	Cement	In-drum mixer
	Slurries	Thickening drainage/ drying / incineration	Cement glass for slag formation	In-drum mixer Zwilag plasma facility
	Fuel assembly channels	Cutting with underwater shears	Cement	Cementing facility
All NPPs	Compressible mixed wastes up to 2004	High-pressure compaction	Cement	Cementing facility
	Combustible mixed wastes up to 2004	Incineration	Cement	Pilot incineration plant PSI
	Mixed wastes from 2005	Incineration / melting	Glass for slag formation	Zwilag plasma facility
	Non-compressible / combustible wastes	Mixing / casting	Cement	Cementing facility
	Weakly activated reactor waste	Cutting	Cement	Cementing facility
	Strongly activated reactor waste	Cutting	–	Packaging in cast containers
	Contaminated metallic substances	Decontamination	Cement / glass [1)]	Conditioning and plasma facility
Former AREVA NC (now Orano Group)	Fission product solutions	Calcination	Glass	Vitrification plant
	Hulls and ends	Drying and high-pressure compaction	–	Packaging in flasks
	Slurries	Calcination	Glass	Vitrification plant
Sellafield [2)]	Fission product solutions	Calcination	Glass	Vitrification plant

[1)] In line with Art. 30 Par. 1 KEG, the objective of decontamination is the clearance measurement (exemption) of decontaminated materials and to reduce the waste volume. Secondary waste is conditioned.

[2)] Other waste from reprocessing at Sellafield Ltd was substituted by additional HLW (see text).

The conditioning of radioactive waste requires a type approval according to Guideline ENSI-B05 (ENSI 2007).

Procedures regulated by the authorities (cf. Guideline ENSI-B05; ENSI 2007) ensure that the properties of the conditioned waste are suitable for further waste management steps and that all the information required in the future is available and documented in a suitable form. This includes the procedure for certifying waste package types as suitable for disposal in a repository. In later steps, procedures for preliminary and final acceptance will be carried out for individual waste packages, during which the conformity of the packages with the relevant specifications will be checked. Before a waste conditioning procedure can be cleared for use by the responsible authority (ENSI), the procedure proposed by the waste producer, and in particular the waste packages that will be produced, have to be evaluated by Nagra with regard to their suitability for disposal. If necessary, the proposed conditioning procedure can be optimised by the waste producer in agreement with Nagra. The prerequisites and measures are defined through procedural coordination with the waste producers and formulated as specifications which ensure that the waste is conditioned into a form that is suitable for transport and disposal and can be held in interim storage and transferred to the repository without any further intervention. In exceptional cases, the waste may have properties (e.g. increased gas production, increased heat output, excessive swelling) that require special measures in the repository. These are applied while the waste is being packaged into disposal containers or during emplacement. The different chemical properties of the waste are also taken into account during emplacement and, if necessary, the waste will be emplaced in different rooms depending on its chemical composition (see Chapter 4).

During conditioning, manufacturing conditions are monitored, and selected package properties are measured. These data are checked for compatibility with the specifications and are documented by the individual waste producers as well as centrally by Nagra. As part of its supervisory role, ENSI monitors and checks the preparation and implementation of conditioning procedures for all radioactive waste and grants the corresponding approvals.

The knowledge of the waste required for planning waste management activities is acquired as part of characterisation programmes and is recorded centrally. The Information System for Radioactive Materials (ISRAM) is used to document information on waste that already exists. The Model Inventory of Radioactive Materials (MIRAM), which is updated periodically, provides a complete overview of both existing waste and waste expected to arise in the future. The information in the two databases provides a reliable and comprehensive description of the properties of all waste for disposal as a basis for the planning and implementation of further waste management steps (interim storage, transport, geological disposal).

The overall process of selecting conditioning procedures and characterising and inventorying the waste was defined by Nagra together with the waste producers. Each conditioning procedure is specified by the waste producers, evaluated by Nagra in terms of suitability of the resulting waste packages for disposal and, if the outcome is positive, approved by ENSI. The supporting technical work takes into account regulatory guidelines (Guideline ENSI-B05; ENSI 2007) and is regulated in agreements. The tools required (preliminary waste acceptance conditions, instruments for evaluating the safety of the waste, databases for all available information and data analysis, etc.) are already available.

Besides suitability for disposal, the waste properties are evaluated by Nagra as part of safety analyses required for the different decision-making milestones. Aside from the radionuclide inventory (radiotoxicity, radiogenic heat, radiolysis), the chemical and physical properties of the raw wastes and their treatment and solidification as well as packaging are evaluated. The effects of gas formation due to metal corrosion under anoxic conditions (Diomidis 2014) and through degradation of organic materials (Warthmann et al. 2013a, Warthmann et al. 2013b) are also evaluated.

The status of the technology for waste treatment is re-evaluated periodically and developed further as appropriate. Taking waste acceptance criteria into consideration, it is possible to use the plasma facility at the Zwilag interim storage facility to reduce the content of organic materials for some of the waste. For a further assessment of the relevance of reducing potential gas formation, see Appendix A.8.1. In addition to radiological safety, chemical toxicity also has to be taken into consideration. This is done formally as part of the Environmental Impact Assessment (USG 1983; cf. Section 3.1.7). The waste inventory is therefore also characterised in terms of its chemical toxicity (Häner et al. 2014). Even taking into account conservative release models, no risk to the environment is expected from the chemical toxicity of radioactive waste.

In WMP16, the waste producers stated that they consider the treatment of already conditioned waste to be unnecessary and disproportionate. The authorities could follow this line of argument and indicated that metallic waste should not be irreversibly conditioned elsewhere. A further discussion on the relevance of metallic waste with regard to potential gas formation can be found in Appendix A.8.1.

3 Deep geological repositories

Key differences between WMP16 and WMP21

The focus of Chapter 3 is on presenting different aspects of the waste management and disposal concepts. The overview with regard to the waste management concepts for HLW and L/ILW were updated in WMP21 based on the progress made in several countries.

The decision of the Federal Council on Stage 2 of the Sectoral Plan forms an important basis for the information provided in WMP21. In November 2018, the Federal Council approved focusing on the Opalinus Clay as the host rock for all repository types and decided that the Jura Ost (JO), Nördlich Lägern (NL) and Zürich Nordost (ZNO) geological siting regions were to be further investigated in Stage 3. Based on intensive collaboration with the siting regions and cantons, siting areas for the surface facilities were identified. These were documented in object sheets for Stage 2, and approved by the Federal Council.

Chapter 3 explains the more comprehensive knowledge base in WMP21 compared to WMP16. This is reflected in the progress with the Sectoral Plan since 2016 and the field investigations (including 3D seismics, deep boreholes and Quaternary investigations) conducted within the framework of Stage 3. Based on the analysis of the 3D seismic surveys and the determination of the so-called main underground connection area, it was possible to propose specific sites for the surface infrastructure.

While the principles for the design of an HLW and L/ILW repository or a combined repository as outlined in the WMP16 remain valid, the facility elements are being planned in increasingly specific detail. Following the decision of the Federal Council on Stage 2 of the Sectoral Plan, only geological siting regions (JO, NL and ZNO) remain that, based on current knowledge, are suitable for hosting both a combined repository or two individual repositories. Results of the advanced field investigations confirm that all three siting regions provide enough space for a combined repository layout. As realising a combined repository is associated with operational, safety-related, ecological and economic advantages compared to two individual repositories (see Section 3.1.1) and covers all functions required for constructing and operating a deep geological repository, thereby also essentially covering both an L/ILW repository and an HLW repository (Nagra 2020a), the repository conceptual design is explained based on a combined repository in the WMP21. The design for the individual repositories will be mentioned insofar as to specify which repository components of a combined repository will no longer be required for the corresponding individual repository.

3.1 Introduction and objectives

3.1. 1 Waste disposal concepts: an overview

The principle of protecting humans and the environment from ionising radiation is firmly anchored (cf. IAEA 2006 and ICRP 2007) and there is international consensus that high-level waste in particular should be disposed of in the deep geological underground. Only this can ensure that the waste is safely enclosed for a very long time and with no intention of retrieving it. While repositories for low- and intermediate-level waste exist or are being planned deep underground but also at or near the surface, most countries plan to dispose of high-level waste (including spent fuel assemblies) in deep geological repositories.

Tab. 3.1-1 provides information on selected L/ILW or HLW repository sites abroad and on their planning and implementation status.

Tab. 3.1-1: Information on selected repository sites abroad and their planning and implementation status

a) Repositories for low- and intermediate-level waste (if not specified otherwise: underground)

Country	**Repository site**	**Planning and implementation status**
Belgium	Dessel (surface)	Operation from around 2024
Germany	Asse (former potash and salt mine)	In use from 1965 to 1995 to test waste disposal; current planning foresees the retrieval of the waste
	Konrad (former iron ore mine)	Completion from 2027
	Morsleben (former salt mine)	Operation completed, decommissioning/clean-up underway
Finland	Olkiluoto	In operation since 1992
	Loviisa	In operation since 1998
France	Centre de la Manche (surface)	Decommissioned (operated till 1994)
	Centre de l'Aube (surface)	In operation since 1992
UK	Dounreay (surface)	In operation since 1957
	Drigg (surface)	In operation since 1959
Japan	Rokkasho (surface)	In operation since 1992
Canada	Kincardine	Construction licensing procedure interrupted in 2020 (vote defeated)
	Port Hope – "historic waste" (surface)	Operation from around 2024
Sweden	SFR1	In operation since 1988, extension of operation planned for 2023
Spain	El Cabril (surface)	In operation since 1992
South Korea	Gyeong-ju, Wolsong	In operation since 2015
Czech Republic	Richard (near-surface)	In operation since 1964
	Dukovany (near-surface)	In operation since 1995
Hungary	Püspökszilágy (surface)	In operation since 1976
	Bátaapáti	In operation since 2012, additional drifts are being constructed on an ongoing basis
USA	Numerous surface repositories in operation (Hanford Site, Idaho National Laboratory, Los Alamos National Laboratory, Nevada National Security Site, Savannah River Site, Barnwell, Clive, Andrews County) and closed (Beatty, Maxey Flats, Sheffield, West Valley)	First facility operational from 1963

Tab. 3.1-1: (cont.)

b) Repositories for spent fuel, vitrified high-level waste and long-lived intermediate-level waste, with information on the host rock (in brackets)

Country	Repository site	Planning and implementation status
Belgium	Site not yet identified	In planning, fundamental government resolution expected, generic EIA submitted in 2020
Germany	Site not yet identified (clay rock/granite/salt)	New procedure begun in 2017, potential geological siting regions ("sections") identified in 2020, site selection planned for 2031, exploratory research in Gorleben completed (begun in 1979)
Finland	Olkiluoto (granite)	Site determined, ONKALO Rock Laboratory, construction licence granted in 2015, construction started in 2016, start of operation from around 2024 (SF)
France	Bure region (clay rock)	Underground rock laboratory in operation in siting region, construction licence application 2022, start of operation from around 2038
Canada	Site not yet identified	Site selection process ongoing, currently two regions still involved, site selection around 2023
Sweden	Forsmark (Östhammar) (granite)	Construction licence application submitted in 2011, start of operation from around 2031 (SF)
USA	Site not yet identified	Licensing process interrupted and options investigated, deep geological disposal recommended by "Blue Ribbon Commission" Current status: no progress
	WIPP, for long-lived ILW (salt)	In operation since 1999

The most important source of information on disposal concepts worldwide is the regular reporting by various international mechanisms. As part of the "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management" (IAEA 1997) of the International Atomic Energy Agency (IAEA), periodic country reports are prepared which document the measures taken to fulfil the obligations of the Convention. The reports also contain information on the corresponding facilities and the radioactive materials to be emplaced in them.

Within the framework of the European Atomic Energy Community, the 2011/70/Euratom Guideline (Euratom 2011) was adopted in 2011. This obliges member states to regularly prepare, as of 2015, an updated national waste management programme which sets out the strategy for the disposal of spent fuel assemblies and radioactive waste. Since then, the member states have submitted initial "national programmes". Individual countries have already prepared a second edition.

Nagra also obtains detailed information on individual national programmes through participation in a large number of international bodies (particularly as part of the International Association for Environmentally Safe Disposal of Radioactive Materials, EDRAM), working groups and projects (particularly within the framework of the Nuclear Energy Agency, NEA, of the OECD), as well as through bilateral collaboration agreements with other waste management organisations.

Situation in Switzerland

In Switzerland, the Nuclear Energy Act (Art. 3 & 31 KEG) stipulates deep geological disposal as the waste management concept for all radioactive waste. In 2000, a working group (Expert Group on Disposal Concepts for Radioactive Waste, EKRA) appointed by DETEC provided the legal framework in its final report (EKRA & Wildi 2000). The working group was tasked with evaluating all possible waste disposal concepts and came to the conclusion that only deep geological disposal can ensure the required long-term safety. At the same time, EKRA presented a concept that took account of societal wishes for monitoring and waste retrievability. This concept met with wide approval and, based on this, the deep geological disposal of Switzerland's radioactive waste was legally stipulated (KEG 2003). A deep geological repository[15] is defined by the following features:

- type and volume of waste for disposal (waste inventory)
- safety concept for the post-closure phase (Section 3.1.2), tailored to the waste types and geology
- monitoring of the repository and possibilities for corrective measures, including the potential retrieval of the waste
- the selected site:
  - this must exhibit a favourable geological situation with:
    - sufficient long-term stability (suitably large geological area and favourable local situation)
    - a containment-providing rock zone with suitable barrier properties and a favourable hydrological situation
    - a sufficient extent of the host rock at the preferred depth that can accommodate the required layout of the underground facilities
  - local situation at the earth's surface which allows the configuration of the surface infrastructure of the repository (surface facility, auxiliary access facilities, site development, etc.) to be realised in such a way that potential conflicts in terms of land use and the environment can be avoided as far as possible during exploration, construction, operation and monitoring.

Appendix A.1 provides an overview over the legal framework and includes a corresponding compilation of federal laws relevant for realising the project of deep geological disposal in Switzerland.

[15] Art. 3c KEG defines a deep geological repository as a facility in the geological underground that can be sealed when the permanent protection of humans and the environment is ensured by a system of passive barriers. According to Art. 64 KEV, the repository consists of a main repository for emplacement of the radioactive waste, a pilot repository and test areas.

In line with international practice, the Swiss waste management concept foresees two repository types: one for L/ILW and one for HLW (for information on allocation of the waste to the repository types, cf. Chapter 4). In many countries, L/ILW is disposed of in special near-surface and comparatively cost-efficient repositories. In contrast, Switzerland has decided to pursue the more costly and complex option of deep geological disposal also for this waste category. By focusing on the Opalinus Clay for all waste types, it is fundamentally possible to dispose of all waste in a so-called combined repository. A combined repository has, as is explained in the following, substantial advantages compared to two individual repositories.

The combined repository is an overall facility, and many elements of the surface infrastructure and some of the underground structures (access structures and central area) can be jointly used. Compared to two individual repositories, realising a combined repository leads to the following advantages:

- Fewer surface facilities and repository accesses have to be constructed and operated. As a result, space requirements, construction volumes and the volume of excavated material are lower. This means that energy and resource consumption decrease as does the negative environmental impact. Realising a combined repository therefore leads to lower emissions of greenhouse gases than would arise from constructing two individual repositories.
- As fewer facilities have to be constructed and operated, there are also advantages with regard to safety:
  - construction risks (incidence rate) are reduced. In addition, when building the HLW repository section, it is possible to benefit from the experience gained from the previously constructed L/ILW repository section at the same site.
  - Fewer facilities have to be secured.
  - The combined repository as an overall facility will be operated for 25 years; the two individual repositories only for 15 years each. The longer operating period simplifies the recruitment of qualified staff and contributes to the continuity and preservation of know-how.
  - In the case of a combined repository, the exploration period for underground geological investigations (see Section 5.2) in the relevant siting section is prolonged; this leads to an extended database on which the required safety demonstrations can be based.

Nagra (2020a) compares the construction activities, operational procedures and environmental impacts of a combined repository with those of two individual repositories and outlines specific aspects of the advantages presented above in more detail. A supplementary discussion can be found in Appendix A.8.3.

Finally, realising a combined repository is associated with advantages regarding the licensing procedure and also socio-ecological and socio-economic perspectives:

- In the case of two individual repositories, all procedural steps must be performed for each of the repository types. In contrast, in the case of a combined repository, individual procedural steps for the L/ILW and HLW repository sections are assumed to be linked (e.g. licence for underground geological investigations) or lead to an overarching licence (e.g. construction licence), which includes sub-licences that are concretised within the framework of the clearance procedures.

- Additional advantages of a combined repository arise with regard to the support and collaboration effort for the project required on site. Among other factors, the administrative burden and number of parties involved will be lower when realising a combined repository than when two individual repositories have to be supported at different sites.
- As explained in Chapter 7, compared to two individual repositories, realising a combined repository leads to a cost reduction of around 15% (CHF 1.6 billion); this difference has ramifications not only for the waste producers but also from an economic perspective.

A combined repository will be realised if, once the HLW repository section has been determined, the remaining space for an L/ILW repository section is equivalent to that of an L/ILW repository at another site from a safety perspective, and if the HLW and L/ILW repository sections do not impact one another negatively in the long term. Results of the field investigations to date confirm that, in principle, all three siting regions provide sufficient space for a combined repository layout. Based on the advantages outlined above, and if the conclusive overall safety-based assessment allows, the general licence application will be submitted for a combined repository.

The law specifies that, in principle, Swiss radioactive waste should be disposed of within Switzerland (cf. Art. 30 Par. 2 KEG). Under certain conditions, disposal abroad could also be an option (cf. Art. 34 Par. 4 KEG). The Swiss waste producers have ruled out disposal of foreign waste in a repository located in Switzerland.

To date, there is no deep geological repository in operation in Switzerland, but there is a sound technical-scientific basis for realising the project. Wide experience already exists in preparing repository projects and establishing the necessary background. Repository concepts capable of ensuring the required long-term safety have been developed. In particular, this includes the demonstration of disposal feasibility for L/ILW (Nagra 1985) and for HLW (Nagra 2002b, Nagra 2002c), i.e. the so-called *Entsorgungsnachweise*. The existing knowledge base has been expanded as part of the Sectoral Plan process, safety has been evaluated and the results have been summarised in a series of reports (Stage 1 of the Sectoral Plan: (Nagra 2008b, Nagra 2008c, Nagra 2008a); Stage 2 of the Sectoral Plan (Nagra 2014o, Nagra 2014n, Nagra 2014m, Nagra 2010)).

As part of a research project on "repository conceptual design" carried out by the Swiss Federal Workgroup for Nuclear Waste Disposal (Agneb), questions relating to the repository conceptual design for the two facility types were widely discussed and the results brought together in a synthesis report (ENSI 2016). The repository concepts proposed by Nagra are generally considered as meaningful and appropriate for ensuring safety. Extensive international experience is used as well; this applies particularly to France that is planning its HLW repository in a host rock that is very similar to the Opalinus Clay (e.g. Andra 2012, report published for a licence application). With regard to realising deep geological repositories, relevant experience is available from Sweden and Finland (e.g. SKB 2011, Posiva 2012b), as the implementation of these programmes is already far advanced. It is also possible to draw on the extensive know-how available in the area of conventional underground construction.

3.1.2 Repository concepts and associated safety concepts

Concepts for deep geological repositories provide information on the main features of the facilities and are defined by the underlying safety concepts.

The elements of the Swiss repository concepts are briefly described in the following.

The **safety concept for the post-closure phase** of a deep geological repository ensures the permanent protection of humans and the environment using staged, passive barriers (Art. 3c KEG). In Switzerland, the safety concept for HLW and L/ILW is based on a multi-barrier system optimised with regard to long-term safety. This includes engineered barriers consisting of the waste matrix, disposal canisters, backfilling and sealing as well as the containment-providing rock zone as a natural barrier.

The multi-barrier system ensures that the repository fulfils the required safety functions taking its evolution over time into consideration. In line with Guideline ENSI-G01, Appendix 1 (ENSI 2011), safety functions are overarching functional requirements on the multi-barrier system that, taken together, ensure long-term safety. The required safety functions include:

- **Isolation** of radioactive waste from the earth's surface
- **Complete containment** of the radionuclides for a certain time period
- **Immobilisation, retention and slow release** of radionuclides
- **Compatibility** of the multi-barrier system elements and the radioactive waste with each other and with other materials
- **Long-term stability** of the multi-barrier system with regard to geological and climatic long-term evolution

The HLW and L/ILW repository concepts are designed in such a way as to fulfil not only requirements for implementation but also those requirements that, with a view to ensuring long-term safety, can be derived from the required safety functions. The concepts currently being pursued for the combined repository as well as for the two individual repositories envisage HLW and L/ILW disposal areas with emplacement drifts or emplacement caverns that roughly extend through the middle of the Opalinus Clay layer. The corresponding safety concepts for SF and HLW(WA) as well as for L/ILW and ATW are shown in Fig. 3.1-1 and are characterised as follows:

- The geology (Section 3.1.5) as a natural barrier isolates the radioactive waste from humans and the environment: On the one hand, together with the engineered barriers, the containment-providing rock zone ensures the containment and retention of the radionuclides. On the other hand, a favourable geological situation provides long-term stability and protects the repository from unauthorised access and from inadvertent human intrusion. In its decision on Stage 2 of the Sectoral Plan, the Federal Council specified the Opalinus Clay as the host rock for all siting regions and all waste types. The Opalinus Clay makes a very significant contribution to the retention of radionuclides and fulfils the safety-based requirements on a deep geological repository.
- The engineered barriers are designed in such a way as to be compatible with the natural barriers and with one another and to be optimised with regard to the respective waste types.

- In the case of HLW (Fig. 3.1-1), the radionuclides are fixed in a stable, very low-solubility waste matrix, from which they dissolve only slowly even when they come into contact with water. The high-level waste from reprocessing (HLW(WA)) is melted into a glass matrix, and in the spent fuel (SF) assemblies, the radionuclides are immobilised in the UO_2/MOX matrix of the fuel. In principle, the cladding of the spent fuel assemblies and the stainless steel flasks for the reprocessing waste form another engineered HLW barrier, but their contribution is not considered in the safety case.
- A stable and corrosion-resistant HLW disposal canister for spent fuel assemblies and high-level waste from reprocessing can contain radionuclides for several thousands of years. The HLW disposal canister is emplaced in the HLW emplacement drift of a deep geological repository and, due to its mechanical, thermal and chemical stability, contributes directly and significantly to the compatibility of the elements of the barrier system by preventing interactions between the waste matrix and the backfill of the emplacement drift (and the host rock) for several thousands of years. Even after canister integrity has been lost, radionuclides are still released at a delayed rate. Steel is foreseen as the material for the HLW disposal canisters, and different variants exist for this (see Section 3.2.3).
- The backfilling and sealing of the HLW emplacement drifts protect the disposal canisters from corrosion and damage through the overlying rock formations by creating a suitable chemical environment and evenly distributing the load on the disposal canisters caused by overburden pressure. Processed Opalinus Clay and/or bentonite are foreseen for the tunnel backfill and sealing elements of the seal system of the HLW repository. The repository concept is designed in such a way as to supplement the sealing of the HLW emplacement drift by also sealing the disposal area accesses. Different variants exist for both backfilling and sealing (see Section 3.2.3).
- L/ILW and ATW (Fig. 3.1-1) are conditioned in waste packages and packaged and backfilled in L/ILW disposal containers. The disposal containers remain intact for a certain time period, which retards saturation and thus contributes to the containment of soluble radionuclides. The L/ILW emplacement caverns are filled with a cement-based backfill and the resulting near-field conditions have a positive impact on long-term safety. Using a cement-based backfill creates alkaline conditions ($pH > 10.5$) that lead to low metal corrosion rates, which in turn reduce microbial activity and have a positive impact on the retention of radionuclides. As a result, the high pH environment contributes to limiting the generation of gas pressure and any resulting negative impacts on the host rock. The closure of the L/ILW emplacement caverns is ensured by sealing the disposal area accesses. There are several variants for the materials used for backfilling and sealing (see Section 3.2.3).

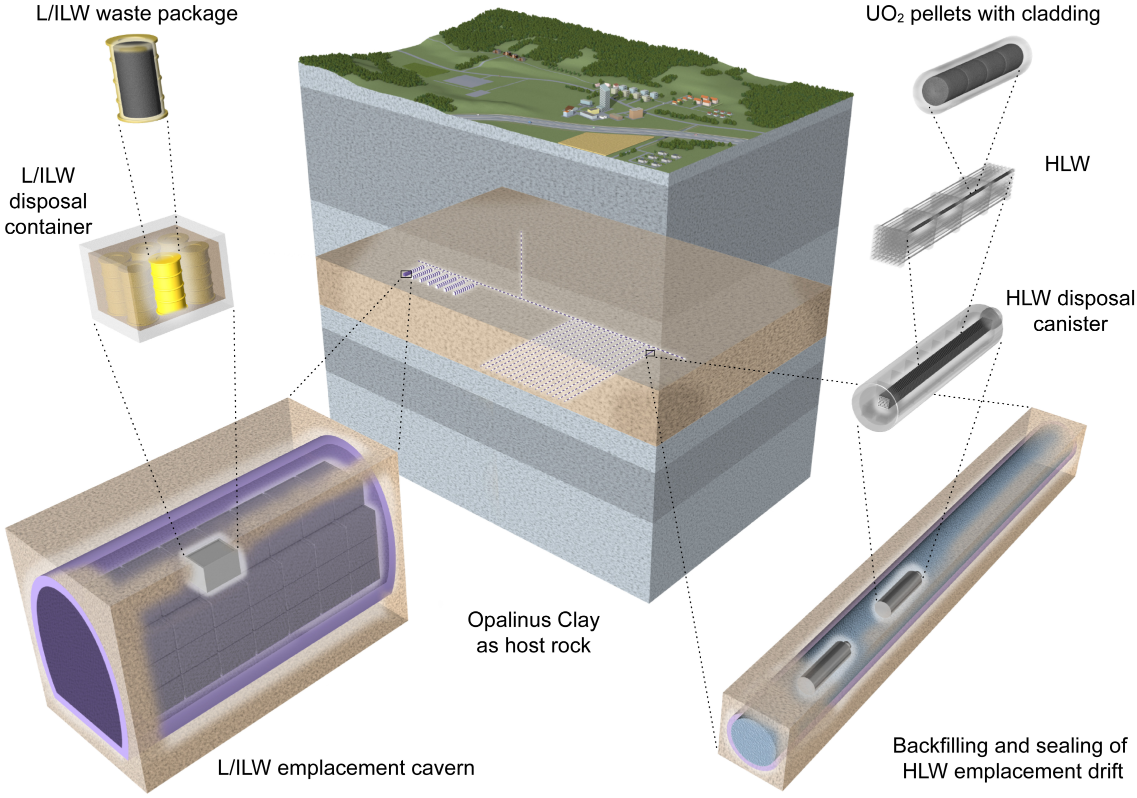

Fig. 3.1-1: Implementation of the safety concept for the post-closure phase in line with the current repository concepts for HLW and L/ILW

The example for HLW (right) is based on spent fuel (SF) assemblies with fuel rods (UO_2 pellets in cladding tubes) packaged in a steel disposal canister. The HLW disposal canisters are placed in an HLW emplacement drift which is then backfilled (for example with bentonite) and sealed.

The example for L/ILW (left) is based on a typical L/ILW waste package type (200 l drum) that is packaged in a disposal container and disposed of in an L/ILW emplacement cavern that, in this example, is backfilled with cement-based reference mortar.

For both HLW and L/ILW, the Opalinus Clay as the host rock represents the natural barrier.

3.1.3 Technology for construction, operation and closure of the repositories

Current concepts for the construction, operation and closure of deep geological repositories (e.g. for handling the waste, installing the engineered barriers and closing the facility) are based on present-day technology. Considerable advances can be expected in general technological fields (robotics, control systems, etc.) up to the time when construction begins, and these will be integrated into the definitive design of the disposal technology. The following documents provide detailed information on development programmes and the assessment of current construction, operation and closure concepts in terms of feasibility and practicability: Nagra (2021e) and Nagra (2021f). Relevant experience gained in foreign programmes should also be considered. For this reason, even with regard to the final technology to be used, sufficient flexibility must be retained to allow future technological developments to be considered up to the submission of the construction licence application and – depending on the topic – also for later stages of the procedure (see Appendix A.4).

With a view to WMP21, the Federal Council formulated a requirement on repository closure as preliminary work to preparing a concept for the general licence application (Bundesrat 2018). Accordingly, in Appendix A.8.4, Nagra describes how different closure variants impact the operation of a deep geological repository and the implementation period for the closure phase. For more detailed information, see the corresponding background report to WMP21 (Nagra (2021f)).

3.1.4 Monitoring and retrievability as integral components of the repository concepts

Monitoring and retrievability are foreseen as an integral component of the geological disposal concepts in the Swiss programme as well as in several foreign programmes. Technical concepts are available for monitoring and retrievability, and they are modified periodically to maintain the state of the art.

An integral monitoring concept will be submitted together with the general licence application. The concept will include information on the monitoring strategy, selection of measurement parameters and the evolution of methods based on the results and experience obtained from experiments in underground rock laboratories and EU research projects such as "Modern2020" (Development & Demonstration of Monitoring Strategies and Technologies for Geological Disposal; Galson Sciences Limited 2019). In a new EU research project, "MODATS" (Monitoring Equipment and Data Treatment for Safe Repository Operation and Staged Closure), measurement methods and monitoring systems are being developed further, and new data acquisition and data management methods are being developed.

For the topics of environmental monitoring and zero measurements, an initial site-independent concept (Fanger et al. 2021) was prepared that outlines the preliminary work for the zero measurements. The most important insights from this background report for WMP21 in response to Federal Council stipulation 5.5 are summarised in Appendix A.8.5.

Initial site-independent concepts have been developed for underground monitoring during the operational phase of the underground geological investigations (EUU) and the test areas and for monitoring the pilot repository. These are presented in Nagra (2021a, 2021c). The concept for monitoring the pilot repository is described in a background report (Nagra 2021c) to WMP21. It also serves as a response to Federal Council stipulation 5.2 by demonstrating the extent and content of the measurements for monitoring a pilot repository. The most important information is summarised in Appendix A.8.2.

The detailed structuring of the monitoring programme for the pilot repository will only take place after the underground site investigations have been completed and after the results from these investigations that are relevant for monitoring the pilot repository become available, taking into account the technological state of the art.

The possibility to retrieve waste from a repository was thoroughly discussed within the framework of the "Reversibility and Retrievability" (R&R) project of the OECD/NEA (OECD/NEA 2011). Concepts for potential waste retrieval have been developed on the basis of existing technology. In this context, and based on these concepts, Nagra will develop documents on retrievability with a view to the general licence application in which both generic and site-specific retrievability aspects are discussed. Nagra will consider and implement the retrievability requirements specified in Guideline ENSI-G03 (ENSI 2020b) that was revised in December 2020. In line with Art. 37 KEG, this revised guideline also provides more detailed information on "retrievability without undue effort until repository closure". In connection with the issue of retrievability without undue effort, significant technological developments are expected until the nuclear construction licence application (e.g. in robotics and underground construction). In addition, Nagra can expect to benefit from developments and experience in international programmes that are at a more advanced stage. The technological state of the art will be considered appropriately in the conceptual design of the repository within the framework of the nuclear construction and operating licences (Appendix A.4.2).

3.1.5 Geology

Based on several decades of work, there is now a broad understanding both in Switzerland and abroad of aspects of geology that are relevant for waste disposal (for Switzerland: cf. milestone reports Nagra 2002b, Nagra 2002c, Nagra 2008c, Nagra 2014a with references therein, investigation programmes at the Grimsel Test Site: e.g. Vomvoris & Blechschmidt 2019 and the Mont Terri Rock Laboratory: e.g. Bossart et al. 2017, Blechschmidt & Vomvoris 2015; for international programmes: e.g. Andra 2012, SKB 2008, Posiva 2012a). This knowledge base is the outcome of general geological research, hydrocarbon exploration, tunnel construction and the focused investigations of Nagra that have been ongoing for more than 40 years (cf. Fig. 3.1-2). The knowledge base is sufficient for defining the geological requirements for site selection as a function of the allocated waste inventory and the selected safety concept.

Starting with the whole of Switzerland (the so-called "blank map of Switzerland"), potential host rocks and siting regions from the viewpoint of both safety and geology were identified in Stage 1 of the Sectoral Plan. In 2008, Nagra proposed six siting regions for an L/ILW repository and three for an HLW repository (Nagra 2008b, Nagra 2008c). When preparing the proposals, Nagra applied the criteria for site selection defined in the conceptual part of the Sectoral Plan using a multi-stage systematic approach (Nagra 2008b). With the decision of the Federal Council on Stage 1 in 2011, the proposals for potential L/ILW and HLW siting regions were recorded in object sheets for further investigation in Stage 2 of the Sectoral Plan process.

In Stage 2 of the Sectoral Plan, the narrowing-down process continued, consisting of a stepwise evaluation with a view to proposing at least two siting regions for each repository type.

Optimised geological configurations for the HLW and L/ILW repository in the individual siting regions were selected and their suitability in terms of safety was investigated. In addition, an overall comparative assessment was conducted based on decision-relevant features and any clear disadvantages of the siting regions.

Based on this, Nagra proposed the Jura Ost and Zürich Nordost siting regions for further investigation in Stage 3 of the Sectoral Plan, with the Opalinus Clay as the host rock (Nagra 2014o) for either two separate repository types or for a combined repository at the same site (see Section 3.1.1). At the end of 2018, and based on the expert opinions of the authorities, the Federal Council approved focusing on the Opalinus Clay as the remaining host rock and placing the Jura-Südfuss, Südranden and Wellenberg siting regions in reserve. In addition, the Federal Council decided that, in addition to the Jura Ost and Zürich Nordost siting regions, the Nördlich Lägern siting region should also be further investigated in Stage 3.

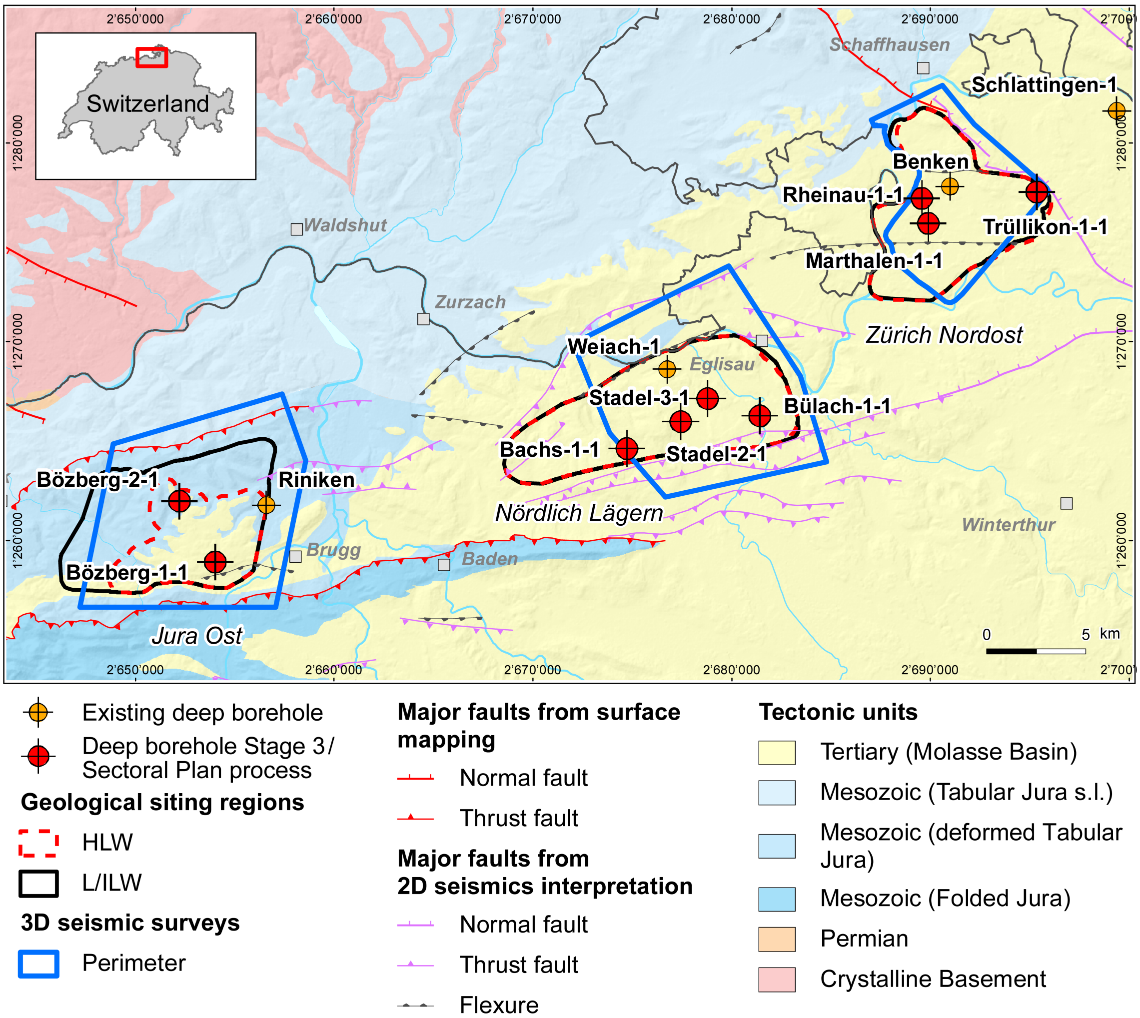

Fig. 3.1-2: Tectonic overview map with the three siting regions to be further investigated in Stage 3 of the Sectoral Plan, the extent of the datasets from the 3D seismic investigations and the sites of the deep boreholes

In the ongoing Stage 3 of the Sectoral Plan, extensive geoscientific investigations have been carried out in the three remaining siting regions based on the exploration concepts (Nagra 2014b) submitted together with the reports for Stage 2 of the Sectoral Plan. Between autumn 2015 and spring 2017, two new 3D seismic datasets were acquired for the Jura Ost and Nördlich Lägern siting regions and, for the Zürich Nordost siting region, existing 3D seismic data from 1997 were supplemented (Fig. 3.1-2). Based on the initial evaluation of the 3D seismic investigations (Nagra 2019c, 2019d, 2019e), the exploration strategy for the deep borehole campaign was concretised and the work programmes for the deep boreholes were developed. By the end of October 2021, eight boreholes had been completed: Trüllikon-1, Marthalen-1 and Rheinau-1 in Zürich Nordost, Bülach-1, Stadel-2 and Stadel-3 in Nördlich Lägern and Bözberg-1 and Bözberg-2 in Jura Ost. One deep borehole (Bachs-1 in Nördlich Lägern) is still ongoing but is expected to be concluded shortly[16].

[16] The Waste Management Programme 2021 was compiled based on the information available as of 31st October 2021.

Further field investigations were conducted with a view to assessing the long-term geological evolution. These addressed erosion-related questions and included high-resolution 2D seismic campaigns and 11 Quaternary boreholes (cf. Fig. 3.1-3). Together with the geoscientific system analyses and further studies on process understanding, the ongoing evaluation and integration of the field investigations form the basis for the safety-based comparison of the siting regions and for the justification of the site selection. The latest results from the deep boreholes and other field investigations confirm that all siting regions are suitable for constructing a safe deep geological repository and have sufficient space for both a combined repository or two individual repositories.

The geological findings are summarised in a geosynthesis for the general licence application for the selected site(s). The geosynthesis will also include new insights from tests conducted in underground rock laboratories, investigations conducted by international waste management organisations and from other relevant fields of work (e.g. the hydrocarbon industry, geothermics).

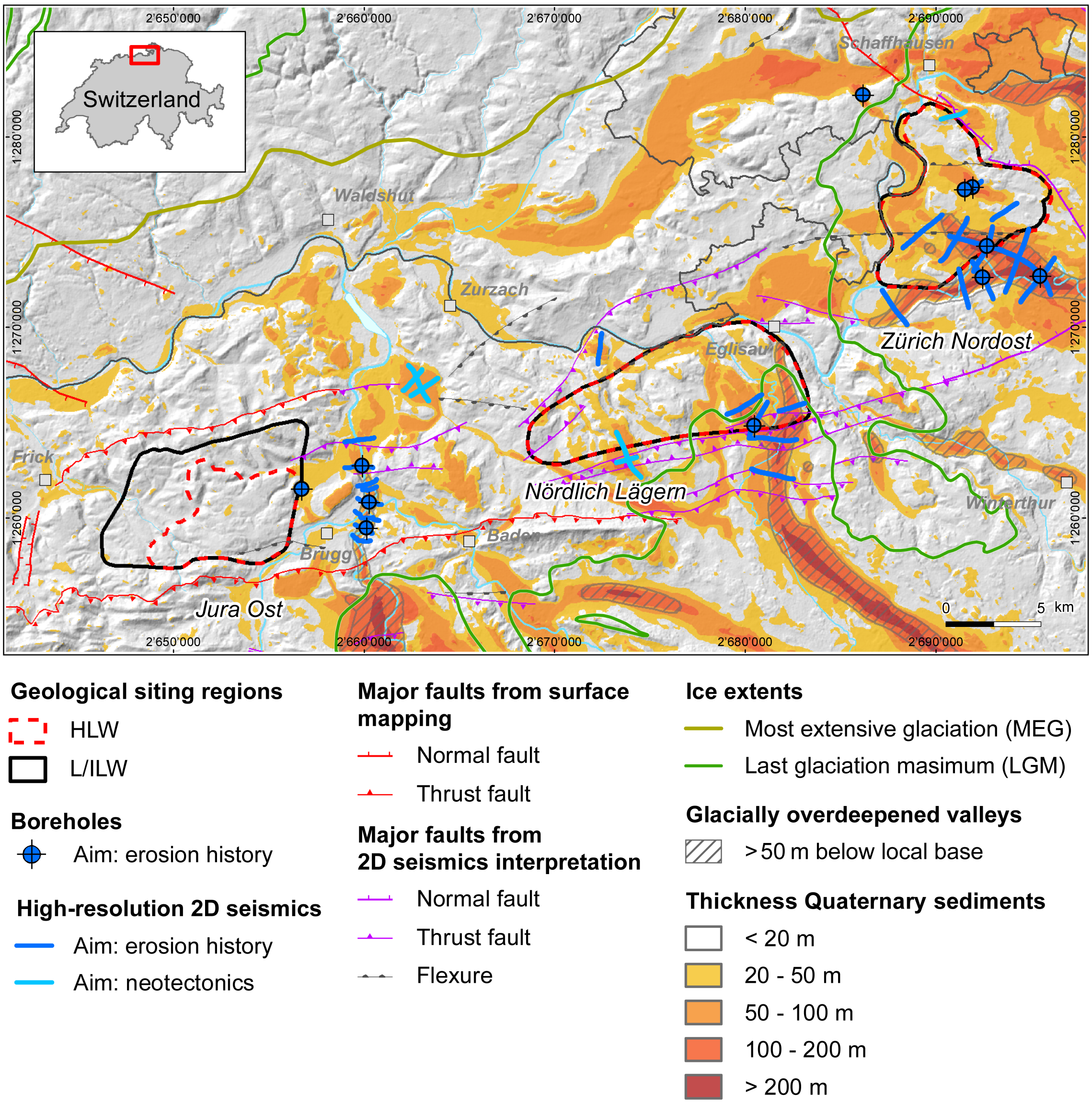

Fig. 3.1-3: Locations of the high-resolution 2D seismic investigations and boreholes conducted to investigate the fluvial and glacial erosion history in the Quaternary

3.1.6 Safety demonstrations

The Nuclear Energy Ordinance (KEV 2004) and Guideline ENSI-G03 (ENSI 2020b) call for safety demonstrations for the operational phase (operational safety) and for the post-closure phase (demonstration of long-term safety) for all licensing steps required to realise a deep geological repository. For the final closure of a repository, a conclusive demonstration of long-term safety (safety case) is required. Guideline ENSI-G03 contains detailed requirements for preparing the safety demonstrations. In particular, they must be carried out based on the current status of science and technology, have an appropriate degree of detail depending on the stage of the project and must be documented in safety reports.

The results of the safety demonstrations and of the review by the authorities are integrated into the safety demonstrations for each subsequent milestone. The next safety demonstrations are required for the general licence. To this end, the authorities have clarified the requirements for both the operational phase and the post-closure phase in accordance with KEG (2003), KEV (2004) and Guideline ENSI-G03 (ENSI 2020b) for Stage 3 (ENSI 2018c). Information on the safety-related work planned for the coming years can be found in Chapter 5 and Tab. A.2-2.

Long-term safety

Based on the general protection objective in the Nuclear Energy Act (Art. 1 KEG) and in line with Guideline ENSI-G03 (ENSI 2020b), the overarching objective of ensuring the long-term safety of a deep geological repository can be summarised as follows: the permanent protection of humans and the environment from the effects of ionising radiation from the emplaced waste following the orderly closure of the repository, without placing any undue burdens or obligations on future generations.

According to the Sectoral Plan, long-term safety also has the highest priority in the site selection process. A report justifying the site selection is therefore required for the general licence application (ENSI 2018c, KEV 2004). In this report, the applicant must justify the results of the safety-based comparison and the selection of the site for a deep geological repository. Pursuant to Art. 62 Letter a und b KEV, the applicant must compare the siting options in terms of repository safety and evaluate the properties that are decisive for site selection.

For each of the selected site(s), the applicant must also prepare a formal safety case for the general licence application. Based on a comprehensive and systematic analysis, the safety case demonstrates how the repository will evolve with time, what the radiological consequences will be and that the overarching protection objective and associated guidelines and protection criteria are met in line with Guideline ENSI-G03 (ENSI 2020b). This also includes a description and an evaluation of the methodology and data used, the use of supporting arguments and a systematic and comprehensive analysis of existing uncertainties and their relevance for long-term safety.

With regard to methodology, aside from regulatory requirements Nagra can draw on previous safety demonstrations, particularly the '*Entsorgungsnachweis*' feasibility demonstration for the HLW repository (Nagra 2002a), as well as on provisional safety analyses (Nagra 2014o, Nagra 2014m) conducted within the framework of Stage 2 of the Sectoral Plan. International recommendations on preparing a safety demonstration also exist, and Nagra has actively contributed to developing these. Nagra also follows international developments, e.g. through participation in important bodies (e.g. Integration Group for the Safety Case of the OECD/NEA). The "Sourcebook of International Activities Related to the Development of Safety Cases for Deep Geological Repositories" (OECD/NEA 2017) provides a comprehensive and up-to-date overview of these information sources and projects. Nagra is also involved in international projects related to the safety case, for example the EU research programme EURAD; aspects related to handling uncertainties in considerations of long-term safety are discussed as part of its "Uncertainty Management Network" work package.

Particular significance is attributed to demonstrating the robustness of the system and outlining the consequences of remaining uncertainties for long-term safety. Systematic analyses assessing the barrier performance under the influence of remaining uncertainties such as all safety-relevant features, events and processes allow a number of scenarios to be developed that illustrate basic evolution pathways of the repository system.

Operational safety

During the construction phase, aspects of worker safety and health protection as well as escape and rescue must be considered, as is the case for the construction of conventional underground facilities. Corresponding guidelines (occupational safety, accident prevention, Swiss National Accident Insurance Fund guidelines, Swiss Federal Coordination Commission for Occupational Safety guidelines, fire protection guidelines, etc.) can be relied on for input.

For waste emplacement operations, Swiss requirements relating to nuclear operational safety, radiological protection and security and safeguards are particularly important. These include radiological protection (StSG 1991, StSV 2017); the DETEC ordinance on hazard assumptions and protection against incidents (UVEK 2009); the DETEC ordinance on hazard assumptions and security measures for nuclear facilities and nuclear materials (UVEK 2008, SaV 2021), the Goods Control Ordinance (GKV 2016) and various ENSI guidelines (s. Appendix A.1).

According to ENSI (2020b), the safety demonstration for the operational phase comprises a systematic, comprehensive safety analysis both for normal operation and accidents or incidents. Safety for the operational phase was evaluated as part of Stage 2 of the Sectoral Plan (Nagra 2013g, Nagra 2014a) and evaluated as plausible by the authorities. The general licence application requires a safety report (Art. 23 KEV) for the selected site that also serves as the basis for the safety demonstration for the operational phase. Based on a conceptual description of the facilities and systems, safety assessments are conducted with the focus on the suitability of the site for the safe operation of the deep geological repository. In line with Art. 8 KEV and DETEC Ordinance (UVEK 2009), this work includes a conceptual outline of the measures taken with regard to radiation protection and conducting a generic safety assessment for incidents originating within and outside the facility. In particular, a quantitative, site-specific hazard analysis is required to determine the hazard incidence due to externally triggered events.

With regard to safe repository operation and the analysis of potential accidents and incidents, a very broad knowledge and experience base is available from nuclear installations both in Switzerland and abroad. In Nagra (2020a), Nagra also outlined the advantages for construction and operation that result from realising a combined repository (see Section 3.1.1). For the safety demonstrations for the general licence application and the following procedural steps, it is thus possible to rely on proven methods based on the existing state of the art.

3.1.7 Land use and environmental impact

The construction and operation of a deep geological repository including the surface infrastructure has impacts on the environment and landscape, as well as on the land use of the affected communities and cantons. These impacts are identified, analysed and described in socio-economic-ecological impact studies (BFE 2014).

The conceptual part of the Sectoral Plan (BFE 2008) provides guidelines on procedural issues in the areas of spatial planning and environmental impact. Correspondingly, in Stage 2 of the Sectoral Plan, and based on collaboration with the regions and cantons (regional participation), siting areas for the surface facility were identified in an initial step. In these areas, the Federal Council has specified locations for the surface facility and recorded this an interim result in the Sectoral Plan (BFE 2018b).

General specifications on land use and environmental impact are clearly regulated by legislation in Switzerland and also apply to repository project[17]. In line with the Environmental Impact Assessment Ordinance (UVPV 1988), deep geological repositories for radioactive waste are subject to an Environmental Impact Assessment (Appendix UVPV, Item 40.1). The objective of the Environmental Impact Assessment (EIA) is to ensure that the applicable environmental regulations are observed. Environmental conflicts must be reduced or avoided wherever possible.

In Stage 2 of the Sectoral Plan, preliminary investigations on the environmental impact were carried out for the repository sites and repository types remaining open for discussion and documented in corresponding reports; these are included for the Jura Ost (JO), Nördlich Lägern (NL) and Zürich Nordost (ZNO) siting regions to be further investigated in Stage 3 of the Sectoral Plan in SC+P & Roos+Partner (2014a, 2014b, 2014c, 2014d, 2014e, 2014f, 2016a, 2016b, 2016c, 2016d, 2016e, 2016f). In Stage 3 of the Sectoral Plan, the preliminary investigations for the Environmental Impact Assessment are updated, including the performance specifications for Stage 1 of the EIA main investigation. Stage 1 of the Environmental Impact Assessment will be carried out in the course of the general licensing procedure (Art. 12 ff. KEG, Art. 23 KEV). Stage 1 of the Environmental Impact Report (including the performance specifications for Stage 2 of the EIA) for the selected site describes the impact of the surface infrastructure during construction and operation and forms part of the general licence application. Stage 2 of the EIA will be carried out within the framework of the construction licence procedure (Art. 15 ff. KEG, Art. 24 KEV). For the underground geological investigations (see Chapter 5), a single-stage Environmental Impact Assessment on construction and operation will be carried out as part of a separate construction licence procedure.

A report on compliance with spatial planning, i.e. spatial planning aspects when evaluating the site and layout of the surface infrastructure, is a further component of the general licence application. This report also includes information on spatial planning specifications set out in the Sectoral Plan.

[17] See various laws and regulations such as USG 1983 / UVPV 1988 (environmental protection), StFV 1991 (incidents), the DETEC Ordinance on lists for handling waste (UVEK 2005), RPG 1979 / RPV 2000 (spatial planning), LRV 1985 (air), LSV 1986 (noise), GSchG 1991 / GSchV 1998 (water protection), AltlV 1998 (contaminated sites), VBBo 1998 (soil protection), VVEA 2015 (waste), NHG 1966 / NHV 1991 (natural and cultural protection), guidelines of the Swiss Federal Office of the Environment ChemRRV 2005, cantonal structure plans or exploitation plans (Appendix A.1).

3.2 Repository conceptual design

3.2.1 Requirements and assumptions for the repository conceptual design

The concepts for the HLW and L/ILW repositories are based on the safety concepts (multi-barrier system) for HLW and L/ILW presented in Fig. 3.1-1. A combined repository consists of spatially separated sections for HLW and L/ILW at the same site. The legal and regulatory requirements are, in principle, the same for all repository types (cf. Appendix A.1). The long-term safety for the combined repository is fundamentally ensured when the HLW safety concept is applied to the HLW repository section and the L/ILW safety concept is applied to the L/ILW repository section, and when no adverse interactions result between the repository sections (see Appendix A.8.3).

All repository types include a main repository, pilot repository and test areas at disposal level. Further elements include the surface infrastructure and accesses to the underground.

The repository conceptual design is refined in a stepwise manner within the framework of the licensing procedure according to KEG (2003) and modified to meet local conditions. When these site-specific conditions are considered in the repository conceptual design, this is referred to as a repository project. Aside from legal and regulatory requirements (see Appendix A.1), a repository project also includes requirements on land use and environmental impact.

The general licence specifies the site and the main features of the project (see Section 5.1). The model repositories (combined repository, HLW and L/ILW repositories) outlined in Sections 3.2 to 3.4, as well as corresponding variants of the design, illustrate the current repository design at the conceptual stage.

As the details of the repository project become more concrete, the suitability of the different variants for individual repository elements will be reviewed, analysed and evaluated with a view to decision-making; this corresponds with the optimisation requirement according to ENSI (ENSI 2020b; see Appendix A.4).

A final specification of the repository project (including the layout of the underground emplacement rooms, detailed design of the engineered barriers) is carried out as part of the nuclear construction licence application and in the subsequent legal clearance procedure and is based on the results of the underground geological investigations (see Section 5.4.2 and Tab. A.2-4). The results of future RD&D activities should also be taken into account (see Section 5.6), as should relevant experience from foreign programmes. To ensure optimisation of the repository project, sufficient flexibility should be maintained to allow new findings to be taken into consideration up to the time of the nuclear construction licence application (see Appendix A.4).

A combined repository includes all facility elements and structures required for the construction and operation of the HLW and L/ILW repository sections. It covers all the functions of an L/ILW repository and an HLW repository, and the requirements (cf. Appendix A.1) are fundamentally the same. For this reason, it is possible to derive the conceptual design for the HLW repository and L/ILW repository by leaving out the corresponding specific repository sections for L/ILW and HLW from the combined repository.

Section 3.2 describes a model combined repository on a conceptual level; this is based on a site-independent project according to the current status of the project. Sections 3.3 and 3.4 then present the differences between the individual HLW and L/ILW repositories and a combined repository.

A site-independent comparison of a combined repository with two individual repositories with regard to construction and operating procedures as well as environmental aspects is presented in detail in Nagra (2020a).

3.2.2 Model implementation of the conceptual requirements and assumptions based on a combined repository

Facility elements and structures

Figs. 3.2-1 and 3.2-2 show a potential configuration of the different underground facility elements and structures for a combined repository. The representation does not relate to any specific site.

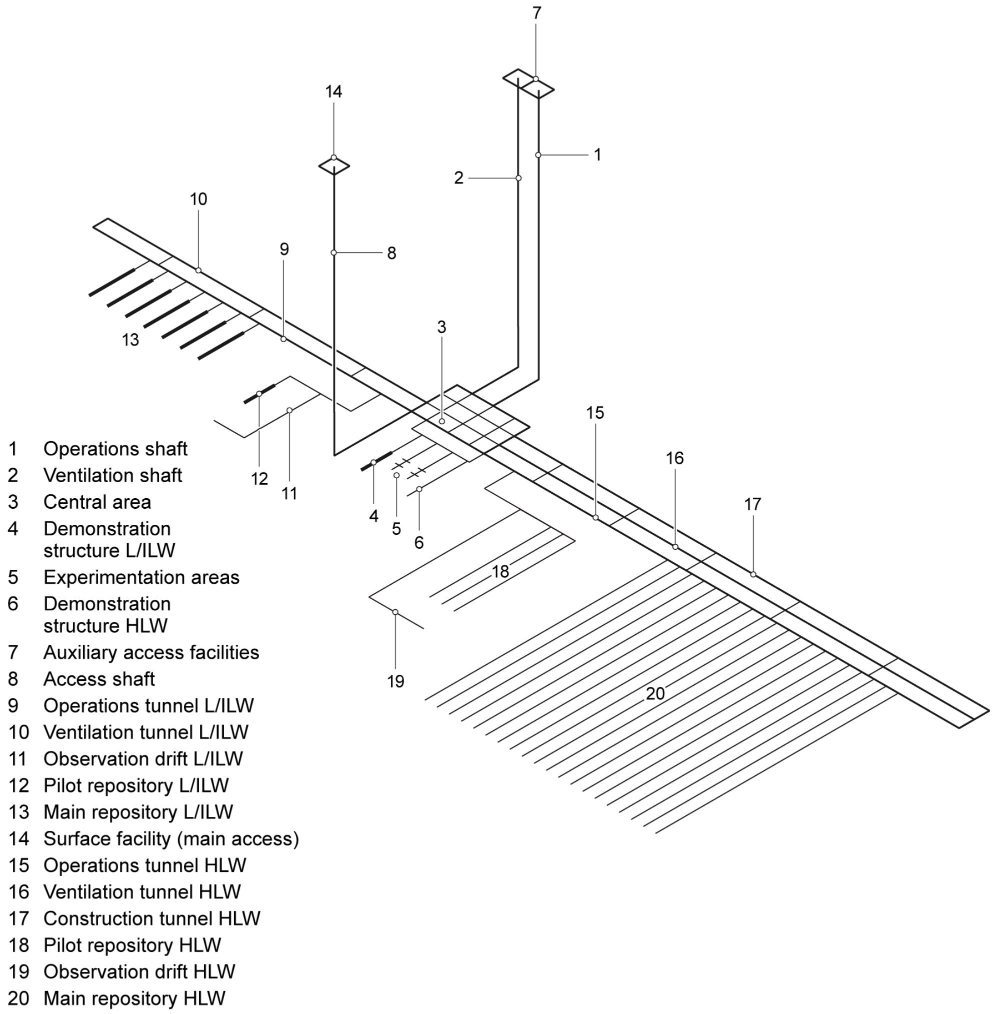

Fig. 3.2-1: System sketch for the underground facility elements and structures of a combined repository

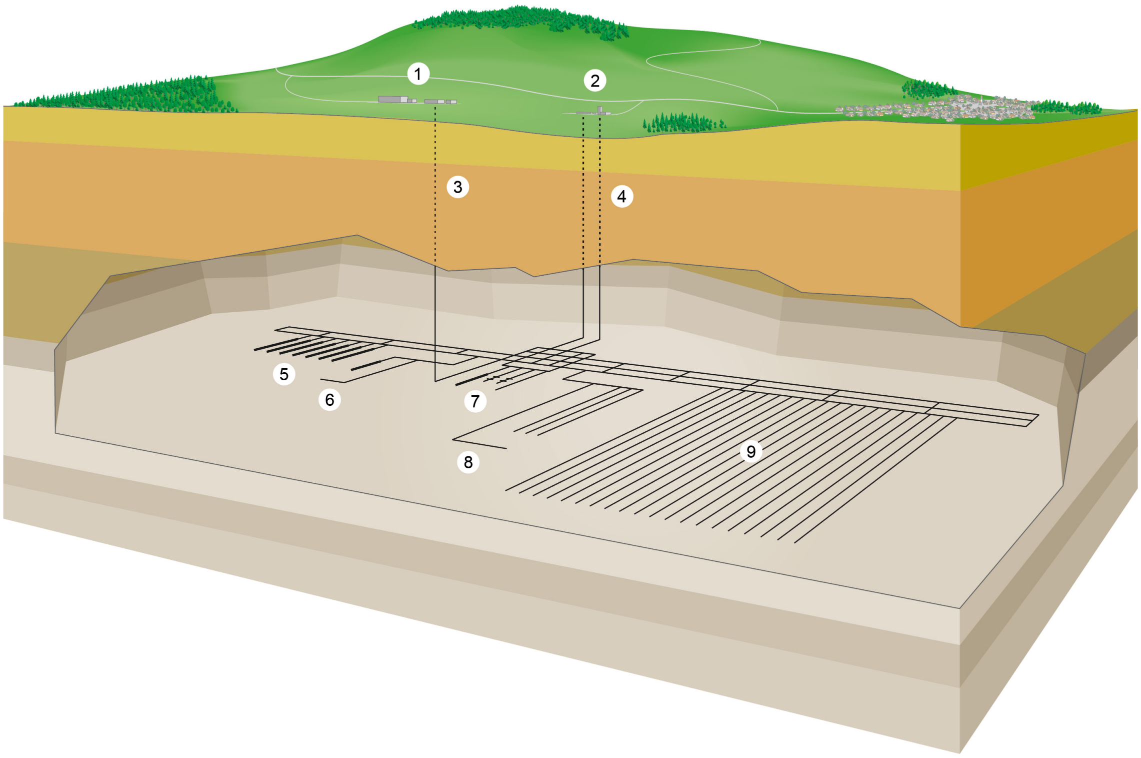

Fig. 3.2-2: Potential configuration of the different facility elements and structures for a combined repository

Legend: 1) Surface facility; 2) Auxiliary access facility; 3) Access shaft (main access); 4) Operations and ventilation shafts (auxiliary accesses); 5) Main repository L/ILW; 6) Pilot repository L/ILW; 7) Facilities for underground geological investigations/test areas; 8) Pilot repository HLW; 9) Main repository HLW.

The facility elements and structures required to operate a combined repository can be broadly split into three categories:

- Surface infrastructure
- Underground accesses[18]
- Facility elements and structures at disposal level

In the following, the elements and structures of these three categories are described from top to bottom corresponding with the pathway the waste will follow, starting with its delivery at the surface and ending with its underground emplacement.

[18] The underground accesses can be constructed as tunnels or shafts (see text under "underground accesses").

Surface infrastructure

According to Art. 49 KEG, the repository includes the surface infrastructure associated with construction, operation and dismantling insofar as this has a close spatial and functional connection with the project.

Fig. 3.2-3 shows a schematic representation of the surface infrastructure of a combined repository (Nagra 2019f). The most important elements are the surface facilities and the auxiliary access facilities. Other elements include access structures, construction site installations and sites for the handling and deposition of resulting excavated materials (Art. 49 KEG).

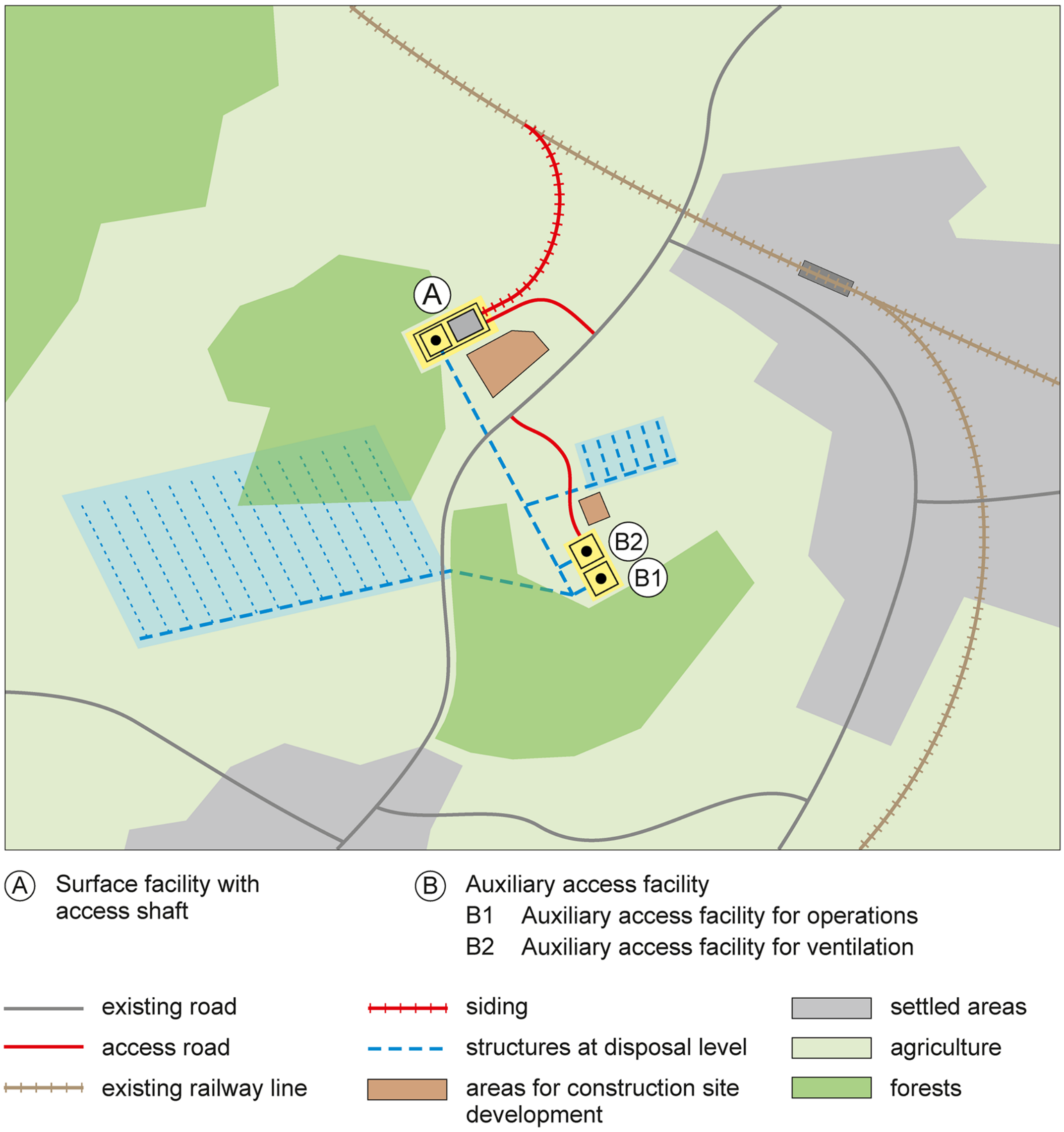

Fig. 3.2-3: Schematic layout of the different elements of the surface infrastructure

Surface facility

The surface facility constitutes the core of the surface infrastructure. After delivery and entry control, the radioactive waste is prepared for emplacement, i.e. it is delivered to encapsulation plants where it is packaged in disposal containers (unless the waste is already delivered in disposal containers). Following this, the disposal containers are transported underground through the main access (access shaft or tunnel).

Figs. 3.2-4 and 3.2-5 show a potential layout and design of the required facility elements and surface facility structures for a combined repository.

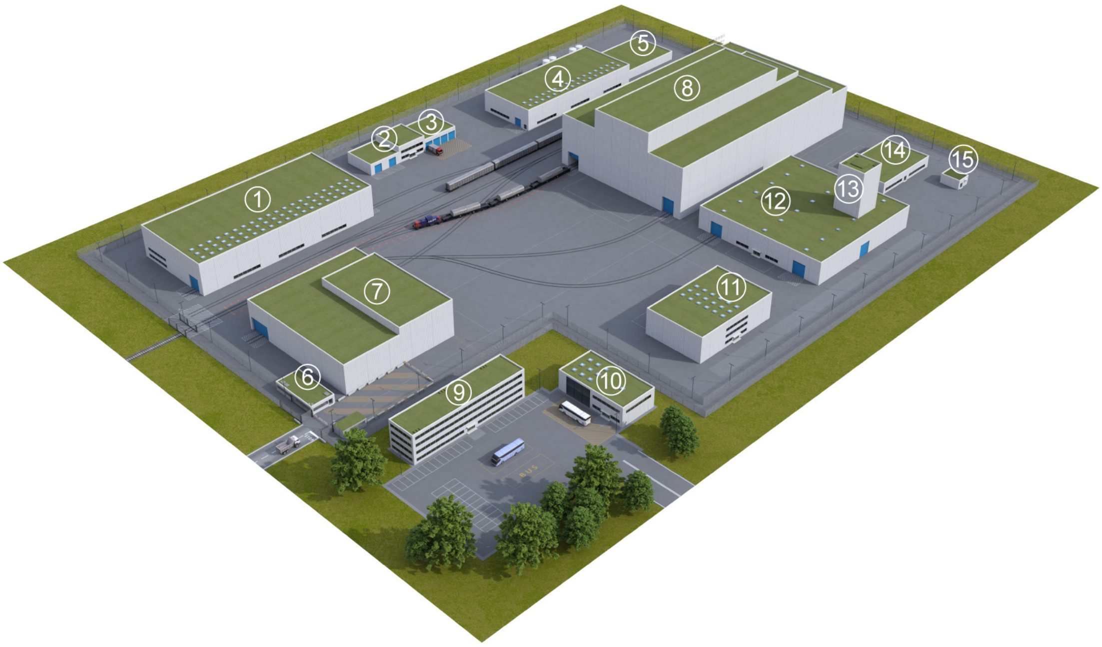

Fig. 3.2-4: Schematic layout and design of the facility elements and surface facility structures for a combined repository

Legend: 1) Treatment facility for transport casks; 2) Fire station; 3) Garages; 4) Processing plant for backfill and sealing materials; 5) Treatment facility for operational waste; 6) Gate/access control; 7) L/ILW encapsulation plant; 8) HLW encapsulation plant; 9) Administration; 10) Visitor centre; 11) Workshops; 12) Shaft hall; 13) Shaft tower; 14) Ventilation facility; 15) Power supply facilities.

Based on current planning[19], the most important elements of the surface facility are the following:

- Encapsulation plant for SF and HLW from reprocessing (SF/HLW(WA)) The packaging of SF and HLW(WA) could, in principle, take place in a facility located outside the surface facility. Nagra (2020b) outlines that the only reasonable locations for realising the SF/HLW(WA) encapsulation plant are the site of the deep geological repository or the Zwilag interim storage facility in Würenlingen. Other siting options for an SF/HLW(WA) encapsulation plant have clear disadvantages.

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[19] The basis is provided by the corresponding planning studies for the combined repository. Depending on the site-specific situation and realisation concept, structures can be arranged differently or combined into buildings.

- Encapsulation plant for L/ILW and ATW. L/ILW and ATW can also be packaged in a facility located outside the surface facility (e.g. Zwilag)
- Treatment facility for transport and storage casks and possibly additional conditioning plants for the treatment and potential conditioning of radioactive operational waste. These facilities can also be arranged at the surface facility site or, alternatively, at an external site such as the Zwilag interim storage facility
- Production facility for backfill/sealing materials for repository closure after emplacement of the radioactive waste
- Power supply and ventilation buildings for the controlled removal of exhaust air from the emplacement area
- Shaft hall and shaft tower for transport underground (in the case where the access from the surface facility to the underground is realised as a shaft as shown in Figs. 3.2-1, 3.2-2, 3.2-4 and 3.2-5)
- Delivery structures for road or rail transports
- Administration buildings and service buildings (workshops, garages and fire station)
- Security structures including perimeter, access control and security control centre
- Visitor centre

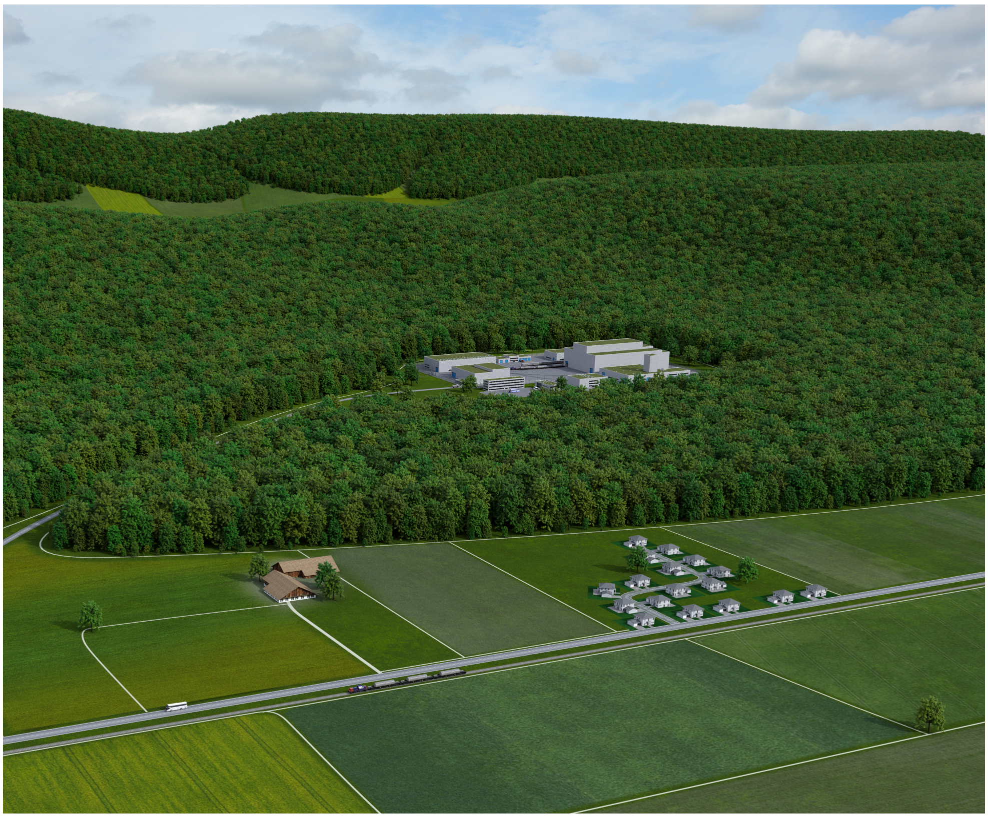

Fig. 3.2-5: Model design of the surface facility of a combined repository in a fictitious environment

Auxiliary access facilities

Together with the main access, the auxiliary access facilities secure the interfaces to the underground facilities.

- Repository construction mainly takes place via the auxiliary access facility for operations. During the waste emplacement phase, the auxiliary access for operations serves primarily as the access for the construction of the emplacement drifts, including the associated transports of materials and construction workers. Further functions of the auxiliary access for operations include ventilation (exhaust air) of the conventional parts of the repository, energy and water supply, removal of groundwater and visitor access.
- The auxiliary access facility for ventilation is mainly responsible for supplying fresh air to the structures at disposal level. It also serves as an escape or intervention route.
- The auxiliary access facilities for operations and ventilation can also be placed in a joint area. Fig. 3.2-6 shows a possible design of the structures for auxiliary access facilities for a combined repository and the case of a joint access facility for ventilation and operations with two shafts.

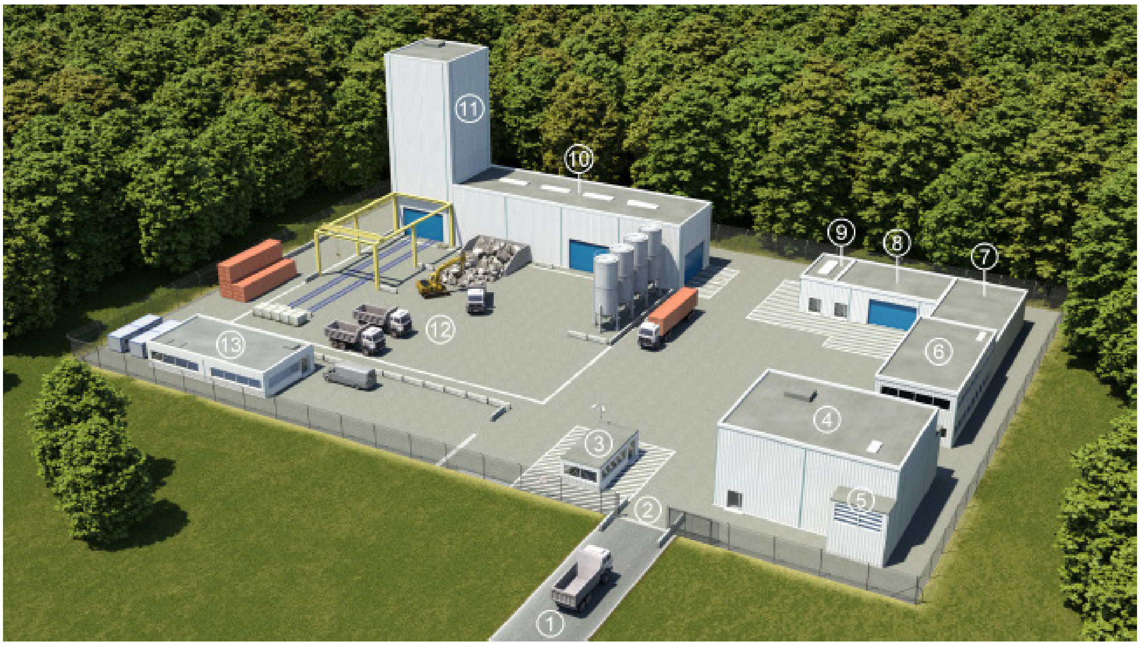

Fig. 3.2-6: Schematic design of the required structures for the auxiliary access facilities in the case of a joint ventilation and operations access with two shafts

Legend: 1) Access road; 2) Perimeter fence with access gate; 3) Gate/access control; 4) Shaft hall above ventilation shaft; 5) Structure(s) for fresh air supply; 6) Staff building with administration wing; 7) Sewage building; 8) Power supply building; 9) Workshop; 10) Shaft hall next to operations shaft; 11) Shaft tower above operations shaft with exhaust air structure; 12) Area for construction logistics; 13) Building for construction workers.

Additional surface infrastructure elements

Aside from the surface facility and auxiliary access facilities, the surface infrastructure includes additional elements that are temporarily or permanently required for the construction, operation and closure of a deep geological repository, such as general site development, construction site installation areas and locations for the recycling or deposition of excavated material (Art. 49 KEG). Depending on local conditions, existing infrastructure can be used or modified for these purposes (landfills, roads).

Site development:

- *Site development for the surface facility:* The radioactive waste is delivered by road or by rail. The latter would require a connection to the railway network as well as a road connection, cables and pipes for the sewage system, water supply, power grid, communication grid and a drainage or discharge system (to a body of water) for discharging clean groundwater, seepage water or precipitation.
- *Development for auxiliary access facilities:* The auxiliary access facilities require a road connection and the same supply and disposal infrastructure as for the surface facility to the existing network.
- *Development for construction sites:* The construction sites are developed using temporary construction accesses as well as supply and disposal infrastructure. Depending on the material management concept for the local surroundings and recycling or deposition sites for excavated material (see below), the construction materials and arising excavated material can be delivered and removed by rail, lorry or conveyor belt.

Areas for construction site installations:

- During construction as well as during dismantling and closure (realisation phases, see Section 5.3), temporary installation sites are required in addition to the construction sites at the surface facility and the auxiliary access facilities and should be located in the vicinity of these.

Sites for the recycling and deposition of excavated material:

- The arising excavated materials (e.g. Opalinus Clay) are, when reasonably feasible, recycled as material for construction and possibly for the subsequent backfilling of the repository. Some of the material could also be used for impact mitigation measures or for landscaping. Otherwise, the material must be recycled externally or permanently disposed of in a landfill. The corresponding evidence of disposal proof must be provided along with the construction records.

Underground accesses

Access structures (shafts, tunnels) ensure the connection between the surface and the structures at the disposal level. Figs. 3.2-1 and 3.2-2 outline a potential layout in the form of three shafts. For safety reasons (escape, intervention, spare supply and disposal accesses), at least two separate underground accesses separated with regard to space and ventilation must be available. For reasons related to construction, operation and operational safety, the following, functionally separated accesses are planned:

- Access shaft or access tunnel[20] (main access from the surface facility to the disposal level)
- Operations shaft or operations access tunnel (auxiliary access from the auxiliary access facility for operations to the disposal level)
- Ventilation shaft (auxiliary access from the auxiliary access facility for ventilation to the disposal level)

Facility elements and structures at disposal level

According to Art. 64 KEV, the repository consists of a main repository for emplacement of the radioactive waste, a pilot repository and test areas. This corresponds to the concept for monitored long-term disposal as set out in EKRA & Wildi (2000), which was incorporated into the KEG (2003) and the KEV (2004). Both the HLW and L/ILW pilot repositories will be constructed in an area of the host rock that fulfils the safety requirements relating to the main repository and can ensure the long-term containment of the waste ("natural barrier"). The test areas must be configured in such a way as to allow the characterisation of the underground geological situation and thus the evaluation of the safety of the repository without compromising the barrier performance of the repository and the suitability of the site for a repository (Art. 35 KEG).

Figs. 3.2-1 and 3.2-2 outline a potential layout of the pilot repositories and the associated observation drifts. In line with current planning, the pilot repositories and the observation drifts are accessed via a short access branch originating from the operations tunnel. Depending on the configuration, both distance and access can be realised differently.

Figs. 3.2-1 and 3.2-2 also show a possible layout of the test areas. By arranging them close to the central area, the experiments at disposal level can be started as early as possible, i.e. characterisation of the geological situation at the underground disposal level can already begin while the central area is still under construction (see Tab. A.2-4). It is currently assumed that the geological differences between the central area and the disposal zone are not significant. However, depending on the geological situation, alternative layouts of the test areas might be considered.

The structures of a combined repository at disposal level can be divided into the following categories (cf. Fig. 3.2-2):

- HLW repository section (main repository HLW and pilot repository HLW)
- L/ILW repository section (main repository L/ILW and pilot repository L/ILW)
- test areas
- central area

[20] In the past, access tunnels were also referred to as "ramps".

HLW repository section (HLW main repository and HLW pilot repository)

The HLW repository section includes:

- The HLW main repository with the corresponding drifts for emplacement of HLW disposal canisters as well as the associated disposal area accesses. The HLW main repository contains one or more disposal areas in which the emplacement drifts are arranged. Current planning for the HLW emplacement drifts foresees excavation using lining (tubbing)segments.
- The purpose of the HLW pilot repository, including the observation drifts, is to monitor the behaviour of the barrier system using a small representative waste volume. A potential schematic layout is illustrated in Fig. 3.2-1. The design of the HLW pilot repository corresponds to that of the HLW main repository.

L/ILW repository section (main repository L/ILW and pilot repository L/ILW)

The L/ILW repository section includes:

- The L/ILW main repository with the corresponding caverns for emplacing L/ILW disposal containers as well as the associated disposal area accesses. The L/ILW main repository is arranged into one or more disposal areas. Current planning for the L/ILW emplacement caverns foresees excavation using an inner shell made of concrete.
- The purpose of the L/ILW pilot repository, including the observation drifts, is to monitor the behaviour of the barrier system using a small representative waste volume. A potential schematic layout is illustrated in Fig. 3.2-1. The design of the L/ILW pilot repository corresponds to that of the L/ILW main repository.

Test areas

- The test areas for HLW and L/ILW form an integral part of the deep geological repositories (Art. 64 KEV). In the test areas, the safety-relevant properties of the host rock are determined in detail to substantiate the site-specific safety case and to demonstrate the safety-relevant techniques (emplacement and removal of the backfill material, retrieval) and verify their functionality (Art. 65 KEV).
- The test areas consist of an HLW demonstration structure, an L/ILW demonstration structure and HLW and L/ILW experiment areas. A potential schematic layout is illustrated in Fig. 3.2-1.
- The test areas result from repurposing the existing facilities for underground geological investigations (BEUU) within the framework of the nuclear construction licence (see Section 5.1).

Central area

- The central area includes all centrally arranged underground structures that contain operational infrastructure facilities for the structures located at the disposal level (supply and disposal, transport logistics, operating equipment).
- The endpoints of all access structures, accesses to the HLW and L/ILW repository sections and test areas connect to the central area.

Construction and operation

The implementation of the facility elements takes place according to the realisation plan outlined in Section 5.3.

Construction of facility elements required for the underground geological investigations

- For the underground geological investigations, two separate underground accesses will be developed from the auxiliary access facility area(s) in an initial step, thereby securing the connection to the surface required for the investigations at the disposal level. Once the nuclear construction licence has been granted (see Section 5.1), the main access is constructed and the access structures for the underground geological investigations are repurposed.
- Further underground structures are needed for the underground geological investigations. These are configured in such a way as to allow the characterisation of the underground geological situation and the evaluation of the safety of the repository without compromising the suitability of the site (Art. 35 KEG).
- For the underground geological investigations, various facilities are required at the surface (e.g. access structures, facilities for the supply and disposal for the underground structures, administration buildings, construction installations including installation sites and locations for the processing and deposition of excavated materials). Even after the access and other structures as well as surface infrastructure facilities required for the underground geological investigations have been completed, these installations do not yet constitute a nuclear facility (see Section 5.1). The structures and facilities are planned in such a way that they can be repurposed once the nuclear construction licence has been granted and can be integrated into the repository [21] [22].

Construction of the main and pilot repositories

- Emplacement of the L/ILW begins after construction of the L/ILW emplacement caverns has been completed.
- The HLW repository section and the associated HLW pilot repository will partly be constructed in parallel with the emplacement of the L/ILW disposal containers. The combined repository must therefore be designed so that the construction of the HLW repository section and HLW pilot repository is spatially separated from the emplacement operations in the L/ILW repository section. To this end, the auxiliary access facility for operations (e.g. operations shaft) and, at the disposal level, the construction and operations tunnels of the HLW repository section are foreseen as construction access.
- In parallel with the emplacement of HLW disposal canisters, which takes places through the main access, additional HLW emplacement drifts are excavated as required. During emplacement operations, these drifts are constructed via the auxiliary access facility for operations. This ensures that the repository sections of the HLW main repository that are under construction are also spatially separated from those where emplacement operations are ongoing.

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[21] This approach corresponds to a safety-oriented design in the sense that the space available in the host rock within the disposal perimeter is optimised, damage to the host rock is restricted and the underground cavities in the host rock are restricted in their number and extent.

[22] With a view to a subsequent repurposing, requirements relating to construction, engineering, organisation and administration have to be considered. Corresponding requirements are documented in, e.g., the DETEC Ordinance on hazard assumptions and safety measures for nuclear facilities and nuclear materials (UVEK 2008; SaV 2021; PSPVK 2006; VAPK 2006; VBWK 2006) and several ENSI guidelines (see Appendix A.1).

Packaging and transport

- To deliver the waste to the surface facility by rail or road using the public transport network, special transport casks are used – where required – in accordance with the transport regulations in force at the time (a transport cask is not always required for low-level waste). On arrival, the waste is checked for conformity with the acceptance conditions.
- The packaging of the SF and HLW(WA) in disposal canisters takes places in a transloading cell within the HLW encapsulation plant, which will either be located at the repository site or at the Zwilag interim storage facility (see Section 3.2.1). According to the current concept, HLW disposal canisters are thick-walled, gas-tight welded steel canisters that are designed in such a way as to remain intact and gas-tight in the event of design-basis accidents. The complete containment of the packaged radioactive waste is thus ensured, and a release of radionuclides can be ruled out in the case of design-basis accidents. To comply with the requirements on the maximum heat output of the HLW disposal canisters, the correct allocation of the delivered SF and HLW(WA) to the disposal canisters must be ensured. This is achieved by ensuring that the HLW encapsulation plant is correspondingly designed, and a suitable packaging strategy is in place. For optimum loading of the disposal canisters, these must be filled with spent fuel assemblies with differing heat outputs (see Section 2.1). This requires access to several transport and storage casks at any given time. For this reason, and according to current planning, the HLW encapsulation plant has several docking stations for transport and storage casks and for disposal canisters.
- The L/ILW is emplaced in concrete disposal containers[23]. Prior to emplacement, the conditioned waste (waste packages) is either packaged into disposal containers in the L/ILW encapsulation plant within the surface facility, or disposal-ready containers are delivered from an external encapsulation plant (located at, e.g., the Zwilag interim storage facility). The L/ILW disposal containers are designed to resist mechanical and thermal stress as well as exposure to fluids so that, in the case of a design-basis accident, there is either no or only a restricted release of radionuclides.
- HLW disposal canisters and L/ILW disposal containers are moved underground in internal transport containers[24] which provide them with additional protection from external influences and also ensure additional shielding. In the event of an operational accident, an intervention would thus be possible without major additional measures. The HLW disposal canisters and L/ILW disposal containers are removed from the internal transport containers in the transloading zone located at the entrance to the emplacement drifts and caverns and transferred to their emplacement position.

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[23] The MOSAIK-II containers are made of cast iron and can be directly emplaced without additional concrete casing. MOSAIK-II containers ensure the mechanical stability required for potential retrieval up to repository closure (ENSI 2020b) due to their wall thickness (16 cm).

[24] For certain types of L/ILW waste packages, no internal transport containers are required for the transport to the underground.

Backfilling

- The HLW emplacement drifts are continuously backfilled during the emplacement of the disposal canisters. When an HLW emplacement drift has been completely filled with disposal canisters, it is closed using a sealing structure.
- The L/ILW emplacement caverns are backfilled in sections during the emplacement of the disposal containers. Once the voids of an L/ILW emplacement cavern have been completely filled and backfilled, the caverns are closed with a sealing structure.

Monitoring phase and closure

The monitoring phase begins once emplacement has been completed (see Section 5.3 and Tab. A.2-1); the disposal level remains accessible via at least two accesses. Besides monitoring the pilot repository, this phase includes continuous or repeated measurements of radiological and non-radiological status parameters at the surface in the vicinity of the repository and in the underground structures that remain accessible (see Section 3.1.4).

Closure of the repository proceeds in several stages in parallel with the backfilling and sealing of remaining voids[25]. The individual emplacement rooms (HLW emplacement drifts and L/ILW emplacement caverns) are backfilled and sealed on an ongoing basis during emplacement. Interjacent sealing sections in the HLW emplacement drifts can be dispensed with as the bentonite backfill already provides a hydraulic separation or compartmentalisation between the disposal canisters.

As part of the monitoring phase, after a restricted period of time (assumption 10 years; see Tab. A.4-2), there is a second stage of backfilling and sealing of the accesses to the main HLW and L/ILW disposal areas on the disposal level and of accesses from the surface to the underground that are no longer required. This may apply, for example, if the repository has three accesses. In this case, one can be backfilled and sealed during this second closure stage (generally the main access). The facilities and structures at the surface that were used only for packaging and emplacing the waste are decommissioned and dismantled after emplacement.

The third and final stage consists of closing the entire repository (see Section 5.3); this takes place following the monitoring phase (assumption: 50 years after emplacement, in accordance with Art. 3 SEFV; see Tab. A.2-1) on the order of the Federal Council after the repository owner has submitted a project plan for repository closure (Art. 39 KEG). This final stage involves backfilling the observation drifts, test areas and all other open underground structures that were still in use, including the accesses that have remained open. Closure of the entire repository also includes marking, ensuring long-term isolation of groundwater-bearing rock layers along the access structures above the disposal level with suitable seals, dismantling the remaining surface infrastructure and recultivation of the ground surface if no other use is foreseen.

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[25] Besides the waste matrix, the waste containers and the disposal canisters, sealing and backfill elements represent components of the engineered barrier system (cf. Section 3.1.2).

3.2.3 Variants for the design of a combined repository

Different variants are considered to maintain the required flexibility for taking into account possible future developments within the framework of the realisation plan for optimising the facilities and the operating procedures; these are consistent with the scope for action presented in Appendix A.3. Current planning foresees the following main design variants (the list is not exhaustive):

Surface facility

- SF and HLW(WA) could, in principle, be packaged in a facility outside of the surface facility (e.g. Zwilag interim storage facility; see Section 3.2.1). This would require the packaged HLW disposal canisters to be transported to the surface facility in shuttle overpack canisters, from where they are emplaced in the repository. In this case, it is possible to dispense with an encapsulation plant at the surface facility site.
- Another possibility is to package L/ILW (or parts of it) in L/ILW disposal containers at the location of the consignor using a mobile/temporary facility and to transport the containers to the repository and emplace them directly without additional repackaging. There is also the possibility to use synergies with the Zwilag interim storage facility for packaging the L/ILW, transporting it to the repository and emplacing it there. To this end, the disposal containers would either have to be qualified for transport or they would have to be placed in approved transport containers. In both cases, it might be possible to dispense with an encapsulation plant at the site of the surface facility.
- There is also leeway with regard to the size of the consignment halls for HLW transport and storage casks, HLW disposal canisters, L/ILW transport containers (waste packages) and L/ILW disposal containers.
- The treatment facility for the used transport and storage casks can also be constructed on the terrain of the surface facility or at an external location (e.g. together with the external SF/HLW(WA) encapsulation plant at Zwilag).
- The treatment facility for the operational waste from the repository can be located in the surface facility, or the waste can be treated in an existing, external facility (e.g. Zwilag).

Auxiliary access facilities

- There are several different possibilities for the layout of the auxiliary access facility areas. Auxiliary accesses can either be spatially separated or located in the same area (Nagra 2016c).

Site development of surface facility and auxiliary access facilities

- The areas and construction sites can be extended from existing traffic routes using rail and/or road. The radioactive waste can also be delivered by rail or by road using lorries.

Underground accesses

- In principle, there are several underground access configurations; depending on the situation at the site, these will vary in suitability. The number and functional allocation of the auxiliary accesses can also vary.
- The accesses to the underground can either be in the form of tunnels, shafts (surface shaft head) or blind shafts (underground shaft head with connecting tunnel).

Facilities for underground geological investigations (BEUU)

- With regard to the location of the BEUU, or test areas once the BEUU have been repurposed within the framework of the nuclear construction licence (see Section 5.1), different possibilities exist to arrange them either in the central area or in the main repository/pilot repository area, depending on the properties of the host rock.

HLW and L/ILW repository sections

- The length, cross-sectional size, cross-sectional geometry, excavation technology and layout of the emplacement rooms (HLW emplacement drifts and L/ILW emplacement caverns), the disposal areas and the orientation of the axis of the emplacement rooms and spacing between the emplacement rooms can be adapted to make optimum use of the available space in the disposal zone.
- Depending on the site-specific situation, the lining of the HLW emplacement drifts can consist of alternative methods to the current planning assumption (excavation supported by lining segments); these could include shotcrete, steel arches and nets or combinations of these.
- Aside from pure bentonite, bentonite-additive mixtures (e.g. bentonite/sand mixtures) or other clay materials can be considered for backfilling the HLW emplacement drifts; the granular bentonite material proposed in the demonstration of disposal feasibility (*Entsorgungsnachweis*) (Nagra 2002b) could also be replaced with bentonite blocks. A cement-based backfill would be another variant (Nagra 2016a).
- As backfill material for the L/ILW emplacement caverns, alternative cements (e.g. Ordinary Portland Cement, OPC) and alternative aggregates (e.g. mixed rubble from dismantling) can be considered along with cement-based reference mortar.
- There are several variants for the layout of the disposal area accesses (routing of construction and operations tunnels, realising the HLW repository section with or without ventilation tunnels, bypassing the disposal zone for preliminary investigations, etc.). Other possibilities also exist with regard to size, layout, accesses and locations of the HLW and L/ILW pilot repositories.

Construction and operation

- A wide range of options exists for transporting HLW disposal canisters and L/ILW disposal containers in the repository. Transport to the underground can take place via a shaft conveyor facility or, in the case of a tunnel, via a funicular, railless vehicles or a cog railway.
- For planning purposes, and to allow for any new regulations, experience from foreign repository projects and technical advances up to the nuclear construction licence, different possibilities are considered in connection with the realisation of HLW disposal canisters. These relate to issues of transport (infrastructure, transport casks, vehicles), canister materials and the maximum permissible heat output. Besides carbon steel and cast iron, alternative canister materials (various ceramics) as well as special alloys and copper, titanium or nickel coatings can be considered for HLW disposal canisters (Diomidis et al. 2016).
- Different possibilities are also being considered for the size and loading of the L/ILW disposal containers.
- There is also flexibility with regard to time-related aspects of the realisation plan (see Chapter 5).
- When constructing and backfilling the underground structures, flexibility exists to take into account site-specific features, the potential staged construction of individual structures or requirements based on different construction sections.

Monitoring phase and closure

- Sealing and closure engineering design can be realised in several different ways, and different materials are available for the seals and the backfill material (see Section 3.1.2). There is also the possibility of installing so-called interjacent sealing sections within the HLW emplacement drifts, if necessary. Information on sealing and closure can be found in Nagra (2021f). This background report to WMP21 outlines the sealing concept preferred by Nagra together with possible variants.
- The repository is also designed in such a way as to allow for an extension of the operating periods and the monitoring phase. Construction elements and components would have to be upgraded through corresponding revisions or replacements, if necessary. These possibilities have to be integrated into the corresponding concepts.

3.3 Differences in the conceptual design of an (individual) HLW repository compared to a combined repository

The HLW repository includes all facility elements and structures required for the construction and operation of the combined repository with the exception of those elements and structures that are exclusively required for the L/ILW repository section.

The key differences in the conceptual design of the HLW repository compared to the combined repository (Section 3.2.2) are:

- In the HLW repository, the L/ILW repository section can be dispensed with (L/ILW main repository, L/ILW pilot repository and L/ILW test areas).
- For the surface facility, the L/ILW encapsulation plant and the facilities for the backfill material of the L/ILW emplacement caverns and L/ILW disposal containers can be dispensed with.
- The dimensions of the supply facilities (ventilation, power, water, drainage and sewage disposal) are smaller as fewer underground facilities have to be supplied.
- Due to the overall smaller volume of radioactive waste, emplacement operations in an HLW repository could be completed more quickly than in a combined repository (see Appendix A.2.1).

3.4 Differences in the conceptual design of an (individual) L/ILW repository compared to a combined repository

The L/ILW repository includes all facility elements and structures required for the construction and operation of the combined repository with the exception of those elements and structures that are exclusively required for the HLW repository section.

The key differences in the repository conceptual design of the L/ILW repository compared to the combined repository (Section 3.2.2) are:

- In the L/ILW repository, the HLW repository section can be dispensed with (HLW main repository, HLW pilot repository and HLW test areas).
- For the surface facility, the encapsulation plant for SF/HLW(WA), the treatment facility for the transport and storage casks and the facilities for the backfill material for the HLW emplacement drifts can be dispensed with.
- The L/ILW emplacement caverns, including those of the L/ILW pilot repository, are constructed before emplacement begins. This clearly separates construction and operational activities in time, i.e. no underground construction activities for new emplacement rooms will be required during emplacement operations.
- As no emplacement caverns are constructed in parallel with emplacement operations, only two accesses to the underground are required (main access and one auxiliary access). The main access is used to transport the waste and the backfill materials from the surface to the disposal zone. The auxiliary access is used for ventilation, visitor transport and services for the repository (e.g. energy supply, water supply, waste water removal and water management; Nagra 2016c).

- The dimensions of the supply facilities (ventilation, power, water, drainage and sewage disposal) are smaller as fewer underground facilities have to be supplied.
- The duration of emplacement operations for the L/ILW repository is shorter than in a combined repository (see Appendix A.2.1) because, compared to the combined repository, a smaller volume of radioactive waste must be emplaced.

4 Allocation of the waste to the deep geological repositories

Key differences between WMP16 and WMP21

The waste types have not changed since the Waste Management Programme 2016. In contrast, with the conclusion of Stage 2 of the Sectoral Plan, the sites were narrowed down to those with Opalinus Clay as host rock and with very similar safety profiles. Accordingly, it is no longer necessary to separate long-lived intermediate-level waste[26] (ILW) and emplace it in the HLW repository for safety reasons. Future project planning assumes that the alpha-toxic waste (ATW) will be emplaced in the same repository as the L/ILW.

4.1 Allocation of the waste to the repositories based on waste category

An analysis of the waste disposal concepts being followed and implemented worldwide shows that there are various possibilities for allocating the radioactive waste to the different repositories, depending on waste inventory, the selected safety concept, the repository design and the selected site (different contributions of geology to retention and long-term safety and of the engineered barriers to safety). For L/ILW, there are surface repositories (e.g. Centre de l'Aube, France), repositories several tens of metres below the surface (e.g. SFR in Sweden and VLJ in Finland) and repositories several hundreds of metres below the surface (e.g. Bátaapáti in Hungary) see Section 3.1.1). These facilities differ significantly in terms of the allocated waste inventory.

In line with international practice, the Swiss waste management concept foresees two repository types: one for L/ILW and one for HLW. In the case of a combined repository, the repository consists of an HLW repository section and an L/ILW repository section (see Section 3.1.1). The basic allocation of the radioactive waste to HLW or L/ILW repositories occurs with the general licence and is oriented along the L/ILW, ATW and HLW categories defined in Art. 51 KEV. Spent fuel assemblies and vitrified high-level waste from reprocessing are allocated to the HLW repository, and low- and intermediate-level waste and alpha-toxic waste (ATW; see Section 2.1) are allocated to the L/ILW repository. For the combined repository, a similar waste allocation occurs with the general licence, i.e. HLW is allocated to the HLW repository section and ATW and L/ILW to the L/ILW repository section. However, as it can be assumed that the host rock for the combined repository is very homogeneous and exhibits a comparable barrier function in terms of safety, the flexibility for purpose-oriented waste allocation is greater in the combined repository. With regard to the time horizon until the end of the emplacement operations or possibly until the closure of the deep geological repository, sufficient flexibility must be maintained for optimisation purposes (see Appendix A.4) to allow for minor changes in the allocation of the waste so that, when justified, it remains possible to deviate from the waste allocation determined in the general licence. Possible reasons for such a deviation include the future handling of MIR waste (see Appendix A.8.8) and of L/ILW from the decommissioning of the surface facilities. The administrative and technical measures required to handle such deviations are defined. The waste volumes for each of the categories is shown in Tab. 2.1-1.

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[26] The designation ILW for long-lived low- and intermediate-level waste arose during the time before the current nuclear energy legislation entered into force. It refers to low- and intermediate-level waste that, because of specific safety-related requirements on the geological barriers of an L/ILW repository (particularly with regard to the long-term protection from erosion), was allocated to the HLW repository. This applied e.g. to the Wellenberg site that was, at the time, the focus for L/ILW disposal. However, this is no longer relevant for the siting regions to be investigated in more detail in Stage 3 of the Sectoral Plan.

The general licence application notes that "potential interactions" between different waste types do not lead to any safety-relevant negative impacts (ENSI 2020b) The types of waste allocated to the different repositories, repository sections and emplacement rooms, and the properties of these waste types (radionuclide inventory, material properties, heat production, gas generation, complexants), are mostly homogeneous. For this reason, a repository design that is oriented to specific waste properties (e.g. taking into account heat production, chemical properties, gas generation, etc.) is feasible in principle. The corresponding measures will be outlined within the framework of the nuclear construction and operating licences. A detailed description of the waste and its properties can be found in Nagra (2014c).

The detailed conditions for the emplacement of the waste will be defined only at the stage of the construction and operating licences, when all the required information (results of detailed site investigations and detailed design of the engineered barriers, existing and foreseeable waste, in particular, waste from the decommissioning and dismantling of the surface facilities as well as continuously arising MIR waste[27]) is available.

Considering the time horizon, minor changes in the waste allocation are possible at a later stage in accordance with the realisation of the deep geological repositories described in Appendix A.4 as part of an overall optimisation procedure); corresponding administrative and technical measures have been defined.

[27] The realisation plan assumes a collection period for MIR waste up to the end of 2064 (end of emplacement operations in the L/ILW repository; see Appendix A.2.1). Based on a recommendation by the Federal Nuclear Safety Commission, Appendix A.8.8 contains information regarding the handling of MIR waste after the end of emplacement (from 2065). The Federal Government is responsible for disposal of MIR waste. In line with information provided by the Swiss Federal Workgroup for Nuclear Waste Disposal (Agneb 2019), a disposal-ready waste volume of around 4,000 m^3 must be expected over a period of 90 years (2065 – 2155). This corresponds to around 5% of the volume of all L/ILW expected until 2065. As the final decision on how to deal with MIR waste does not have to be made for another 50 to 100 years, this waste volume is not reflected in any waste inventory framework in the Waste Management Programme.

5 Realisation plan for the deep geological repositories

Key differences between WMP16 and WMP21

Chapter 5 and Appendix 2.1 outline the realisation plan for the deep geological repositories and the underlying requirements and planning assumptions. The realisation plan serves as the basis for the strategic work programme presented in WMP21 and for the cost estimate carried out within the framework of CS21. The status of work and the tasks remaining up to the general licence are described in Section 5.4.1; a description of the work after the general licence can be found in Section 5.4.2.

The key differences between the information provided in WMP16 and WMP21 can be summarised as follows:

- WMP21 includes a realisation plan for the combined repository; the start of operations is foreseen for 2050.
- The most important modifications in the realisation plan are limited to preparing and conducting the underground geological investigations (EUU):
  - WMP16 was based on the assumption that Nagra would prepare the EUU licence application immediately after submitting the general licence application (from 2024), i.e. without taking into account the findings of the expert reviews of the general licence application (2027) and prior to the decision of the Federal Council (2029). Under this approach, the authorities would have had to develop requirements for the underground geological investigations beforehand (by 2024) without being able to take into account the knowledge base in the general licence application. WMP21 resolves these disadvantages. The EUU licence application will only be prepared after the decision of the Federal Council when any requirements and boundary conditions have been conclusively clarified. In addition, the application will only be submitted once the national referendum has been held and the general licence is legally valid.
  - In WMP16, preparations for the construction (from 2028) of the facilities for the underground geological investigations was planned prior to the decision of the Federal Council (2029) and before the general licence became legally valid; this involved a significant business risk. The realisation plans in WMP21 include the new phase "preparation for underground geological investigations" (Phase (2) in Fig. 5.3-1). During this phase, and once the general licence enters into force, construction work will be conducted to prepare for the underground geological investigations. A preparation period of around three years is typical for similar major projects and takes place in parallel with the review of the application. This way, it is possible in the final phase to consider potential conditions attached by DETEC to award contracts for the construction of the facilities for the underground geological investigations.
  - The licensing procedure allows compliance with 2050 as the starting point for waste emplacement in the L/ILW repository or the combined repository. The current plan for the underground geological investigations thus relies on a stronger parallelisation of processes:
    - For the phase "construction of EUU facilities and start of EUU" (Phase (3) in Fig. 5.3-1), WMP21 assumes five instead of four years. However, this change does not influence the overarching realisation plan as it is already possible to start time-sensitive experiments in the facilities for underground geological investigations after four years.

  - In WMP21, the nuclear construction licence application for the L/ILW repository is submitted one year earlier than in WMP16. As a result, the licensing phases for construction (Phase (5) in Fig. 5.3-1) and operation (Phase (8) in Fig. 5.3-1) of the L/ILW repository or combined repository now last five years instead of four; this meets the recommendation made by the authorities for WMP16.
  - The requirements for the documents for the nuclear construction and operating licence applications (Anhang 4 KEV) must be prepared in a hierarchical order (hierarchical levels H1 – H4). In this way, processes can be carried out in parallel, allowing more time for experimental demonstrations gained from the underground geological investigations for both construction (H2) and operation (H3). This parallelisation of processes relating to the underground geological investigations and the construction and operating licence applications is outlined for the first time in WMP21 and is the result of concretising the procedures following the general licence.
- No changes have been made to the planning assumptions for Stage 3 of the Sectoral Plan. The current realisation plan in WMP21 still foresees that, based on the results of field investigations and other insights, Nagra will be able to announce the site(s) for which a general licence application will be prepared in line with the conceptual part of the Sectoral Plan for Deep Geological Repositories (BFE 2008) in 2022 and that the general licence application will be submitted in 2024.

5.1 Legal framework and regulatory requirements for the realisation plan

Tab. A.1-1 (Appendix A.1) summarises the procedural stipulations in KEG (2003) and KEV (2004), in the conceptual part of the Sectoral Plan (BFE 2008) and Guideline ENSI-G03 (ENSI 2020b). Together with other legal provisions in, e.g., the Environmental Protection Act (USG 1983) and the Spatial Planning Act (RPG 1979), these requirements form the foundation for realising the deep geological repositories. The fundamental process for implementation resulting from these requirements, together with the most important specifications, is briefly described below.

Switzerland will dispose of its radioactive waste in deep geological repositories. The most suitable site in Switzerland will be identified within the framework of the site selection process (Sectoral Plan for Deep Geological Repositories, SGT) under the lead of the Federal Government. The Sectoral Plan is a planning instrument of the Federal Government foreseen in the Spatial Planning Act that applies to infrastructure projects of national significance.

The conceptual part of the Sectoral Plan for Deep Geological Repositories (BFE 2008) approved by the Federal Council in 2008 sets out the procedure for selecting geological siting regions with a view to general licence applications for L/ILW and HLW repositories. The Sectoral Plan process ensures that the repository sites are evaluated and identified in a fair, transparent and participatory procedure. The aim is to create the conditions that will allow disposal of Switzerland's radioactive waste in a timely manner. In particular, the objectives include:

- informing the public about the goals, principles and procedures of the Federal Government in the field of nuclear waste disposal
- collaborating with the affected cantons, communities and neighbouring countries
- creating secure planning conditions for the waste producers when searching for a repository site and implementing the repository
- ensuring that the rules, responsibilities and competences related to the site selection procedure are defined from the outset and are clear to everyone involved

- defining the site selection criteria for the repositories
- discussing the different, occasionally conflicting interests, identifying conflicting goals and potential solutions, thereby making the site selection process transparent
- ensuring that the population in the siting regions can be appropriately involved and that their concerns are considered to the greatest extent possible
- developing and realising compensation measures for the affected regions in connection with expected developments from the repository projects and transparently agreeing on potential compensation payments
- ensuring coordination with other resource exploitation plans as well as with the procedures and requirements outlined in the Nuclear Energy Act, Spatial Planning Act and Environmental Protection Act
- relieving the general licensing procedure outlined in the Nuclear Energy Act of conflicts that can be resolved in advance, thereby facilitating the overall procedure

The Sectoral Plan process concludes with the end of Stage 3, i.e. with the approval of the object sheet by the Federal Council. At the same time, the Federal Council decides on the granting of the general licence.

The general licence decides fundamental, politically significant questions related to a nuclear installation (message on the Nuclear Energy Act, BBl 2001).The law therefore requires that, in contrast to the other licensing steps according to the Nuclear Energy Act, the decision of the Federal Council must be submitted to the Federal Assembly for approval (2030) and this is then subject to an optional national referendum (2031). Aside from the fundamental decision on whether to approve the project, the focus is on the siting issue. The general licence specifies the site and the main features of the project (Art. 14 Par. 2 KEG). These include the approximate size and location of the most important structures, as well as the waste categories and maximum disposal capacity (see Section 2.1). The general licence also defines the suitability criteria that must be met during further repository realisation steps, as well as the provisional protection zone.

The requirements in the Nuclear Energy Ordinance for the general licence application and the specifications of the safety requirements for Stage 3 of the Sectoral Plan (ENSI 2018c) require the following investigations and work:

- Provision of a geological synthesis with geological datasets for long-term safety and facility planning
- The site characteristics, purpose and the main features of the project are described in the safety report (Art. 23 KEV); this report also includes the safety demonstration for the operational phase and the safety case for the post-closure phase (ENSI 2018c).
- The safety-based comparison of the siting regions investigated in depth during Stage 3 includes an evaluation of the characteristics that are decisive for the decisions on site selection and repository type, including information on costs. In this report, the waste producers must justify the result of the safety-based comparison and the repository site selection based on the investigations and work carried out within the framework of the Sectoral Plan process.
- The documentation of the spatial planning coordination with regard to spatial planning decisions in line with the Sectoral Plan is outlined in a corresponding report.
- For a better definition of the facility projects (including operation and closure), concepts must be developed for the surface and underground facility elements.

- Clarifications on the environmental impact (EIA, Stage 1)
- Preparing a concept for the observation and monitoring phase as well as a concept for repository closure
- Preparing a security report (concept)
- Preparing an argument report containing the key reasoning and conclusions of the site selection and repository safety reports as well as a document structure plan.

At the time of the general licence, different design variants are kept open with a view to later optimisation within the framework of the multi-stage licensing procedure (see Appendix A3). This makes it possible to reflect new insights from the underground geological investigations conducted only after obtaining the general licence, together with the results and experience from the RD&D programme and from foreign programmes; many of the final decisions will be made at the latest for the nuclear construction licence application. From today's perspective, these include:

- Variants for materials and design concepts for the disposal containers
- Variants for the design of the HLW emplacement drifts and L/ILW emplacement caverns
- Variants for the design and emplacement of backfill materials
- Variants for the design and production of sealing elements for the emplacement rooms
- Variants for the design of the tunnels, including excavation protection, lining and choice of sealing system

In parallel with the general licence procedure, according to Art. 42-48 KEG, foreign countries will be notified about the project by the competent federal authorities within the scope of the Espoo Convention (UN-ECE 1991).

Based on nuclear energy legislation, after the site has been approved in the general licence procedure and is specified in the object sheets of the Sectoral Plan, further licences are required by the Federal Department of the Environment, Transport, Energy and Communications (DETEC) and the Federal Council: the licence for the underground geological investigations, the nuclear construction licence, nuclear operating licence and, after completion of the operating and monitoring periods, a permit for closure issued by the Federal Council. These licensing steps also include aspects from other areas, in particular spatial planning and the Environmental Impact Assessment:

- *Licence for the underground geological investigations (EUU):* The legal framework for the licence for underground geological investigations is specified in KEG (2003) under the topic of underground geological investigations (Art. 35: licensing requirements and conditions; Art. 36: licence content). The primary objective of the investigations is to characterise the underground geological situation. By conducting relevant experiments, important input for the construction of the repository will be confirmed (Tab. A.2-1 – A.2-3). Activities include constructing the facilities for underground geological investigations (BEUU) where long-term experiments are conducted, and safety-relevant techniques are tested and their functionality demonstrated. The application for underground geological investigations specifically refers to an application for the corresponding infrastructure. This includes all aboveground and underground structures required for the EUU phase. Aside from the facilities for underground geological investigations and other structures required for these, facilities include structures at disposal level (e.g. the central area), EUU access structures, required auxiliary access facilities and further infrastructure such as access roads, etc. While these structures do not constitute a nuclear facility at this point in time, the infrastructure for underground geological investigations is planned in such a way as that they can be repurposed once the nuclear construction licence has been granted and then become an integral part of the deep geological repository[28]. The licence for underground geological investigations is, as all licences for geoscientific studies, only temporary (Art. 36 Par. 2 KEG) and does not convey any right to subsequent conversion to a nuclear installation (Art. 3 Letter d KEG).

- *Nuclear construction licence* (Art. 15-18 KEG): The nuclear construction licence defines the planned capacity of the facility and includes a project for the monitoring phase and a plan for closure. The construction licence also specifies the key elements for technical implementation. This includes the test areas; together with the main repository and the pilot repository, these form integral parts of the geological repository (Art. 64 KEV). Long-term experiments initiated within the framework of the underground geological investigations will continue in the test areas during construction[29]. This is necessary to confirm site-specific, safety-relevant characteristics of the host rock in order to strengthen the safety case with a view to the operating licence (Art. 37 Par. 1 Letter a KEG; Art. 65 Par. 1 KEV). In addition, Art. 65 KEV states that safety-relevant technologies should be tested and their functionality demonstrated in the test areas before starting repository operation. This particularly concerns the technology for the retrieval of waste packages without excessive effort up to eventual repository closure (Art. 37 Par. 1 Letter b KEG) and requires demonstration of the introduction and removal of backfill materials (Art. 65 Par. 2 KEV).
- *Nuclear operating licence* (cf. Art. 19-25 KEG): The nuclear operating licence specifies the definitive protection zone of the deep geological repository and the permissible capacity of the facility. It also sets out measures for monitoring the environment and the stages of commissioning, the start of which requires prior clearance by the regulatory authorities (Art. 21 Par. 1 KEG). The operating licence also specifies requirements relating to limits for the activity of the waste to be disposed of (Art. 37 Par. 3 KEG). The emplacement of waste packages in a repository requires approval by ENSI (ENSI 2020b). For sealing elements that were not tested in advance, the sealing technology is tested at this point and their functionality during repository operation is demonstrated in the test areas (Art. 65 Par. 3 KEV).
- *Closure[30] of the deep geological repository* (cf. Art. 39 KEG): After the end of the monitoring phase, the Federal Council authorises closure work provided the permanent protection of humans and the environment can be ensured (Art. 39 Par. 2 KEG). After final closure, the Federal Council may order further, temporary monitoring (Art. 39 Par. 3 KEG). After final closure or after expiry of the monitoring period, the Federal Council determines that the repository is no longer subject to nuclear energy legislation (Art. 39 Par. 4 KEG).

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[28] This procedure implements the following safety requirements: i) the available space within the disposal zone in the host rock is to be optimally, ii) the damage to the host rock is to be restricted and (iii) voids in the host rock should be limited in terms of extent and number.

[29] The formal repurposing of facilities for underground geological investigations to test areas might require further procedural steps once the construction licence has been issued. Nuclear energy legislation provides corresponding options (e.g. Art. 17 Par. 1 Letter f KEG and Appendix 4 KEV).

[30] In the event of an unfavourable development of the boundary conditions during the operating phase, according to Guideline ENSI-G03 (ENSI 2020b), technical and operational measures must be taken for a temporary closure so that the emplacement areas of the repository can be transformed into a passively safe condition for a limited period of several decades to centuries. This must be considered in the repository conceptual design. The construction licence application must include a concept for temporary closure.

5.2 Further specifications and assumptions for defining the realisation plan

In addition to the legal and regulatory requirements discussed in Section 5.1, the following specifications and assumptions must be considered to determine the realisation plan for the repositories:

- In principle, disposal takes place in Switzerland (Art. 30 Par. 2 KEG): for the currently unlikely case of disposal abroad, a permit could be granted as an exception subject to strict requirements (Art. 34 Par. 4 KEG). The final decision on whether some of the waste is to be disposed of abroad would be made, at the latest, before starting construction of the corresponding repository (Appendix A.3).
- The Swiss waste management concept is based on either a combined repository consisting of an HLW repository section and an L/ILW repository section with the L/ILW and HLW repositories constructed at the same site, or on two individual repositories for HLW and L/ILW (see Section 3.1.1).
- The allocation of the radioactive waste to the repositories is carried out in accordance with the categories L/ILW, ATW and HLW defined in Art. 51 KEV (see Chapter 4).
- The timetable for disposal will take the temporal arisings of waste into account, with the aim of keeping the emplacement period short.
- To evaluate the required interim storage capacity, the assumption is that all waste for the scenarios in WMP21 ("60-year NPP operating lifetime", see Tab. 2.1-1; "50-year NPP operating lifetime", see Appendix A.5) will be held in the available interim storage facilities, from where it will be transported to the deep geological repositories. For the HLW section of the combined repository and for the HLW repository, the necessary cooling period due to the initially high heat output of SF/HLW(WA) is to be considered (see Section 2.1).
- The concretisation of the concepts and projects (design of the repositories, the technologies for construction, operation and closure, safety assessment) takes place at a level of detail and reliability appropriate for upcoming decisions. The assurance of safety and fundamental technical feasibility is given high priority at each step; however, early steps require a lower level of detail.
- The decisions on implementing the realisation plan should not only be supported by technology but also by society. The inclusion of appropriate interest groups in the process should thus be assured. In the site selection phase (see Tab. A.2-1 to A.2-3), this is ensured through the Sectoral Plan process (BFE 2008). The various interest groups are also included in the subsequent nuclear licensing procedure as regulated by law. Keeping the public informed is therefore very important (see Chapter 8).

5.3 Realisation plan for the deep geological repositories

Starting from the specifications and assumptions described in Sections 5.1 and 5.2 and considering the time periods required for the execution of the technical work and for the implementation of associated official/regulatory procedures, a realisation plan has been developed that is shown in the form of bar graphs in Figs. 5.3-1, A.2-1 and A.2-2 for the combined repository or the HLW and L/ILW repositories, respectively. Especially for later stages, this planning is associated with uncertainties of several years. The realisation plan is also based on the assumption that the legal remedies available in the licensing process are not exhausted. The time schedule on which WMP21 is based assumes that the combined repository or the L/ILW repository will start operations in 2050; the HLW repository is assumed to start operation in 2060. This time schedule forms the basis for the information provided in Chapter 6 (operating lifetimes of the interim storage facilities) and Chapter 7 (costs and financing). The bar graphs in Figures 5.3-1, A.2-1 and A.2-2 reflect the information provided in Tables A.2-1 to A.2-3 (Appendix A.2.1) with regard to the different phases.

In particular, the realisation plan takes into account:

- the required statutory and regulatory permits and licences and the associated decision-making points (see Appendix A.1)
- the documentation required for these permits and licences and the time required performing the necessary technical-scientific work
- the time required for the official (licensing) procedures
- the time needed to involve the various stakeholders in the decision-making process
- other technical, time constraints (for example, the required cooling period for SF after removal from the reactor until repository emplacement)
- The proposed realisation plan (Figs. 5.3-1, A.2-1 and A.2-2) and the associated decision-making points provide sufficient flexibility to optimise the disposal procedure (in particular the repository conceptual design and, if necessary, conditioning procedures) and provide the required flexibility for accommodating future developments with regard to the waste to be disposed of (e.g. operating lifetimes of the NPPs, changes in the legal framework). This flexibility to adapt to new findings (results from the Swiss programme, experience in foreign programmes, general progress of science and technology) and to take account of new developments regarding the waste should be maintained as long as required, as foreseen in the stepwise licensing procedure according to the KEG (2003). The optimisation procedure is shown in Appendices A.2 – A. 4.

The required level of knowledge and the current state of project development can be summarised as follows:

- For site selection and the preparation of the general licence application, the requirements for Stage 3 of the Sectoral Plan apply (ENSI 2018c). Sufficient knowledge from in-depth field investigations (e.g. seismic surveys, deep boreholes, Quaternary boreholes; see Section 3.1.5) is required to allow robust statements to be made on safety and engineering feasibility; this relates in particular to the properties of the host rock (partly from site-independent investigations, see Section 5.7), the available space and long-term stability, including information on erosion. The general licence will also define the main features of the project, including the approximate size and location of the most important structures. At the stage of the general licence, concepts for selected elements of repository conceptual design might still include different variants (e.g. underground access, design of the engineered barriers and technology for the construction, operation and closure of the facility; see Section 3.2.3).

- For the nuclear construction licence application, the detailed configuration and design of underground repository structures and engineered barriers as well as infrastructure and technology for the construction, operation and closure of the repository will be specified (Art. 24 Par. 2 sowie Anhang 4 KEV). The required input from underground geological investigations necessary for repository construction is taken into account in the application. This realisation plan also allows for experience from other foreign programmes that are relevant for Switzerland (notably Finland, France, Sweden) to be taken into account up to the time when the operating licence is granted (see the time schedule in Tab. 3.1-1).

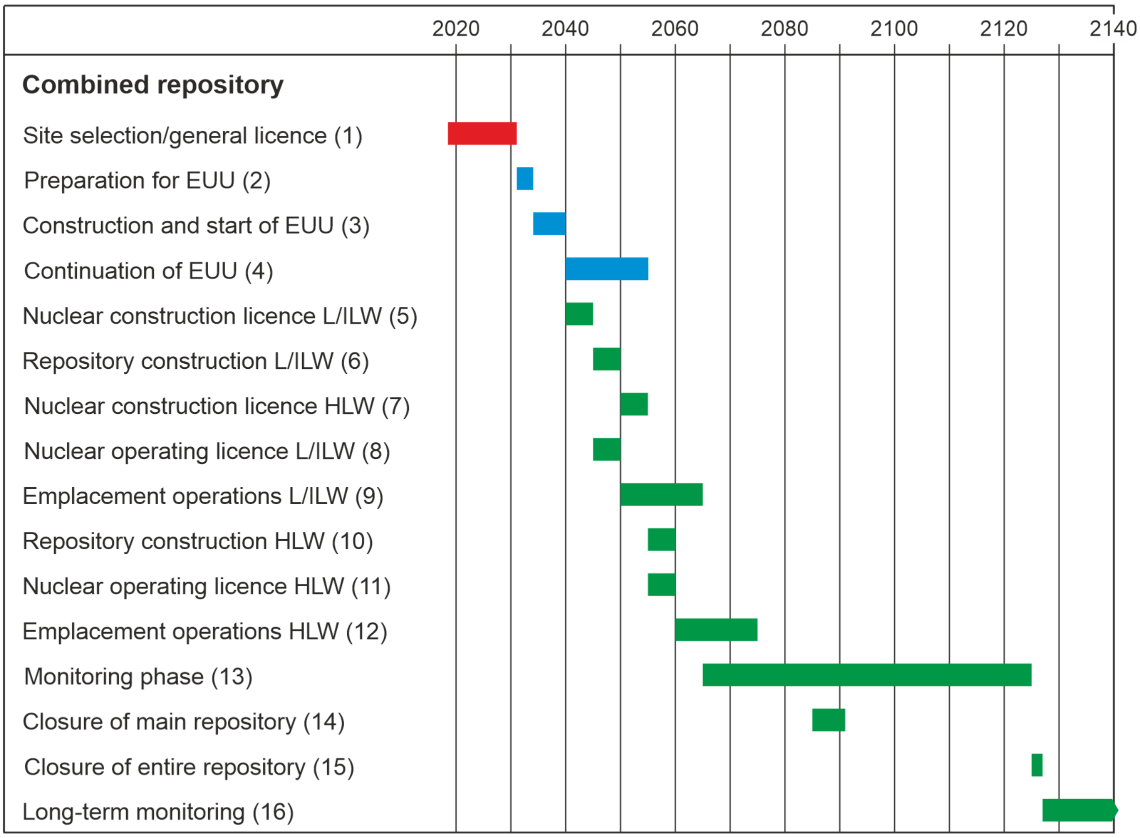

Fig. 5.3-1: Realisation plan for the combined repository based on current assumptions.

For better readability, the phases are numbered sequentially.

The most important features of the realisation plan are:

- The selection of the site for the combined repository or the sites for the L/ILW and HLW repositories are based on the Sectoral Plan process; for two individual repositories, the procedure will run in parallel until the respective general licences are granted.
- The general licence specifies the main features of the project; the detailed design of the facilities will only be decided at the stage of the nuclear construction licence. The nuclear construction licence takes into account information gained from the underground geological investigations.
- The facilities are constructed to the extent necessary to start operations. Additional SF/HLW(WA) emplacement drifts within the developed disposal zone for the HLW repository or the combined repository will be constructed during the operational phase.
- Each emplacement room is closed once emplacement is completed; the encapsulation plants are then decommissioned and dismantled, and any resulting decommissioning waste is disposed of (see also Section 5.4.2 and Appendix A.2.1). The monitoring phase begins at this time (based on the assumption of a 50-year monitoring period, see Tabs. A.2-1 to A.2-3); after a limited period (assumption 10 years), the accesses to the disposal areas of the main repository at disposal level and any accesses from the surface facility that are no longer required are backfilled and sealed.
- After completion of the monitoring phase, the entire facility (access structures, remaining parts of the surface infrastructure) is closed and dismantled. Monitoring can then be continued from the surface.
- To ensure that the phases presented in the realisation plans (Figs. 5.3-1, A.2-1 and A.2-2) can be implemented without significant delays, the following prerequisites must be met on schedule.
- For the general licences to be obtained by 2031, the field investigations in Stage 3 of the Sectoral Plan must proceed without major legal delays or any relevant surprises[31]. For the general licence application, a societally sustainable project must be available, for which well-founded technical and scientific documentation is available. The review of the application documents by the authorities has to proceed according to plan, as does the Federal Council decision and its confirmation. An optional national referendum can be handled without delays and leads to a positive outcome.
- To obtain legally valid nuclear construction and operating licences and to start operation of the L/ILW repository or combined repository by 2050 and the HLW repository by 2060, it is necessary to:
  - submit the application for underground geological investigations as soon as the general licence is legally valid
  - have completed preliminary construction work for the underground geological investigations when DETEC grants the corresponding licence
  - ensure that the construction of the facilities for the underground geological investigations (EUU) and the EUU proceed without relevant unforeseen events; for the L/ILW repository or the L/ILW repository section of the combined repository that has lower

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[31] By the end of October 2021, the licensing procedure and the execution of the deep borehole campaign had not led to any delays impacting the realisation plan.

requirements for long-term safety, a few years are needed to characterise the geological situation at the disposal level and to obtain the data necessary for the nuclear construction licence or nuclear operating licence applications (see Tab. A.2-1 and A.2-3); for the HLW repository or the HLW repository section, more time will be allotted (see Tab. A.2-1 and A.2-2)

- the application documents for the nuclear construction and operating licence applications must be of a sufficient technical-scientific standard and reviewed by the authorities in line with Anhang 4 KEV so that the corresponding licences and approvals can be granted as planned; furthermore, there should also be no legal appeal procedures involving longer delays
- construction of the facilities will begin immediately after obtaining the nuclear construction licence
- the facilities for underground geological investigations, including the necessary accesses, can also be integrated into the deep geological repository as planned and without major expenditure

From today's perspective, the points discussed above are potentially time-critical realisation steps.

A wide range of topics must be covered for the implementation of the realisation plan (cf. Appendix A.2.2 and Nagra 2021e). These include questions about geology, safety, the inventory of radioactive waste and the design and later construction, operation and closure of the repositories. Issues associated with siting are in the foreground for the general licence. A solid foundation must also be developed for the stage-appropriate documentation to support the general licence application in accordance with the provisions of the KEV (2004).

Once the general licence has been granted, work focuses on preparing and conducting underground geological investigations and activities relating to the nuclear construction and operating licence applications. Corresponding specifications are contained in the nuclear energy legislation and in the guidelines of the regulatory authorities.

The realisation procedure and the information on the main work priorities are outlined in the following based on the example of the combined repository, but this procedure could also apply to individual repositories.

5.4 Realisation procedure based on the example of a combined repository

The background for this section is the realisation plan for a combined repository presented in Fig. 5.3-1. As the same activities and milestones are foreseen for a combined repository as for individual repositories, the realisation plan for a combined repository describes, in an initial approximation, a consolidation of the realisation plans for the L/ILW and HLW repositories (Figs. A.2-1 and A.2-2). For information on activities that differ for the individual repositories, see Section 5.5.

The following describes the key planning, construction and operating activities for the individual phases up to the closure of the deep geological repository. For readability reasons, the phases in Fig. 5.3-1 are numbered sequentially. The realisation plan does not fundamentally change if the encapsulation plants are located at an external site (e.g. Zwilag interim storage facility) instead of at the repository. However, the detailed specification of the realisation plan does depend on the site of the encapsulation plant.

5.4.1 Ongoing procedure for site selection in line with the Sectoral Plan for Deep Geological Repositories: current status and remaining tasks to be completed prior to the general licence

The basic procedure for the site selection/general licensing phase (1) is described in the conceptual part of the Sectoral Plan (cf. BFE 2008) and applies to both the realisation of a combined repository and two individual repositories.

As of the end of 2021, the Sectoral Plan process is in its third and final stage. The following information is limited to the remaining tasks to be completed prior to the granting of the general licence. For a recapitulation of the results of Stage 1 and Stage 2 of the Sectoral Plan and for information on activities carried out and work results obtained up to now for Stage 3 of the Sectoral Plan, see Sections 1.3 and 3.1.5 (geology).

Based on the results of the field investigations and further information, Nagra’s announcement of the site(s) for which it will prepare general licence applications (site selection in preparation for the general licence applications in line with the Sectoral Plan Sectoral Plan for Deep Geological Repositories; BFE 2008) is expected for 2022. The comparison of the siting regions must take place in accordance with the safety-related criteria defined in the Sectoral Plan and in the requirements specified by ENSI (ENSI 33/649; ENSI 2018c). Results of the field investigations to date confirm that, in principle, all three siting regions provide sufficient space for a combined repository layout. As realising a combined repository is associated with operational, safety-related, ecological and economic advantages (see Section 3.1.1), the general licence application will be for a combined repository if the final overall safety evaluation supports this. According to specifications in the nuclear energy legislation (Art. 62 KEV) and ENSI (2018c), the documentation of the site selection forms part of the general licence application and includes a safety-based comparison of the options in terms of the safety of the planned repository and an assessment of the properties decisive for site selection.

As the starting point for further collaboration with the siting regions and cantons, at the beginning of Stage 3 Nagra put forward proposals for concretising the surface infrastructure (Nagra 2019g) and for suitable areas for arranging the auxiliary access facilities. The basis for these proposals were the underground perimeters for the main underground connection area of the underground facilities, which were determined for each of the sites on the basis of geological findings (Nagra 2019b). The proposals for arranging and developing the surface infrastructure were discussed within the framework of collaboration and resulted in position statements from the siting regions and cantons with regard to the placement and concretisation of the surface infrastructure (see Section 1.3) as well as to a further proposal made by Nagra (Nagra 2021g).

As a basis for the transregional collaboration, Nagra has shown that the most sensible site for an encapsulation plant for high-level waste would either be at the repository site or at the interim storage facility in Würenlingen (Zwilag) (Nagra 2020b). Analyses included the siting variants at the surface facility of the repository, the Zwilag and ZWIBEZ interim storage facilities, the remaining NPPs and a greenfield site. The responsible working group consisting of representatives from the regional conferences and affected cantons did not make any additional proposals and recommended that Nagra should consider the different associated position statements when selecting the site for the encapsulation plant (AG VA-extern 2020).

Based on the collaboration results, Nagra will publish preliminary planning studies for the surface infrastructure for selected sites on reaching the milestone 'site selection in preparation for general licence applications'. This will form the basis for subsequent collaboration with the siting regions and cantons to clarify questions regarding the surface infrastructure (e.g. approximate size and location of key structures, construction logistics) so that Nagra can prepare the required documents for the general licence application (main features of the facility, Environmental Impact Report, report on coordination with spatial planning).

In this phase, and as specified in the SGT, the involved siting regions will also prepare regional development projects and define the basis for any compensation measures. In Stage 3 of the Sectoral Plan, the waste producers regulate the issue of compensation measures and payments together with the siting regions and canton(s).

After the review of the general licence application by the authorities, a hearing is held as part of the consultation process and the licence application is made available for public inspection. Following this, the Federal Council will decide on the granting of the licence (2029) and, at the same time, will approve the stipulations in accordance with the Sectoral Plan and the Spatial Planning Act and record these in object sheets. The sites placed in reserve in Stage 2 of the Sectoral Plan remain as reserve options and secured in terms of spatial planning until the operating licence for the repository has been issued. In the site selection process (all three stages of the Sectoral Plan), safety has first priority, as specified in the Sectoral Plan (BFE 2008); spatial planning and socio-economic aspects are considered but are subordinate. The general licence decides fundamental, politically significant questions related to a nuclear installation; in particular, it specifies the site. The fact that the general licence represents a fundamental decision is reflected in the fact that, in contrast with further licensing steps specified in the Nuclear Energy Act (Sections 5.4.2 and 5.5.2), the decision of the Federal Council requires the approval of the Federal Assembly, and the decision is subject to an optional national referendum.

5.4.2 Description of the work in the realisation phases following the general licence

Preparation for the underground geological investigations (2)

After the general licence has been granted, the project will continue with a view to preparing and submitting the application for the underground geological investigations (EUU). This application also includes the infrastructure required for the underground geological investigations.

Preparation of the EUU facilities and start of the underground geological investigations (3)

Following the granting of the licence for underground geological investigations, and in line with the Nuclear Energy Act (KEG 2003), the EUU access structures will be constructed down to the disposal level, from where the disposal zone will be explored. Excavation of underground structures is accompanied by a characterisation programme (construction of EUU facilities and start of EUU, Fig. 5.3-1). In addition, time-critical experiments can begin in the facilities for underground geological investigations (Tab. A.2-4). The corresponding findings feed into the nuclear construction licence applications for both sections of the combined repository. At the surface, the infrastructure required for creating the access and operating the facilities for underground geological investigations will be constructed. During construction, temporary areas for construction site development will be required.

Continuation of underground geological investigations (4)

In this phase, the focus is on conducting the underground geological investigations to assess the disposal zone and confirm safety-relevant properties as well as to optimise the design of the structures at disposal level. Long-term experiments are continued to allow the results to be integrated into the construction licence application for the HLW repository section in line with KEG (2003). Tab. A.2-4 presents an overview of planned activities during the "continuation of EUU" phase and their associated objectives for a combined repository from a current point of view. It also shows how the activities are coupled to the realisation plan for the combined repository (Fig 5.3-1) and contribute to milestones and decision-making. A detailed explanation of the purpose, scope and nature of the most important RD&D activities is provided in the RD&D Plan (Nagra 2021e).

Nuclear construction licence L/ILW (5)

As soon as the required results are available, the application for the nuclear construction licence for the L/ILW repository section KEG (2003) can be submitted (2040). As the basis for the design of the facilities and the safety assessment, the construction licence application is based on updated geological reports (including reports from the underground geological investigations), on results from the RD&D programme and on information from other programmes. As part of preparing the nuclear construction licence application, all documents related to facility design will also be prepared in advance (Tab. A.2-1). The required reports on long-term safety, operational safety and the engineered barriers will also be prepared. In 2044, the official review of the documents will lead to a nuclear construction licence for L/ILW issued by the responsible department (DETEC).

Construction L/ILW repository (6)

Once the construction licence has been granted, the facilities required for initiating L/ILW emplacement operations (9) are constructed for the L/ILW repository section. To this end, the previously existing infrastructure is expanded (e.g. by constructing the L/ILW encapsulation plant at the surface facility or at the Zwilag interim storage facility) and both the main access and the L/ILW emplacement caverns are excavated. Tab. A.2-1 presents an overview of planned activities during this period and their associated objectives from a current point of view. In parallel with the construction, the application for the nuclear operating licence L/ILW (8) for the L/ILW repository section is reviewed. In this "construction L/ILW repository" phase, and as required by regulatory procedural steps, the facilities for underground geological investigations are converted to test areas, becoming components of the deep geological repository (Section 5.1). In the test areas, long-term experiments initiated as part of the underground investigations continue and, before repository operations commence, safety-relevant techniques are tested and their functionality is demonstrated (Tab. A.2-4).

L/ILW emplacement operations (9) / construction of HLW repository (10)

With the nuclear operating licence L/ILW (8) for the L/ILW repository section, emplacement operations for L/ILW (9) start in 2050. First, the L/ILW pilot repository is filled with a representative selection of waste packages and long-term monitoring starts.

During construction of the L/ILW repository section, the application for the nuclear construction licence HLW (7) for the HLW repository section is prepared in line with KEG (2003). After the start of operations in the L/ILW repository section, the HLW repository section is constructed (construction HLW repository (10)). For this, the existing infrastructure is expanded, in particular with the SF/HLW(WA) encapsulation plant at the surface facility or at Zwilag, and the disposal area accesses to the HLW emplacement drifts are excavated via the previously constructed operations shaft. During this phase, the application for the nuclear operating licence HLW (11) for the HLW repository section is also prepared.

HLW emplacement operations (12)

After the nuclear operating licence HLW (11) for the HLW repository section has been granted, the emplacement of SF/HLW(WA) disposal canisters in the emplacement drifts begins. First, the HLW pilot repository is filled with a representative selection of waste packages, and long-term monitoring is started. Additional SF/HLW(WA) emplacement drifts are excavated in parallel with emplacement operations.

Monitoring phase (13)

The monitoring phase begins once waste emplacement is complete (Tab. A.2-1). Deep geological disposal combines the concept of disposal in geological formations with the possibility of retrieval. This means that, prior to the closure of a deep geological repository, its evolution is monitored by means of measurements for an extended time periods in, e.g., the pilot repository (observation drift) and test areas and through monitoring activities in the vicinity of the repository. During this time, it must remain possible to retrieve the waste without undue effort. For planning purposes, based on Art. 3 SEFV, a monitoring phase of 50 years is assumed, but its duration can be adjusted if necessary.

Closure of main facility (14)

With a view to the closure of the entire repository, in a first step the accesses to the disposal areas and to the L/ILW and HLW main and pilot repositories [32] are backfilled and sealed at the disposal level during the monitoring phase. In addition, the surface facility elements that are no longer required (e.g. encapsulation plants) are dismantled and the main access is closed.

Continuation of monitoring phase (13)

Even after the main and pilot repositories have been closed, the access to the test areas and to the HLW and L/ILW observation drifts in the pilot repositories will remain open via the remaining accesses (in general, operations and ventilation shafts) and monitoring will continue.

[32] Based on current planning assumptions, the closure of the L/ILW main repository will be carried out in two stages; this ensures the emplacement of the decommissioning waste from Zwilag and the SF/HLW(WA) encapsulation plant.

Closure of entire repository (15)

After the end of the monitoring phase, the Federal Council authorises closure work provided the permanent protection of humans and the environment can be ensured (Art. 39 Par. 2 KEG). This includes the closure of the test areas, observation drifts in the pilot repositories and all other open underground facilities that have been kept operational until that point in time, including the last open accesses, and the dismantling of the remaining parts of the surface infrastructure. After final closure, the repository enters the post-closure phase. If necessary, it is still possible to continue monitoring activities from the surface during this phase (environmental monitoring). At the end of this potential additional limited period of monitoring from the surface (Art. 39 Par. 3 KEG), the Federal Council will decree that the sealed repository be released from nuclear energy legislation (Art. 39 Par. 4 KEG). The responsibility for the closed repository then transfers to the Federal Government, which, within the framework of long-term monitoring (16), can conduct further measures, in particular environmental monitoring (Art. 39 Par. 4 KEG).

5.5 Procedure for the realisation of two individual repositories

The basis for this section is provided in the realisation plans for the HLW and L/ILW repositories outlined in Figs. A.2-1 and A.2-2.

5.5.1 Site selection according to the Sectoral Plan and the general licence

In this phase, the procedure for two individual HLW and L/ILW repositories is identical to that for a combined repository, and the statements made in Section 5.4.1 therefore also apply to the HLW and L/ILW repositories.

Based on in-depth geological investigations in the remaining geological siting regions and on additional information, Nagra will announce the sites for which it will prepare general licence applications in 2022 (BFE 2008) (Section 5.4). In the case of a decision to construct two individual repositories, Nagra will prepare general licence applications for an HLW and L/ILW repository, respectively, and submit these to the authorities for review as opposed to preparing one general licence application for a combined repository.

5.5.2 Activities after the general licence

The fundamental procedure and the general conceptual requirements and assumptions for the individual repositories are identical to those for the combined repository. However, while specific requirements and assumptions valid for both repository types apply to the combined repository, in the case of two individual repositories only those have to be considered that specifically apply to the respective repository type.

In the case of the L/ILW repository, these include:

- In the facilities for underground geological investigations, only those experiments that are relevant to the realisation of the L/ILW repository are conducted (see Tab. A.2-4).
- The repository is not expanded in parallel with emplacement operations.

For the HLW repository, these include:

- In the facilities for underground geological investigations, only those experiments that are relevant to the realisation of the HLW repository are conducted (see Tab. A.2-4).

Diverse synergy effects that come into play for the combined repository (see Section 3.1.1) no longer apply to the individual repositories (Nagra 2020a). These include the preparation and implementation of the underground geological investigations (e.g. synergy effects with regard to characterisation of the geological situation as well as the associated experimental programme), construction (e.g. elements of the surface infrastructure and underground access), operation of the HLW and L/ILW repository sections (e.g. use of underground access structures) and the joint monitoring phase and closure.

5.6 Research and development

The realisation of deep geological repositories is a stepwise process extending over several decades and requires a comprehensive planning basis for the scientific and technical work priorities. In the RD&D Plan (Nagra 2021e), the purpose, scope, nature and duration of various future activities involving research, development and demonstration resulting from the realisation plan as well as from the conceptual specifications and assumptions outlined in WMP21 are presented in full.

WMP21 outlines topics and activities to be addressed for the implementation of the realisation plan from today's point of view (Appendix A2.2). For a detailed discussion of the research activities, see Nagra (2021e). Work on the RD&D programme covers a wide range of topics, including issues related to geology, safety and safety-relevant phenomena and processes, radioactive waste, the disposal concept, the engineered barriers and closure of the geological repositories.

In the various waste management projects worldwide, RD&D programmes have been ongoing for many years, some of them running as international collaborations. For some of these, the RD&D carried out in underground rock laboratories plays a central role. For Nagra, the findings from the Mont Terri (Switzerland), Bure (France), Grimsel Test Site (Switzerland), Aspö (Sweden) and Mol (Belgium) underground rock laboratories are of particular relevance. RD&D activities also include laboratory programmes, model development and topic-specific studies. In Switzerland, an RD&D programme has been running for approximately 45 years. Competence centres are included in this (see Section 5.7) to extend and supplement the work being carried out abroad as required. The international collaboration within the framework of the European research programme, EURATOM, continues to be of great importance to Nagra. Within a European network, it is easier to realise and respond to cost-intensive experiments and complex issues. Research topics and activities are oriented to the level of information and decision-making needs of the individual milestones for realising the repositories. The assessment of the urgency and the depth of work on these issues required for the various milestones takes into account the state of knowledge as well as the assessments by the authorities and their experts. It is also oriented towards the requirements and specifications set out in Appendices A.1 and A.3.

Specific RD&D topics are to be investigated in depth with a view to the nuclear construction and operating licence applications. Certain demonstrations are provided during operation of the repository. Examples of such RD&D activities include the development of the disposal canisters for SF/HLW(WA), the review and demonstration of emplacement and retrieval of waste packages, backfilling and sealing as well as monitoring. A brief description of these topics can be found in Appendix A.2.2; more detailed information can be found in the RD&D Plan (Nagra 2021e).

5.7 Information on performing the work and quality management

According to legal requirements, the responsibility for disposal lies with the waste producers (Art. 31 KEG). These (operators of the NPPs and the Swiss Confederation) founded Nagra in 1972 to carry out all tasks with regard to the realisation of the deep geological repositories.

To carry out its work professionally, Nagra has a flexible organisation which can be adapted to evolving needs. Nagra is currently established as a project management organisation. Work is awarded to qualified contractors when the tasks can be sufficiently clearly defined and the interfaces to other tasks are easily manageable. In work areas that require special knowledge (in particular RD&D activities), long-standing collaboration arrangements run with established competence centres (such as PSI or the University of Bern)[33], complemented by institutes in Switzerland and abroad and by experienced contractors with topic-specific knowledge and infrastructure. Selected aspects are handled in joint projects with partner organisations, partly in the context of the European Commission Research Framework Programmes and partly under other contractual arrangements. This includes, in particular, research programmes in the international underground rock laboratories.

For the above-mentioned work, Nagra relies not only on qualified contractors available on the market but has also secured multi-year contracts with qualified competence centres, institutes in Switzerland and abroad and with partner projects. Nagra itself has qualified employees with the safety awareness required for their tasks and is responsible for planning of work, producing synthesis reports and presenting results and conclusions to stakeholders (if necessary, involving key contractors). Commissioning and execution of the work takes place within a clearly defined management system, which has been certified since 2005 as meeting quality management requirements according to ISO 9001. Within this system, reviews play a central role. The system also results in to a significant promotion of quality awareness for internal work processes and for external reporting in the planning phase; this is of great importance considering the long-term nature of the repository project.

[33] Based on long-term contracts, competence centres ensure that an experienced pool of employees as well as special infrastructure for selected work areas are available. In their field of expertise, the competence centres carry out the research work independently, without the influence of Nagra on the outcome of the research. This ensures that the results are recognised as being scientifically objective.

5.8 Transmission of information to future generations

The nuclear energy legislation foresees a set of measures for the transmission of information about a repository to future generations. The owner of a deep geological repository must prepare documentation that will ensure suitable long-term preservation of knowledge of the geological repository (Art. 71 KEV). Art. 40 KEG requires the Federal Council to ensure that this information is retained, and that the knowledge of the repository is preserved (long-term archiving). In addition, the law prescribes the marking of the repository; a marking concept must be submitted by the owner as part of the nuclear construction licence application (ENSI 2020b).

The extent of work in the field of transmission of information to future generations varies internationally. In 2011, the Nuclear Energy Agency (NEA) of the OECD launched the project "Preservation of Records, Knowledge and Memory (RK&M) Across Generations", and its final report was published in 2019 with the following recommendation (OECD/NEA 2019): Questions of long-term archiving and marking should not be considered individually, but rather within the framework of a global system – together with a wide range of measures to preserve information and knowledge.

The follow-up project, "Information, Data and Knowledge Management (IDKM)", was started in 2020. Its aim is to integrate technical considerations internationally, analyse possible solutions and communicate decisions.

6 Interim storage

Key differences between WMP16 and WMP21

The basic assumptions regarding the configuration of interim storage for L/ILW and ATW have not changed since 2016. Due to a modification of some points in the realisation plan and taking into account certain scenarios, the information on the configuration, duration and capacity of interim storage was reviewed and modified where necessary (including the number of storage positions available or to be considered). For this purpose, WMP21, as was already the case in WMP16, considers interim storage logistics (acceptance of waste in disposal containers, boundary conditions for stacking heights, maximum floor loads).

To meet condition 5.8 of the Federal Council regarding the interim storage capacity for spent fuel assemblies and vitrified high-level waste, a concept was developed to increase the number of storage positions for transport and storage casks containing SF and HLW(WA) (Kasemeyer 2021). The evaluation of the interim storage capacities in WMP21 is based on the potential number of storage positions that can be justified through the optimised conditions described in the concept.

6.1 Configuration, duration and capacity of interim storage

The waste arising today from the NPPs and from medicine, industry and research (MIR) that is destined for deep geological disposal is held in interim storage. The NPP operational, reactor and decommissioning waste is held in the Zwilag or ZWIBEZ interim storage facilities, while MIR waste, which is the responsibility of the Swiss Confederation, is stored in the Swiss Federal Interim Storage Facility (BZL-1 or BZL-2, which is currently under construction) located on the grounds of PSI.

In the long term, the following facilities or units are available or planned for interim storage (nomenclature for use is shown in Tab. 6.1-1):

- BZL-1: existing Swiss Federal Interim Storage Facility at PSI for MIR waste
- BZL-2: planned Swiss Federal Interim Storage Facility at PSI for MIR waste[34]
- ZWIBEZ LLW: interim storage facility at the Beznau NPP for low-level waste
- ZWIBEZ HLW: interim storage facility at the Beznau NPP for vitrified high-level waste and spent fuel assemblies
- Zwilag L/ILW: storage facility for low-level waste and certain types of intermediate-level waste[35]
- Zwilag ILW: storage facility for low- and intermediate-level waste and/or combustible waste conditioned for final disposal[36]
- Zwilag SF/HLW(WA): storage facility for canisters containing vitrified high-level waste and spent fuel assemblies

[34] The Swiss Federal Interim Storage Facility at the Paul Scherrer Institute has to be expanded. To this end, PSI submitted a construction and operating licence application to the Swiss Federal Office of Energy (BFE) in 2014. BZL-2 is currently under construction.

[35] Zwilag L/ILW includes disposal areas spread out over two buildings, storage facility S and storage spaces above storage bays in storage facility M.

[36] Zwilag ILW primarily consists of storage bays in storage facility M.

The spent fuel assemblies are placed into transport and storage casks without pre-treatment and are held in the Zwilag SF/HLW(WA) or ZWIBEZ HLW interim storage facilities, after sufficient cooling in the fuel storage pools of the NPPs or the NPP Gösgen wet storage facility. The waste from reprocessing is also held in interim storage: the vitrified HLW(WA) in transport and storage casks in the Zwilag SF/HLW(WA) and the other waste from reprocessing in disposal canisters in the Zwilag ILW.

With the planned start of operation of the L/ILW repository or the L/ILW repository section of the combined repository in 2050, in the case of a 50-year operation of the NPPs ("50-year NPP operating lifetime" scenario; see Appendix A.5), all the waste from the NPPs would have to be held in the Zwilag/ZWIBEZ interim storage facilities, from where it would be transported to the deep geological repositories. In the case of a 60-year operation of the NPPs ("60-year NPP operating lifetime" scenario; see Section 2.1), it would be possible in principle for decommissioning waste from NPP Leibstadt in particular to go directly to the L/ILW repository (see Tab. A.2-5). For a conservative estimate of the maximum required interim storage capacity, however, it is assumed that, even for the "60-year NPP operating lifetime" scenario, all the waste is temporarily held in the Zwilag and ZWIBEZ facilities before being transported to the repositories. WMP21 thus takes into consideration a conservative waste volume as well as a potential delay in the commissioning of the L/ILW repository or combined repository.

The phase after the dismantling of the NPPs and the associated on-site interim storage facilities, is important for evaluating the interim storage capacity. In WMP21, as in WMP16, the capacities of the decentralised L/ILW interim storage facilities at the NPPs are not considered. Sufficient interim storage capacity during the operation of the NPPs is ensured, because the Zwilag/ ZWIBEZ facilities always have enough capacity (for information on operating lifetimes of the NPPs, including their decentralised L/ILW interim storage facilities, see Tab. A.2-5).

As did WMP16, WMP21 provides a more detailed picture of the interim storage capacity (see Appendix A.6); this takes into account the actual interim storage logistics on site. ZWIBEZ LLW and Zwilag L/ILW and ILW are designed to hold disposal containers and, for (smaller) waste packages, stillage cages. Multiple stacking of these stillage cages is possible at each storage space. In addition, concrete containers with waste from the decommissioning of the NPPs are stored directly without placing them in disposal containers or stillage cages; the stacking height of these containers is limited by the maximum floor load. For the ZWIBEZ HLW and Zwilag SF/HLW(WA) interim storage facilities, the transport and storage casks for HLW are emplaced directly, and the maximum capacity is thus limited by the number of storage positions.

This confirms that, also for the "60-year NPP operating lifetime" scenario, sufficient interim storage capacity is available for NPP waste if all waste goes into interim storage (Tab. 6.1-1). With a view to the Waste Management Programme 2021, the Federal Council has formulated a specific recommendation for the number of storage positions for the interim storage of SF and HLW(WA) (Federal Council stipulation 5.8, cf. Appendix A.6) and requires the operators of the nuclear power plants to develop new concepts for increasing the interim storage capacity for spent fuel assemblies and vitrified high-level waste for WMP21. Kasemeyer (2021) states that, even when considering these requirements, different variants exist for increasing and optimising the number of storage positions. Appendix A.6 shows the results of the conceptual clarifications that were carried out.

If the start of operation of the repositories is delayed, interim storage facilities can also be operated for longer with appropriate administrative and technical measures (contracts, maintenance, possibly retrofits, replacement or renewal of selected components)[37, 38].

Tab. 6.1-1: Occupancy of the interim storage facilities for the "60-year NPP operating lifetime" scenario

For details on the "60-year NPP operating lifetime" scenario, see Section 2.1.

Interim storage facility [1)]	**Occupancy** [4)] [%]
BZL-1 and BZL-2 [2)]	98.5
ZWIBEZ LLW	64
Zwilag ILW	93 [5)]
Zwilag L/ILW	78
Zwilag SF/HLW(WA) + ZWIBEZ HLW [3)]	91 (105) [6)]

1) For information on the operating lifetimes of the interim storage facilities, see Tab. A.2-5.

2) The dismantling of the PSI West facilities is planned after 2050. As the L/ILW repository or the combined repository will be available by then, this waste does not have to be held in interim storage; otherwise space must be found on site.

3) Zwilag SF/HLW(WA) and ZWIBEZ HLW can be considered as a single unit in terms of capacity.

4) The detailed derivation of the occupancy rate can be found in Appendix A.6.

5) In case of the need for additional storage capacity in Zwilag ILW, stored materials can be conditioned or re-packaged for storage in Zwilag L/ILW at any point in time.

6) Without optimisation measures, an occupancy rate of 105% can be expected for Zwilag SF/HLW(WA) and ZWIBEZ HLW. However, optimising the number of storage positions can lead to an occupancy rate of 91% of the interim storage facilities for spent fuel assemblies and vitrified high-level waste (see Appendix A.6).

For emplacement in the repositories, the waste is removed from the interim storage facilities and – where necessary – transported to the encapsulation plants (at Zwilag or at the repository site) in special transport casks.

Spent fuel assemblies and high-level waste from reprocessing must be transported in suitable certified transport casks, and the use of existing transport and storage casks is foreseen[39]. This requires a transport permit for the time of transport. If the encapsulation plant is located externally at Zwilag, the loaded disposal canisters are transported in special transport casks that fulfil the requirements of transport law. Corresponding concepts have been developed.

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37 In the event of an extended operation of interim storage facilities, age management must be taken into account.

38 Should a delay in the commissioning of the L/ILW repository or the combined repository become apparent (Section 5.3), new capacity reserves would have to be planned for the interim storage of MIR waste (production as of 2050) and for the decommissioning of the PSI West facilities.

39 In line with Guideline ENSI-B17 (ENSI 2020a), the cask owners implement a concept to monitor ageing.

The concept for age management shows that simplified recertification of transport and storage casks for transport is possible. This is based on the ENSI guideline for dry interim storage (ENSI 2018a); this guideline also regulates monitoring the ageing of transport and storage casks for spent fuel assemblies and high-level waste.

After their use, transport and storage casks are recycled to the greatest extent possible; radioactive waste resulting from the decontamination and dismantling of the transport and storage casks will be disposed of appropriately. However, the majority of the transport and storage casks can – after corresponding decay storage where necessary – be disposed of conventionally or recycled. The infrastructure required for transport (loading and unloading of transport casks) either exists or is available as a concept. This also applies to the rail wagons and road vehicles necessary for transport. The potential to take account of new experience, technical innovation and changes in regulations is ensured (Tab. A.3-1).

The revisions of the Radiological Protection Ordinance (StSV 2017) and the nuclide-specific exemption limits (fully taken into account in the WMP21 scenarios; see Section 2.1 and Appendix A.5), result in additional material (around 3,500 m^3) compared to WMP16. However, this is exempt and can –after decay storage where necessary – be recycled in a conventional manner. Through decay storage, radioactive materials reach their exemption limit at a later time. This is achieved by storing these materials to take advantage of radioactive decay until levels fall below the exemption limits defined in the Radiological Protection Ordinance (StSV 2017), leading to radiological exemption. This requires decay storage sites where the materials are held until their final release and conventional disposal. These storage facilities must be equipped in such a way as to prevent an uncontrolled release of radioactive substances.

The materials considered for decay storage consist of very low-level radioactive materials; due to the low level of radioactivity, these will fall below the exemption limits in the Radiological Protection Ordinance after 30 years[40]. Most of this material consists of metal and construction debris from decommissioning. Decay storage is already used today as a proven method for recycling and exempting materials and minimising radioactive waste.

With a view to the Waste Management Programme 2021, the Federal Council made a specific recommendation with regard to the long-term stability of spent fuel assemblies (Federal Council stipulation 6.1; see Appendix A.7) and has tasked Nagra with considering research activities with regard to the ageing and dry storage of fuel assemblies in future Research, Development and Demonstration Plans. Additionally, the results of the research projects and experiments presented in the previous version of the RD&D plan must be outlined. Appendix A.8.7 therefore contains specific references to Nagra-internal investigations as well as to work carried out elsewhere related to the long-term stability, ageing and dry storage of spent fuel assemblies.

[40] The decay storage period has been set to 30 years after the original material was last used (Art. 117 StSV).

6.2 Outlook interim storage

In the case of a delay in the commissioning of the deep geological repository, the Zwilag/ ZWIBEZ interim storage facilities can provide sufficient storage capacity for all scenarios and waste categories. Based on an assumed waste emplacement period of 15 years, the current realisation plan (Section 5.3) foresees the end of L/ILW emplacement at the end of 2064 and for HLW at the end of 2074.

Extending operations at the interim storage facilities is also basically possible. Proven technology for transporting the waste is already in place and concepts have been formulated for the infrastructure that will be required in the future.

7 Costs and financing of waste management

Key differences between WMP16 and WMP21

The last Cost Study (CS16) was submitted in 2016. The projects and calculations that formed the basis for CS16 were reviewed by the Swiss Federal Nuclear Safety Inspectorate (ENSI), independent financial auditors and the Swiss Federal Audit Office. Based on Art. 4 of the Decommissioning and Waste Disposal Funds Ordinance (SEFV 2007), the Administrative Commission of the Decommissioning and Waste Disposal Funds (referred to as Commission in the following) then submitted a request to specify the expected decommissioning and waste disposal costs for each of the nuclear facilities to the Swiss Federal Department of the Environment, Transport, Energy and Communications (DETEC). On 12th April 2018, DETEC decreed the costs for CS16 with amendments compared to the request of the Commission. This prompted the facility operators to file a complaint with the Federal Administrative Court. On 20th March 2019, the Administrative Court decided that DETEC was responsible for determining the costs for CS16, whereupon the operators filed a complaint with the Swiss Federal Supreme Court. On 6th February 2020, the Federal Court upheld the complaint and assigned the Commission with the responsibility for determining the costs for CS16. With a decree of 10th March 2021, the Commission specified the decommissioning and waste disposal costs at CHF 23.856 billion[41].

In accordance with the decision of the Federal Council on the Waste Management Programme 2016, WMP21 must be submitted together with CS21 (see Appendix A.7).

According to the requirements of the Administrative Commission (STENFO 2021b), the 2021 cost calculation for the deep geological repositories is based on the same model sites as the 2016 Cost Study. In addition, the costs for disposal must be calculated based on two individual repositories; other siting variants have to be shown separately. This approach ensures that all variants (including the combined repository variant) remain open. Aside from further specifications, three decommissioning goals must be outlined separately:

- Decommissioning goal 1: release from nuclear energy legislation.
- Decommissioning goal 2: complete dismantling, including removal of all foundations to a depth of – 2 metres from top of terrain.
- Decommissioning goal 3: complete dismantling, including removal of all foundations.

In addition, the Commission set out detailed requirements for CS21, as it did for CS16, regarding the cost structure and presentation of reserves for inaccuracies in predictions, reserves for risks and deductions for chances, as well as with regard to an additional general safety reserve.

[41] The BKW Energie AG company filed a complaint against this decree with the Federal Administrative Court; no decision has been reached as yet (as of 31st October 2021).

7.1 Legal framework

According to the legal provisions, the waste producers are responsible for the disposal of radioactive waste and must bear the full costs of this (polluter pays principle). To ensure the financing of the decommissioning of the nuclear installations and the disposal of the resulting waste and the disposal of the radioactive operational waste and the spent fuel assemblies following the decommissioning of the nuclear installations, the owners must contribute to the Decommissioning and Waste Disposal Funds (Art. 77 KEG). The Decommissioning Fund secures the financing of the decommissioning of the nuclear facilities and the disposal of the resulting waste. The Waste Disposal Fund finances the disposal of all the operational waste arising after the shutdown of the corresponding nuclear power plant, interim storage, transport, transport and storage casks, the disposal of spent fuel assemblies and the preparation, construction, operation, decommissioning and monitoring of the required repositories. The costs arising before shutdown are borne directly by the owners and are to be set aside (Art. 82 KEG).

The Decommissioning and Waste Disposal Funds and their historical performance are discussed in more detail in Section 7.3.1. The Funds represent the form of financing for decommissioning of the nuclear facilities and waste disposal costs after shutdown of the nuclear power plants which is anchored in the Nuclear Energy Act (Art. 77 KEG) and the Decommissioning and Waste Disposal Funds Ordinance (SEFV 2007). The monies paid into the Funds are removed from direct access by the owners and are under state control, which ensures their appropriate application. At no time are the owners relieved of their obligation to bear costs (Art. 31 KEG), either during or after the end of the obligation to contribute to the Funds.

To determine the amount of the annual contributions to be made to the Decommissioning and Waste Disposal Funds and the amount of reserves to be set aside by the owners of the nuclear facilities, the anticipated decommissioning and waste disposal costs are calculated every five years by the owners within the framework of cost studies (Art. 4 SEFV). The cost studies are based on the decommissioning plans for the nuclear installations, the Waste Management Programme for the radioactive waste, the current scientific and technical knowledge base and the prices that apply at the time of the calculations (Art. 4 SEFV). These cost studies are reviewed by the Swiss Federal Nuclear Safety Inspectorate (ENSI) in terms of aspects relevant for safety and technical feasibility and by independent experts with respect to the cost calculations (Art. 4 SEFV). Although CS21 includes several cost calculations (swissnuclear 2021c, 2021d, 2021b, 2021a), for reasons of simplicity it will be referred to as the *Cost Study* in the following.

The Cost Study and the Waste Management Programme have different objectives. WMP21 represents the current status of planning for deep geological disposal and takes into account the existing options for realising the repositories in an open manner, without pre-empting decisions on the sites or on detailed technical design.

The objective of the 2021 Cost Study (CS21) is to provide a sufficiently accurate, realistic and transparent cost estimate based on the stipulations of the Administrative Commission for calculating the contributions to the Decommissioning and Waste Disposal Funds and for determining the level of the reserves to be made for the decommissioning and waste disposal costs. To determine the costs of deep geological disposal, modelling assumptions must be made regarding the realisation of the repositories without pre-empting decisions or making statements on preferences. These modelling assumptions are consistent with the Waste Management Programme but, as in WMP21, do not make any premature findings on later decisions on the way to realising the repositories. Accordingly, aside from the costs for the base scenario, costs for variants are also determined and then considered as chances or risks. In this context, it must be emphasised that the sites remaining in Stage 3 of the Sectoral Plan are exclusively sites that are also suitable for a combined repository. In accordance with the stipulations set out by STENFO on CS21 (STENFO 2021b), two individual repositories must be considered when determining the basic costs (HLW repository at the ZNO site and L/ILW repository at the JO site). Further variants, such as the combined repository, are described as chances or risks in CS21.

7.2 Calculated costs

CS21 represents the basis for the following costs.

It takes into account the following:

- the information on the waste for disposal in Appendix A.5, Tab. A.5-1 for a 50-year operating lifetime (Beznau, Gösgen and Leibstadt NPPs) and a 47-year operating lifetime (Mühleberg NPP). The volumes for a 60-year and 47-year NPP operating lifetime are documented in Section 2.1, Tab. 2.1- 1
- the description of the waste management facilities and infrastructure
  - calculation of the waste management costs – deep geological disposal; see Section 1.7 and Chapter 4 in swissnuclear (2021d) swissnuclear (2021d)
- the realisation plan, in particular:
  - operating lifetimes of the NPPs and the waste management facilities
  - decision points (licences) for the facilities still to be realised (for deep geological repositories: see tables in Appendix A.2)
  - key activities (for deep geological repositories: see Appendix A.2)

The costs of decommissioning and disposal include all past and future costs for decommissioning the nuclear installations, planning, construction and operation of the waste management facilities, interim storage, acquisition costs for transport and storage casks and the costs for services of third parties (e.g. for transport or reprocessing). These cost elements are estimated by Nagra, Zwilag and the nuclear power plants and are divided thematically as follows:

- reprocessing
- interim storage (Zwilag and ZWIBEZ facilities/Gösgen NPP wet storage facility)
- acquisition of transport and storage casks for SF/WA-HLW; see Section 2.1)
- transports
- preparation, construction, operation, monitoring and closure of the L/ILW repository
- preparation, construction, operation, monitoring and closure of the HLW repository
- preparation, construction, operation, monitoring and closure of the combined repository
- decommissioning of the nuclear installations

The total costs for decommissioning and waste disposal divided into thematic blocks are presented in Tab. 7.2-1. These amount to CHF 19,417 million for the disposal costs without consideration of the chance of a combined repository and to CHF 18,191 million with consideration of the chance of a combined repository. The following three decommissioning goals were newly defined for CS21 based on the stipulations of the Administrative Commission (STENFO 2021b); these must be depicted in terms of costs:

- decommissioning goal 1 (Z1): release from nuclear energy legislation
- decommissioning goal 2 (Z2): full dismantling, including removal of all foundations to - 2 m from top of terrain
- decommissioning goal 3 (Z3): full dismantling, including removal of all foundations

Depending on the decommissioning goal, decommissioning costs will amount to CHF 3,364 million (Z1), CHF 3,589 million (Z2) or CHF 3,666 million (Z3).

The costs include outgoings that have already been paid (accumulated costs per end of 2020) as well as outgoings to be paid by the facility owners in the future either directly or via the Funds (future costs from 2021).

Tab. 7.2-2 shows the division over time of the decommissioning and waste disposal costs. Financing of the respective costs is discussed in Section 7.3.

Tab. 7.2-3 presents the costs for waste disposal and decommissioning according to the breakdown of costs specified by the Commission. Aside from the total costs, the table contains information on the base costs, the reserves for prediction uncertainties and risks, as well as the deductions for chances and a general safety reserve. Based on the breakdown, the total costs result from the sum of the different cost blocks presented in the following. The base costs are made up of the initial costs and the costs of risk reduction. Reserves for uncertainties in predictions are added to the base costs. Reserves for risks and deductions for chances are then factored in. As required, a general safety reserve is taken into account. The sum of all the cost blocks yields the total costs.

Tab. 7.2-1: Total costs for waste disposal and decommissioning divided into thematic blocks without taking into account the chance of a combined repository

In line with stipulations of the Administrative Commission for CS21, three decommissioning goals (Z1, Z2, Z3) are now defined (see Section 7.2) and must be depicted in terms of costs.

Information in CHF million according to swissnuclear (2021c, 2021a, 2021d, 2021b). Information without brackets includes the costs of the Federal Government; information in brackets corresponds to costs without those of the Federal Government. Deviations in amounts are due to rounding. PB21 is price basis 2021.

Topics		**Costs** CS21/PB21
Reprocessing		2,737 (2,737)
Interim storage (Zwilag), including centralised waste treatment		2,703 (2,641)
ZWIBEZ and NPP Gösgen wet storage facility		310 (310)
Acquisition of transport and storage casks for SF/WA-HLW		1,028 (1,025)
Transports		280 (277)
Preparation, construction, operation, monitoring and closure of the L/ILW repository [1), 2)]		4,692 (3,674)
Preparation, construction, operation, monitoring and closure of the HLW repository (including encapsulation plant for SF and HLW from reprocessing) [2)]		7,659 (7,620)
Total waste disposal		19,417 (18,293)
Decommissioning of NPPs and interim storage facilities [3)]		
	Z1	3,364
	Z2	3,589
	Z3	3,666
Overall total		
	Z1	22,781 (21,657)
	Z2	23,006 (21,882)
	Z3	23,083 (21,959)

1) Without costs for decommissioning waste (total costs in the amount of CHF 119 million).

2) If two individual repositories are constructed. In the case of the L/ILW repository, the costs excluding the Federal Government amount to 76.74% of the future fixed costs of an L/ILW repository. In the case of the HLW repository, the costs excluding the Federal Government amount to 99.82% of the fixed costs of the HLW repository. This corresponds with the method used in the financial agreement concluded in June 2020 between the Federal Government and the operators and is updated based on the current waste inventory framework.

3) Including overall costs for the disposal of decommissioning waste.

Tab. 7.2-2: Overview of distribution with time of the decommissioning and waste disposal costs

In line with stipulations of the Administrative Commission for CS21, three decommissioning goals (Z1, Z2, Z3) are newly defined (see Section 7.2) and must be depicted in terms of costs.

Information in CHF million. Information without brackets is based on the disposal costs for realising two individual repositories. Information in brackets includes a 75% realisation chance of a combined repository in the disposal costs. Deviations in amounts are due to rounding. Price basis 2021.

	Only deep geological repositories	**Waste management**	**Decommis-sioning**	**Total**
Accumulated costs until end of 2020	1,700 [1)]	6,326 (6,326)	135	6,461 (6,461)
From 2021 to shutdown of the nuclear power plants	496 (483)	1,033 (1,020)	Z1: 237 Z2: 238 Z3: 238	Z1: 1,270 (1,257) Z2: 1,271 (1,258) Z3: 1,271 (1,258)
After shutdown of NPPs	9,243 (8,134)	11,120 (10,011)	Z1: 2,992 Z2: 3,216 Z3: 3,293	Z1: 14,112 (13,003) Z2: 14336 (13,227) Z3: 14,413 (13,304)
Future cost share of Federal Government from 2021	911 (807)	938 (834)	- (-)	938 (834)
Total	**12,350** **(11,124)**	**19,417** **(18,191)**	Z1: 3,364 Z2: 3,589 Z3: 3,666	**Z1: 22,781** **(21,555)** **Z2: 23,006** **(21,780)** **Z3: 23,083** **(21,857)**

1) Including contributions from the former GNW: CHF 65 million passed through Nagra, an additional CHF 25 million were directly paid by the utilities to GNW. Total contributions amounting to CHF 90 million are included here.

Tab. 7.2-3: Estimate of total costs for decommissioning and disposal with the cost breakdown according to the specifications of the Commission

In line with stipulations of the Administrative Commission for CS21, three decommissioning goals (Z1, Z2, Z3) are newly defined (see Section 7.2) and must be depicted in terms of costs.Information in CHF million according to swissnuclear (2021c), including the costs of the Federal Government for disposal of MIR waste [1]. In line with official requirements, the information is based on a 50-year NPP operating lifetime (Mühleberg NPP 47 years). Deviations in amounts are due to rounding. PB21 is price basis 2021.

Total costs CS21/PB21	**Waste disposal**	**Decommissioning**			**Total**		
Accumulated costs until end of 2020	**6,326**	**135**			**6,461**		
Future costs from 2021		**Z1**	**Z2**	**Z3**			
Initial costs	8,865	2,313	2,476	2,536	11,178	11,341	11,402
Costs of risk reduction	289	58	58	58	347	347	347
Base costs	9,154	2,371	2,534	2,595	11,525	11,688	11,749
Prediction uncertainties	1,514	290	320	323	1,804	1,834	1,837
Risks	1,618	459	484	494	2,077	2,102	2,111
Chances	-71	-9	-10	-10	-80	-81	-81
General safety reserve	876	119	127	130	994	1,002	1,005
Reserve for future base costs	3,936	858	921	937	4,795	4,857	4,873
Total costs CS21/PB21	**19,417**	**3,364**	**3,589**	**3,666**	**22,781**	**23,006**	**23,083**
Considering combined repository as a chance	-1,226	0	0	0	-1,226	-1,226	-1,226
Total costs considering combined repository as a chance (75% weighted)	**18,191**	**3,364**	**3,589**	**3,666**	**21,555**	**21,780**	**21,857**
Total costs CS16 PB21 [2]	**19,525**	**3,630**	**nn**	**3,874**	**23,155**	**nn**	**23,399**
Difference CS21/CS16	**-1,334**	**-266**	**nn**	**-208**	**-1,600**	**nn**	**-1,542**
Difference CS21/CS16 [in %]	**-6.8**	**-7.3**	**nn**	**-5.4**	**-6.9**	**nn**	**-6.6**

1) The Federal Government is responsible for disposal of MIR waste. No contributions are made to the Decommissioning and Waste Disposal Funds for the associated costs. An agreement was reached between the owners of the nuclear installations and the Federal Government and other organisations from the MIR area regarding their contribution to the construction costs of the repositories (BAG 2018),. This was approved by the Federal Council on 27th September 2019 and led to a new cost breakdown as of 1st January 2020. According to Art. 38 KEG, the owners of the repositories have a right to compensation to cover costs of disposal of waste from third parties.

2) The comparison basis in CS16 corresponds to the CS16 figures reviewed by STENFO, including a general safety reserve with price basis 2021. The combined repository variant is compared with the same likelihood of realisation (75% chance of a combined repository).

The costs for the deep geological repositories are shown in Tables 7.2-2 to 7.2-4 in accordance with the cost breakdown stipulated by the Commission for the HLW and L/ILW repositories; these are based on a 47-year operating period for the Mühleberg NPP and a 50-year operating lifetime for the other nuclear power plants. In addition, Tab. 7.2-4 lists the overall costs for the case in which the realisation of the combined repository is considered as a chance with a 75% likelihood of being implemented as opposed to two individual repositories; the waste producers still classify such weighting as conservative. The combined repository is an advantageous, likely variant. Results of the advanced field investigations confirm that all three siting regions provide sufficient space for a combined repository layout. This fulfils the same requirements regarding operational and long-term safety as two individual repositories, but also has clear advantages regarding risks in construction, resource consumption and the emission of greenhouse gases as fewer facilities have to be constructed and operated at the surface and below ground. Compared to two individual repositories, realising a combined repository is thus linked to operational, safety-based and ecological advantages (see Section 3.1.1). In addition, the public also perceives the combined repository as the likely repository variant.

Tab. 7.2-4 shows that the future initial costs make up around 54% of the total costs and that around 2% of the total costs are applied for future measures for risk reduction. The future base costs amount to 57% of the overall costs, and the accrued costs amount to around 14% of the overall costs. The total activated reserves and deductions for inaccuracies, risks and chances amount to around 52% of the future base costs.

Tab. 7.2-4: Detailed presentation of the total costs for the HLW and L/ILW repositories and the variant combined repository as well as the total costs taking into account the combined repository variant as a chance

Information in CHF million according to swissnuclear (2021d); cost breakdown according to the specifications of the Commission.

The realisation of a combined repository as opposed to two individual repositories is considered as a chance with a 75% likelihood of being realised.

The general safety reserve was specified in line with CS16 as the cost calculation method, i.e. cost structures and cost breakdown, have not changed compared to CS16, and the general level of project detail has not changed significantly; this ensures a comparability of the reserve levels with CS16 (Nagra 2021c, Nagra 2021a, 2021d).

Cost division according to specifications of the Commission. The total costs for the disposal of the decommissioning waste in the amount of CHF 119 million (overall costs, individual repositories) and CHF 147 million (overall costs, combined repository) are not included in the figures. The information is based on a 50-year NPP operating lifetime (47 years for Mühleberg NPP). Deviations in amounts are due to rounding.

	HLW repository [CHF million]		**L/ILW repository** [CHF million]		**Total individual repositories** [CHF million]		**Combined repository** [CHF million]	
Accumulated costs [3]	954		747		1,700		1,700	
Future costs from 2021	**6,705**		**3,945**		**10,650**		**9,015**	
Future initial costs	4,291		2,426		6,717		5,693	
Future costs of risk reduction	172		117		289		264	
Future base costs	**4,463**		**2,543**		**7,006**		**5,957**	
Reserves for uncertainties in predictions [1]	20%	885	20%	501	20%	1,386	19%	1,150
Reserves for risks [1]	19%	857	23%	596	21%	1,452	21%	1,234
Deductions for chances [1]	-1%	-58	-1%	-13	-1%	-71	-1%	-71
General safety reserve [1]	12.5%	558	12.5%	318	12.5%	876	12.5%	745
Total reserves on future base costs [1]	50%	2,242	55%	1,402	52%	3,644	51%	3,058
Total costs	**7,659**		**4,692**		**12,350**		**10,715**	
Taking into account of combined repository as chance [2]	-10%	-736	-10%	-490	-10%	-1,226		
Total costs considering combined repository as a chance (75% weighted)	**6,923**		**4,202**		**11,124**			

1) In percentage of future base costs.

2) In percentage of overall costs.

3) Contributions to former GNW: CHF 65 million passed through Nagra, an additional CHF 25 million were directly paid by the utilities to GNW. Total contributions amounting to CHF 90 million are included here.

7.3 Financing

As already presented in Section 7.1, financing of the decommissioning of nuclear installations and the disposal of radioactive waste are regulated by law – on the one hand by the state-controlled Funds and on the other by the obligation of the owners/operators to make their own provisions.

7.3.1 State-controlled funds

The Nuclear Energy Act (Art. 77 KEG) obliges the owners of nuclear installations to make contributions to the Funds to secure the financing of the decommissioning of their installations and the disposal of the waste.

The Decommissioning Fund was established in 1984 to secure the financing of the costs of decommissioning the nuclear installations and the disposal of the resulting waste.

The Waste Disposal Fund, established in 2000, secures the financing of disposal of radioactive waste and spent fuel assemblies after the shutdown of the power plants. The Nuclear Energy Act (Art. 77 Par. 2 KEG) makes a distinction between waste disposal costs that arise during the operation of a nuclear power plant and those arising after shutdown. In line with the Nuclear Energy Act (Art. 82 KEG), the costs arising during operation are met directly by the owners by means of their own monies or reserves.

The two Funds ensure that sufficient financial means are available to cover all decommissioning costs as well as all outstanding disposal costs following the final shutdown[42] of the nuclear power plants.

The two Funds are supervised by the Federal Council (Art. 20 Par. 2 und Art. 29a Par. 1 SEFV).

In addition to the obligation of the owners to make payments into the Funds and to set aside internal reserves, the Nuclear Energy Act foresees further security measures and an obligation to make additional payments (Art. 79-80 KEG).

Funds assets and development of returns on investment

Tab. 7.31 shows the capital in the Decommissioning and Waste Disposal Funds and the target assets of the Funds as per 31.12.2020 according to the annual reports of the two Funds (see STENFO 2021a).

[42] The final shutdown of a nuclear power plant is defined as the final cessation of operation. For the 2021 Cost Study, the final cessation of operation is thus assumed as the starting point for the use of monies from the Waste Disposal Fund. In addition, the Decommissioning Fund secures the decommissioning costs prior to the final cessation of operation.

Tab. 7.3-1: Status target-actual Funds assets as per 31.12.2020 (in CHF million)

	Decommissioning Fund	**Waste Disposal Fund**
Target amount per 31.12.2020 with a return on investment of 3.5%	2,623	5,361
Actual amount per 31.12.2020 after effective return	2,822	6,030
Excess/(shortfall)	198	669
Excess/(shortfall)	7.55%	12.49%

Tab. 7.3-2 shows the annualised return on investment of the Decommissioning and Waste Disposal Funds achieved since the first deposit in the Funds up to 31.12.2020 compared to the target return on investment according to STENFO (2021a).

Tab. 7.3-2: Historical annualised return on investment achieved since the establishment of the Funds compared to the return on investment according to STENFO (2021a), Sections 2.2, 3.2 and 3.3

STENFO changed the comparison basis in the business year 2020 (STENFO 2021a). Historical returns are no longer compared to the current regulations on "budgeted values" but on a time-weighted average of past stipulations ("target values"). In line with the stipulations of Art. 8a Par. 2 and Appendix 1 SEFV, these "target values" result from the time-weighted average of the return on investment and inflation (2002 – 2014: return on investment 5%, inflation 3%; as of 2015: return on investment 3.5%, inflation 1.5%, real return unchanged at 2%; as of 2020: return on investment 2.1%, inflation 0.5%, real return 1.6%).

Decommissioning Fund

	Effective values 1.1.1985 – 31.12.2020	**Target values**	**Difference**
Return of portfolio	4.88% (p.a.)	4.71% (p.a.)	0.17% (p.a.)
Minus inflation	0.7% (p.a.)	2.72% (p.a.)	-2.02% (p.a.)
Real return of portfolio	4.18% (p.a.)	1.99% (p.a.)	2.19% (p.a.)

Waste Disposal Fund

	Effective values Q1 2002 – 31.12.2020	**Target values**	**Difference**
Return of portfolio	3.95% (p.a.)	4.45% (p.a.)	-0.50% (p.a.)
Minus inflation	0.27% (p.a.)	2.47% (p.a.)	-2.20% (p.a.)
Real return of portfolio	3.68% (p.a.)	1.98% (p.a.)	1.70% (p.a.)

7.3.2 Financial provisions of the owners

Before shutdown, the arising costs are either paid directly by the facility owners or from reserves.

The expenditure associated with post-operation is considered part of the operational costs. These are also to be borne by the owners in accordance with the polluter pays principle anchored in the Nuclear Energy Act (Art. 31 Par. 1 KEG). Post-operation costs are financed directly by the owners.

7.3.3 Reserves for costs before shutdown

Based on the cost studies, the owners put aside financial reserves for costs arising before shutdown. Their external auditors check whether the reserves created prior to shutdown are at least as high as the reserves plan approved by the Funds Commission and whether the monies are being used as earmarked (Art. 82 Par. 2 Letter c KEG). The owners must submit the audit reports to the Commission (Art. 19 Par. 2 SEFV).

8 Collaboration and information concept

Key differences between WMP16 and WMP21

The information concept presented in WMP21 differs only slightly from that presented in WMP16. Nagra communicates actively and in a timely manner with all stakeholders, both through the bodies set up under the Sectoral Plan and directly. It also supports the authorities in carrying out their legal mandate to inform and communicate, and addresses its communication directly and indirectly at politicians, the siting regions and the broader public. The chapter on collaboration and the information concept was re-structured for WMP21 and assigns greater importance to outlining implementation measures and instruments. These were also adapted or further developed to meet the current needs of the regions as well as those of public media target groups (e.g. digital channels and the increased use of visual communication).

8.1 Background and mandate

Switzerland will dispose of its radioactive waste in deep geological repositories. This principle is anchored in the Nuclear Energy Act. The Federal Government will determine the most suitable site in Switzerland within the framework of the site selection process (Sectoral Plan for Deep Geological Repositories). The lead authority in this process is the Swiss Federal Office of Energy. Nagra's principal tasks in the Sectoral Plan process are to develop a siting proposal in line with regulatory requirements and to prepare the documents to be submitted for the general licence application for the repositories. For the safe, societally acceptable disposal of radioactive waste to succeed in the long term, goal-oriented collaboration of the actors and transparent, comprehensible information are indispensable during the Sectoral Plan process and beyond.

The conceptual part of the Sectoral Plan clearly regulates the roles of the contributing actors and their **collaboration**. In accordance with these regulations, Nagra works together with the licensing and regulatory authorities and also reports regularly on how the work is progressing. In addition, participatory collaboration is anchored in the Sectoral Plan process. Its purpose is not only to inform the affected siting regions on issues related to spatial development across regional and national borders but also to effectively involve them via the regional conferences. Nagra is also engaged in this collaboration, particularly in connection with the discussions surrounding the process to determine the areas for the required surface infrastructure.

The legislators already assigned great importance to **communicating and informing** the public when developing the Nuclear Energy Ordinance. In the explanatory report of 6th April 2004 on the Nuclear Energy Ordinance (KEV 2004), the following was underlined: *"Public communication and transparency play a key role in a politically sensitive area such as nuclear waste management. In their Waste Management Programme, the waste producers therefore have to provide details of their information strategy."* A mandatory status was assigned to the important role of information and communication in Art. 74 KEG, addressing the authorities in particular. As a result, the conceptual part of the Sectoral Plan BFE 2008, Section 2.3.1) attached equivalent weight to communication and information. Specifically, these are mentioned as follows: *"In the Sectoral Plan process, importance is attached to information and communication – an acknowledgement that providing open and transparent information is essential for successful implementtation of the site selection process. The work that will be carried out in the three stages and the decisions made, together with justification of these decisions, must be traceable and transparent."*

In line with the Aarhus Convention ratified and put into effect by Switzerland, collaboration and communication are also carried out across borders. The Convention stipulates that environmentally relevant activities must be communicated in an appropriate and timely manner and the public must be involved from an early stage. In addition, Sectoral Plan requirements ensure that neighbouring countries are included in the process and kept informed.

In accordance with its task of providing relevant technical contributions to the Sectoral Plan process and to safe disposal, Nagra considers itself obliged to become involved in this collaboration process as a judicious partner and to support the authorities in their communication and information mandate within the framework of its technical responsibility for the project. Nagra also commits itself to covering the distinctive information needs of the siting regions and of the media and political public – both in Switzerland and abroad. Great emphasis is thus placed on transparent communication that is tailored to the corresponding target groups. Nagra has anchored these principles in its mission statement and code of conduct. To realise this communication goal, it applies suitable and effective measures and instruments (cf. Section 8.3).

8.2 Objectives and content of Nagra's public outreach activities

The aim of Nagra’s public outreach approach is to ensure that Nagra's activities, results and proposals as part of the Sectoral Plan process and beyond can be understood by the respective stakeholders, both by the scientific community and by society in general. In addition, it seeks to acknowledge and discuss the concerns and questions of the actors, especially from the affected regions, and to include these in the process whenever possible. With this approach, Nagra aims to contribute to an objective discussion with politicians and the regions in the narrower sense and the public in the broader sense. The aim is to promote a joint sense of responsibility for the safe disposal of radioactive waste in Switzerland.

Nagra therefore collaborates directly with the actors involved in the Sectoral Plan and communicates actively and without delay, either directly or through the Sectoral Plan bodies. It also supports the authorities with their legal mandate to inform and communicate. In addition, Nagra directly and indirectly addresses politicians, the siting regions and the broader public.

In terms of content, Nagra’s public outreach is oriented towards the progress of the Sectoral Plan process and research activities, but also towards a more general need for information regarding the waste to be disposed of, the concept of deep geological disposal, the future realisation of the repository and the corresponding societal issues. In the ongoing Stage 3 of the Sectoral Plan process, the selection of the sites for which general licence applications will be prepared (around 2022), the submission of these applications (around 2024) as well as statements and expert opinions surrounding the decision-making process until the granting of the general licence are important communication milestones. The public could interpret the announcement of the site for which a general licence application will be prepared as the actual "site selection". Under the lead of the Swiss Federal Office of Energy, a communication process and communications means were established with the involved actors to communicate the announcement in a transparent manner. This included the point that the documentation for the general licence is not yet available and that, even after submitting the general licence application, a lengthy phase will follow during which the authorities and cantons will prepare their expert opinions and position statements before, probably around 2029, the Federal Council will decide on the site selection and grant the general licence.

8.3 Implementing public outreach: measures and instruments

To achieve the objectives set out in Section 8.2 and to be able to communicate and discuss the above-mentioned content, Nagra applies the following combination of measures and instruments in the ongoing phase:

- In accordance with the requirements, Nagra collaborates with the actors in the Sectoral Plan process. It regularly and transparently informs authorities, bodies and regional conferences about the progress of work and all relevant information surrounding site selection and radioactive waste disposal. Nagra involves itself in the Sectoral Plan process as a judicious and reliable discussion partner.
- All Nagra Technical Reports (NTBs) and – if relevant – Nagra Work Reports (*Arbeits-berichte*, NABs) are continuously made available publicly. In Stage 3 of the Sectoral Plan, and in accordance with the concept of submitting reference reports for the general licence applications to ENSI (Nagra 2019a) at an early stage, the reports on field investigations (deep boreholes) are published as soon as they become available. All relevant information and results are made available in the expert exchange with authorities and bodies as well as with the scientific community.
- Nagra supports the authorities in their legal mandate to provide information within the framework of the Sectoral Plan process in the narrower sense, e.g. at information events, media events or the training modules organised by the Swiss Federal Office of Energy. Nagra is also involved in the Information and Communication Working Group of the Swiss Federal Office of Energy and ENSI's Technical Forum on Safety.
- In addition, interested members of the broader public are kept informed about Nagra's work and other disposal-related issues via contemporary media relations, the most popular digital channels (website, blog, Facebook, Twitter) and printed brochures. Interested parties can also subscribe to Nagra's electronic newsletter.
- In addition, Nagra uses the following instruments to meet the special information and discussion needs of political bodies and the siting regions:
  - Nagra regularly provides current information on its work results and radioactive waste disposal on a federal, cantonal and local level. This ranges from providing brief informa-tion to organising visits to nuclear facilities in Switzerland and abroad ("fact-finding trips"). Local authorities are also involved in the procedure and kept informed through the regional conferences.
  - Opportunities to visit Nagra's field investigations (e.g. deep boreholes) in the siting regions: this is a valuable platform for providing information on the status of the work and insights gained and also offers opportunities to engage in dialogue with the interested public in the regions. Anyone from outside the regions is, of course, also welcome to register for a visit.
  - Participation at events and trade fairs in or close to the siting regions: at these events, Nagra offers an additional platform for personal dialogue. Visitors can obtain information on the current status of work, obtain a glimpse of what a future repository might look like using 3D visualisation and discuss their questions with Nagra staff.

  - Nagra provides the siting communities with up-to-date information on regional issues related to Nagra's work for publication on their information platforms or websites.
  - Nagra staff regularly participate at public events or, on invitation, at events organised by interested groups and organisations (e.g. panel discussions or annual meetings). Depending on the nature of the event, Nagra will either inform participants or engage in dialogue with them.

- Interested individuals or groups can get in touch with Nagra at any time (info@nagra.ch) and register for a tour where they can "look over Nagra's shoulder" or obtain information. Specifically, this is possible at the following venues:
  - Registration for a tour of the Grimsel Test Site (Nagra) or the Mont Terri Rock Laboratory (swisstopo): www.nagra.ch/de/events: At these locations, visitors can experience first-hand the research and development work being carried out and discuss questions with the staff on site. Every year, Nagra organises several open days for the interested public at the two underground rock laboratories.
  - Requests for presentations or participation at events under www.nagra.ch/de/kontakt: On request, Nagra staff will make presentations on nuclear waste management and Nagra's ongoing activities and projects to interested sectors of the population, organisations, political parties, associations or the general public. Nagra participates actively in podium discussions and similar events.
  - Information from Nagra's technical experts by telephone or written correspondence
- Exchange, technical conventions and conferences: Nagra staff regularly present their work to the scientific community at conferences and workshops. Key results are published in recognised technical journals.
- Nagra also follows international developments in the area of public outreach and communication with different target groups. To this end, it maintains an active exchange with organisations from other countries performing similar work. For several years, Nagra has been represented in the Forum on Stakeholder Confidence of the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD).

Within the framework of evaluating WMP16, the Federal Council found that the NPP operators and their shareholders are barely perceived as waste producers in the public eye. For this reason, it has highlighted the responsibility of the NPP operators and cantons with regard to site selection and radioactive waste disposal and called for them to exercise their role pragmatically and appropriately. Appendix A.8.9 outlines how the operators of the nuclear power plants have responded to the considerations of the Federal Council and to meeting their demands.

9 Conclusions

Switzerland has already taken important steps towards realising radioactive waste disposal and has vast experience with the related activities. This applies to the treatment and packaging of radioactive waste, its characterisation and inventorying as well as interim storage and associated transport. In preparation for the deep geological repositories, the disposal feasibility of all radioactive waste arising in Switzerland has been demonstrated and confirmed by the Federal Council. The repository concepts, required work, time schedule and financing are also known and will enable the long-term and safe deep geological disposal of Switzerland's radioactive waste.

This Waste Management Programme documents the boundary conditions and basic procedure for the timely realisation of the required repositories for safe, long-term disposal, highlights the progress made in the last years and provides information on the range of topics listed in the Nuclear Energy Ordinance (KEV 2004) It also includes a proposal for the repository design at a conceptual level together with the individual steps towards realisation, an outline of the realisation plan and an assessment of the required financing.

The legal regulations are in place and organisational arrangements have been made for implementing the activities planned for disposal in the upcoming years. This includes, in particular, the Sectoral Plan for Deep Geological Repositories (SGT) approved by the Federal Council in 2008; this regulates the current siting procedure in detail (BFE 2008). In addition, Guideline ENSI-G03 was revised (ENSI 2020b) and the requirements for Stage 3 were specified more precisely (ENSI 2018c).

As part of Stage 1 of the Sectoral Plan, Nagra proposed six potential geological siting regions, which were confirmed by a decision of the Federal Council in 2011. In conclusion of Stage 2 of the Sectoral Plan, in 2018 the Federal Council approved focusing on the Opalinus Clay as the host rock and decided that the Jura Ost (JO), Nördlich Lägern (NL) and Zürich Nordost (ZNO) siting regions are to be further investigated in Stage 3. In addition, and based on close collaboration with the siting regions and cantons the siting areas for the surface facilities were designated by the Federal Council. Extensive field investigations (3D seismics, Quaternary boreholes, deep boreholes) have been conducted as part of the ongoing Stage 3 of the Sectoral Plan. Results of the field investigations to date confirm the suitability of all three siting regions; these also have sufficient space for a combined repository layout.

The work programme for the coming years is clearly defined. Based on the results of field investigations and additional insights, Nagra is expected to announce the sites for which it will prepare general licence applications in line with the Sectoral Plan (BFE 2008) in 2022. This also includes the announcement of whether a combined repository or two individual repositories will be realised. Realising a combined repository is associated with operational, safety-related, ecological and economic advantages. It is an overall facility, and many elements of the surface infrastructure and some of the underground structures (access structures and central area) can be jointly used. Compared to two individual repositories, realising a combined repository thus leads to important simplifications for construction and operation; it can also be seen as more positive with regard to the licensing procedure and collaboration. Based on the advantages outlined above, and if the overall safety-based assessment allows, a general licence application will be submitted for a combined repository.

The site selection will be recorded as part of the documents for the safety-based comparison to be submitted along with the general licence application in 2024. This will include information on the available options with regard to the safety of the planned repository, an evaluation of the properties that were decisive for site selection, and cost information.

In Stage 3 of the Sectoral Plan, Nagra showed that the encapsulation plant for spent fuel assemblies can be constructed either at the Zwilag interim storage facility or at the surface facility at the repository; these are the only sensible siting variants, and a transregional working group has supported this finding. Based on the results of this collaboration, Nagra will publish preliminary planning studies for the surface infrastructure for selected sites as part of the preparation for the general licence application. These form the basis for the subsequent collaboration with the siting regions and cantons to clarify issues regarding the surface infrastructure. Nagra can then prepare the required documents for the general licence application (Environmental Impact Report, report on coordination with spatial planning). In connection with these, the purpose and basic layout of the facilities are determined (approximate size and location of the key surface structures).

The current realisation plan assumes that the general licence application will be submitted in 2024. As a result, it can be assumed that, within the framework of the 2026 Waste Management Programme, specific information on the realisation of a site-specific repository project can be outlined for the first time.

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Appendix A

A.1 Compilation of key legal requirements and official guidelines for the design and implementation of deep geological repositories in Switzerland

Tab. A.1-1: Requirements from the Nuclear Energy Act (KEG), Nuclear Energy Ordinance (KEV) and Guideline ENSI-G03

The Waste Management Programme 2021 was prepared on the basis of current legislation as of 31st October 2021. The requirements of the KEG (2003) and KEV (2004) are concretised in Guideline ENSI-G03 (ENSI 2020b). The following list is not exhaustive. In addition to the KEG, KEV and Guideline ENSI-G03, many other relevant laws and guidelines are in place (e.g. with regard to environmental protection, nuclear installations and the Sectoral Plan process).

Requirements	**Reference**
Deep geological repositories: general information	
Any person who operates or decommissions a nuclear installation is obliged to safely manage all radioactive waste arising from that installation at their own cost.	KEG Art. 31
Radioactive waste shall be managed in such a manner as to ensure the permanent protection of humans and the environment. With deep geological disposal, radioactive waste must be managed in such a way that no unreasonable burdens and obligations are imposed on future generations. These two provisions are defined as "protection objectives".	KEG Art. 1, 3, 13, 16, 20 & 30 Par. 3 and ENSI-G03 Section 4.1
Deep geological repositories: site selection and safety case	
All radioactive waste produced in Switzerland shall, as a general rule, be managed in Switzerland.	KEG Art. 30 Par. 2
A licence for the export of waste for storage or disposal may be granted by way of exception if specific conditions have been fulfilled and if the exporter has entered into a binding agreement with the importer of the radioactive waste that has been approved by an authority designated by the Federal Council, and which stipulates that the exporter shall take back the consignment if necessary.	KEG Art. 34 Par. 4
The Federal Government shall specify in a sectoral plan the objectives and criteria for the disposal of radioactive waste in deep geological repositories which are legally binding for the relevant authorities.	KEV Art. 5
The requirements for selecting repository sites for all waste categories are specified in the conceptual part of the Sectoral Plan for Deep Geological Repositories (BFE 2008).	ENSI-G03 Section 3
The results of the underground geological investigations must confirm the suitability of the repository site.	KEG Art. 13 Par. 1g
The risks that arise in the future from deep geological disposal must not be greater than those currently permitted in Switzerland.	ENSI-G03 Sections 4.2 b-c
The site for a deep geological repository must have the following properties to ensure long-term safety: a. sufficient extent of suitable host rock b. favourable hydrogeological conditions c. long-term geological stability.	KEV Art. 11 Par. 1 and KEV Art. 63

Tab. A.1-1: (cont.)

Requirements	**Reference**
Deep geological repositories: site selection and safety case (cont.)	
Quantitative protection criteria are used to determine whether the protection objective has been fulfilled, taking the design principles into consideration (see below). Compliance with the protection criteria must be demonstrated within the framework of the safety case. The safety case for the post-closure phase is to be based on the results of a comprehensive safety analysis that investigates the long-term behaviour of a deep geological repository and the resulting safety-relevant impacts.	ENSI-G03 Sections 4.3 & 9
The quantitative protection criteria for the post-closure phase are specified in Guideline ENSI G-03.	ENSI-G03 Section 4.3.2
The safety case must provide information on the reliability of the statements made and on the relevance for safety of uncertainties.	ENSI-G03 Section 9.3b
ENSI-G03 lists specific provisions for the safety analyses, including but not limited to: demonstration period, assumptions on climate evolution and human living habits, developments not to be considered and handling uncertainties.	ENSI-G03 Section 9.3
The complete containment of high-level waste in the disposal canisters for at least one thousand years following emplacement must be demonstrated.	ENSI-G03 Section 4.4e
Deep geological repositories: waste allocation and acceptance conditions	
For the purposes of management and disposal, radioactive waste is classified into categories.	KEV Art. 51
The documents for the general licence application [the purpose and main features of the project] include, in particular, the categories of the waste for disposal and the maximum disposal capacity.	KEV Art. 23 and KEG Art. 14 Par. 2
The documents for the construction licence application include facility concepts and design principles as well as disposition plans and concepts for radiological zones.	KEV Appendix 4
The operating licence specifies the levels of start-up that require a permit from the relevant supervisory authority prior to commencement of operation of the installation. Acceptance conditions are to be issued. A release obligation exists in particular for the initial emplacement of waste packages of a given type.	KEG Art 21, KEV Art. 29 Par. 1 and ENSI-G03 Sections 7.2a-d
The operating licence specifies requirements, in particular activity limits of the waste to be disposed of.	KEG Art. 37 Par. 3
The documentation for securing the knowledge of the repository in the long term includes the inventory of emplaced waste, with types and volumes divided according to emplacement rooms.	KEV Art. 38 Par. 2 and KEV Art. 71
Deep geological repositories: conceptual design	
To ensure safety, all measures deemed necessary in the light of experience and the state of the art in science and technology must be taken. Precautions that contribute to further reducing the risk (protective measures) are to be taken to the appropriate extent.	KEG Art. 4 & 5 and KEV Art. 7
A deep geological repository must be designed in such a way as that, after its closure, no further measures are required to ensure long-term safety.	ENSI-G03 Section 4.2a

Tab. A.1-1: (cont.)

Requirements	**Reference**
Deep geological repositories: conceptual design (cont.)	
For geological repositories, the operating licence is granted if, in addition to the conditions stated in Art. 20 Par. 1 KEG: a. the findings obtained during construction confirm the suitability of the site b. the radioactive waste can be retrieved without undue effort until closure of the repository.	KEG Art. 37 Par. 1 and ENSI-G03 Section 7.4
Safety functions must remain in effect even if any type of individual error occurs, independent of the triggering event. They must be redundant. Passive measures are preferable to active safety functions. Sufficient safety allowances must be taken into account in the design.	KEV Art. 10 Par. 1
A deep geological repository must be designed in such a way that: a. it complies by analogy with the principles of Art. 10 Par. 1 KEV [for the design of nuclear power plants, see above] b. long-term safety is ensured via multiple passive safety barriers c. measures taken to facilitate monitoring and repair of the repository or to retrieve the waste in no way impair the effectiveness of the post-closure performance of the passive safety barriers d. the repository can be closed within a period of several years.	KEV Art. 11 Par. 2 and ENSI-G03 Sections 5.1e, 5.2.2, 6.1 & 7.3
The general licence sets out criteria which, if not fully met, lead to the exclusion of a planned disposal area due to lack of suitability.	KEG Art. 14 Par. 1 Letter f
A repository and its surface facilities shall be designed in such a way as to implement the guidelines for achieving the protection objective and for complying with the protection criteria. The principles of nuclear safety and security laid down in nuclear energy legislation apply. ENSI-G03 specifies general requirements as well as requirements for design of the surface facilities and auxiliary access facilities, including the transloading cell and the underground structures.	ENSI-G03 Sections 5.1 & 5.2
A deep geological repository must be designed in such a way as to prevent negative impacts on the engineered and natural barriers relevant for the long-term safety due to repository-induced effects (e.g. heat production, build-up of gas pressure, chemical interactions) or by hazards from the rock itself.	ENSI-G03 Sections 5.2.2 & 7.2f
Duty to optimise: safety-relevant decisions are to be made within the framework of an optimisation procedure. At every step of the realisation process and for every safety-relevant decision, different alternatives and their significance for long-term safety must be considered in a qualitative manner and a decision made that, considered overall, favours safety.	ENSI-G03 Section 4.4
An integral, stage-appropriate monitoring programme must be developed for the construction, operational and, if applicable, post-closure phases of a deep geological repository. Monitoring of a deep geological repository and its geological surroundings must be conducted in a timely manner, starting at the latest with the general licence, and must continue until the repository is no longer subject to nuclear energy legislation.	ENSI-G03, Section 6.1

Tab. A.1-1: (cont.)

Requirements	Reference
Deep geological repositories: design (cont.)	
A concept for the potential retrieval of radioactive waste must be submitted along with the general licence application, and must be concretised and continuously updated in subsequent licensing steps. Documentation on the deep geological repository must include information on interim storage insofar as this is relevant for potential retrieval of the waste.	ENSI-G03 Sections 7.4.2 & 11i
A deep geological repository comprises a main repository for emplacement of the radioactive waste, a pilot repository and test areas.	KEV Art. 64
The purpose of the test areas is to clarify the safety-relevant properties of the host rock in order to substantiate the site-specific safety case. The retrieval technology and the functioning of the measures for temporary closure prior to waste emplacement must also be demonstrated in the test areas.	KEV Art. 65 Par. 1 and ENSI-G03 Sections 7.4.2, 7.5 & Appendix 1 "Test areas"
During repository operation, the sealing of caverns and drifts in the test areas must be tested and shown to be functional.	KEV Art. 65 Par. 3
In the pilot repository, the behaviour of the waste, backfill and host rock must be monitored until the expiry of the monitoring phase.During monitoring, data must be collected in order to confirm long-term safety with a view to closure.. The design of the pilot repository must consider a monitoring programme for the temporal evolution of the pilot repository and its geological environment. Prior to waste emplacement in the main repository, the pilot repository must be filled with waste, backfilled and sealed.	KEV Art. 66 Par. 1 and ENSI-G03 Section 6.2
The monitoring results [from the pilot repository] must be applicable to the processes in the main repository. They form the basis for the decision on repository closure.	KEV Art. 66 Par. 2
When designing the pilot repository, the following principles must be observed: a. The geological and hydrogeological conditions must be comparable to those of the main repository b. The pilot repository must be spatially and hydraulically separated from the main repository c. The construction method of the pilot repository and the emplacement and backfilling methods must correspond to those applied in the main repository d. The pilot repository must contain a small representative amount of waste.	KEV Art. 66 Par. 3
Incidents in the pilot repository may not adversely affect the operational and long-term safety of the main repository and vice versa. Any transfer of waste from the pilot repository to the main repository should be taken into account in the design.	ENSI-G03 Sections 6.2b& d
Deep geological repositories: specific requirements for the underground geological investigations	
The licensing procedure is specified in the KEV.	KEV Art. 58-61
Geoscientific investigations must be conducted in such a way as to allow reliable statements to be made on the operational and long-term safety of a deep geological repository. They may not have a negative impact on the long-term safety of the repository. The construction licence application must demonstrate a sufficient safety distance between safety-relevant sections of the repository and the facilities for underground geological investigations.	ENSI-G03 Section 7.1

Tab. A.1-1: (cont.)

Requirements	**Reference**
Deep geological repositories: specific requirements for planning and construction	
ENSI-G03 lists specifications regarding planning and construction of the underground structures, the surface facility and the auxiliary access facilities.	ENSI-G03 Section 8
Deep geological repositories: specific requirements for operation	
The operating licence specifies the safety, security and emergency measures to be taken by the licence-holder during operation.	KEG Art. 21
The general obligations of the operating licence holder (including operational safety) are listed in the KEG.	KEG Art. 22
ENSI-G03 lists requirements for operating a repository, including provisions for monitoring, emplacement and ongoing backfilling of the HLW drifts as well as for sealing emplacement caverns and emplacement drifts.	ENSI-G03 Sections 6.1, 7.2 & 7.3
ENSI-G03 lists basic requirements, stipulations and protection criteria as well as a safety demonstration for the operational phase.	ENSI-G03 Sections 4.3.1, 5.1 and 9.2
Radiological protection during the operational phase of a deep geological repository and its associated surface facilities must be optimised in accordance with the Radiological Protection Ordinance (Art. 4 StSV) taking into account any effects on long-term safety.	ENSI-G03 Par. 4.4d
Preventive and protective measures must be taken to avoid accidents in nuclear installations that may originate either within (internal) or outside (external) the installation	KEV Art. 8
The safety demonstration for the operational phase must be supported by comprehensive safety analyses for both normal operation of the facility and for the impact of incidents or accidents. Safety analyses must be conducted in accordance with the current regulations for nuclear installations, in particular Art. 8 of the KEV, the DETEC Ordinance (UVEK 2009) and Guidelines ENSI-A01 (ENSI 2018f), ENSI-A05 (ENSI 2018d), ENSI-A08 (ENSI 2010) and ENSI-G14 (ENSI 2009).	ENSI-G03 Sections 5.1 & 9.2
Waste must be (partially) retrieved if, during the operational phase, safety can no longer be demonstrated, and an effective repair of the safety barriers is impossible.	ENSI-G03 Section 7.4
Technical and operational measures must be taken for temporary closure to allow the emplacement areas of a repository to be converted into a passively safe state at any time during the operational phase. Temporary closure must be presented in a concept to be submitted together with the construction licence application.	ENSI-G03 Section 7.5
Deep geological repositories: specific requirements for the monitoring phase and closure	
The owner of a deep geological repository must backfill the caverns and drifts after the waste packages have been emplaced. Long-term safety must be ensured and the retrieval of the waste must remain possible without undue effort. As part of the closure process, the owner must backfill all remaining open parts of the repository and seal those parts that are essential to long-term safety and security.	KEV Art. 67 & Art. 69 Par. 1

Tab. A.1-1: (cont.)

Requirements	**Reference**
Deep geological repositories: specific requirements for the monitoring phase and closure (cont.)	
Once emplacement of the radioactive waste has been completed, the owner must update the project for the monitoring phase and the closure plan. The Federal Council orders closure work after the end of the monitoring phase. After proper closure, it may order further, limited monitoring period. After proper closure or after conclusion of the monitoring period, the Federal Council determines that the repository is no longer subject to nuclear energy legislation. The Government may carry out further measures after this time, in particular environmental monitoring.	KEG Art. 39 and KEV Art. 42 & 68 and ENSI-G03 Sections 7.6a-b & Appendix 2
To calculate the costs for the Cost Studies, a 50-year monitoring period is assumed. Based on the updated project for the monitoring period, the repository owner recommends a duration of the monitoring phase, which is then specified by the Department.	SEFV Art. 3 and KEV Art. 68
The closure application must include an updated safety case that takes into account the findings from the monitoring phase. With the application to confirm proper closure, an additional demonstration must be provided for the post-closure phase that considers the effective implementation of the closure procedure.	ENSI-G03 Sections 7.6d-e
Deep geological repositories: documentation, marking and protection zone	
The owner of a deep geological repository must prepare documentation that will ensure suitable long-term preservation of knowledge of the geological repository. The documentation must contain: a. Location and extent of the underground structures b. Inventory of radioactive waste, allocated to the emplacement rooms by type and volume c. Design of the engineered safety barriers, including the sealing of the accesses d. Fundamentals and results of the final analysis of long-term safety. The documentation concept for all phases must be submitted along with the application for the underground geological investigations.	KEV Art. 71 Par. 1 & 2 (see also KEG Art. 38 Par. 2) and ENSI-G03 Section 11f
The requirements for long-term and operational safety must be documented and the transparency of key decisions on deep geological disposal and their consequences regarding long-term safety and operational safety must be assured.	ENSI-G03 Sections 11d-e
The operating licence-holder must maintain complete documentation of the technical installations and operations, modify the safety report and the security report, if necessary, and update the project for the monitoring phase and the closure plan. Construction documentation must be prepared in line with Art. 27 KEV and Guideline HSK-R-08, and the operating documentation must be prepared in line with Art. 14 KEV and Guideline ENSI-G09. For the underground structures, construction and operating documentation must be supplemented according to SIA standard 197.	KEG Art. 22, Par. 2, Letters i & k and ENSI-G03 Section 11g

Tab. A.1-1: (cont.)

Requirements	**Reference**
Deep geological repositories: documentation, marking and protection zone (cont.)	
Monitoring results must be documented in periodic reports and submitted to ENSI. Among other requirements, retained samples must be kept and made available to the authorities upon request.	ENSI-G03 Sections 6.1h-i
The licence-holder must update the organisational and technical documents during the entire operational period of the installation until closure and must adapt them according to the current status of the nuclear installation. He must transparently document operations at all times. The documentation must be safely stored until closure or until expiry of the monitoring period. After closure or after expiry of the monitoring period, it will be handed over to the Department.	KEV Art. 41 and Art. 71 Par. 3
The documentation to be submitted after orderly closure must be delivered at least in triplicate. The long-term durability of the documentation must be demonstrated and the required maintenance and repair measures explained. ENSI-G03 specifies the minimum information which the documentation must contain.	ENSI-G03 Sections 11h-i
The Federal Council determines the criteria for the protection zone. A provisional protection zone is defined when the general licence is granted and reported to the land register office. The zone is definitely established when the operating licence is granted. The Federal Council ensures that the information about the repository, the waste and the protection zone is maintained and the corresponding knowledge is preserved.	KEV Art. 40 and KEV Art. 70
The Federal Council stipulates the permanent marking of the repository.	KEG Art. 40 Par. 7
The owner must present a concept for the marking of the deep geological repository as part of the construction licence application, which must be concretised in subsequent licensing steps.	ENSI-G03 Section 6.3a
Permanent marking may not adversely affect long-term safety and must be taken into account in the safety case.	ENSI-G03 Section 6.3b
Upon closure, the owner of the deep geological repository must ensure that the marking of the deep geological repository is permanent.	KEV Art. 69 Par. 3 c
Deep geological repositories: quality management	
A quality management programme must be prepared for all safety-related work on the project planning, construction, operation, monitoring and closure of a deep geological repository.	KEV Art. 25 & 31 and ENSI-G03 Section 11a-c
Deep geological repositories: security and safeguards	
Security measures must be taken to prevent any interference with the safety of nuclear installations and nuclear materials through unauthorised acts or the theft of nuclear materials.	KEG Art. 5 Par. 3
Systematic security and safeguards assessments are to be performed throughout the lifetime of the facility. The safety and security reports must be adjusted if necessary.	KEV Art. 22 Par. 2 Letters d & i

Tab. A.1-1: (cont.)

Requirements	**Reference**
Deep geological repositories: security and safeguards (cont.)	
Safety-related requirements for securing nuclear installations, including the classification of nuclear materials and radioactive waste, and associated security measures are listed in the relevant legislation.	KEV Art. 9 & Appendix 2, ENSI G-03 Par. 10.1 and UVEK 2008 Par. 2-3
A deep geological repository and the associated surface facility and auxiliary access facilities must be designed in such a way as to allow inspections of fissile materials. The required measures may not impair the long-term safety of the repository.	ENSI-G03 Section 10.2
The operating licence-holder must define material balance zones for those areas in which nuclear materials are located.	Safeguards Ordinance Art. 8 Par. 1
The licence-holder must limit or divide a material balance zone such that the inventory and movement of nuclear materials can be determined at any time.	Safeguards Ordinance Art. 8 Par. 2 and 3
The licence-holder must keep a constantly updated inventory of nuclear materials in each material balance zone and submit the relevant reports to the responsible federal office.	Safeguards Ordinance Art. 9 and 10

A.2 Phases, time periods and relevant topics and activities to be addressed

A.2.1 Overview of phases, time periods and key activities for the combined repository, HLW repository and L/ILW repository projects in line with the realisation plan

Tab. A.2-1: Overview of phases, time periods and key activities for the combined repository in the different phases outlined in the realisation plan in Fig. 5.3-1.

Convention for time periods: from January (start of year) to December (end of year).

Phase	Time period	Objective	Key activities
Site selection	2019 – 2024	Stage 3 of the Sectoral Plan: field investigations, selection of sites for preparation of the general licence application, preparation of general licence application	Execution and evaluation of field investigations, safety-based comparison of the siting regions, siting proposals for the surface infrastructure, preparation of documents for the general licence application
General licence	2025 – 2031	Granting of the general licence	Regulatory review of documents, decision of the Federal Council, approval by Parliament, optional national referendum Borehole at the shaft location
Preparation for underground geological investigations (EUU)	2032 – 2034	Licence for underground geological investigations	Preparation for the construction of the facilities for underground geological investigations Review of application for underground geological investigations, decision of DETEC
Construction of EUU facilities and start of EUU	2035 – 2039	Construction of EUU facilities and start of underground geological investigations	Construction of EUU facilities and start of underground geological investigations (accompanying characterisation during construction of the access structures for the EUU, start of initial experiments in the facilities for EUU; see Tab. A.2-4), preparation of documents for the nuclear construction licence procedure for L/ILW
Continuation of EUU	2040 – 2054	Continuation of underground geological investigations	Setup and execution of experiments underground, and observation (see Tab. A.2-4), syntheses, preparation of evidence based on results of EUU for the nuclear construction and operating licensing procedures for L/ILW and HLW
Nuclear construction licence L/ILW	2040 – 2044	Granting of nuclear construction licence for L/ILW repository section	Review by the authorities of the nuclear construction licence application for L/ILW, decision of DETEC; preparation of documents for the nuclear operating licensing procedure for L/ILW
Repository construction L/ILW	2045 – 2049	Construction of L/ILW repository section	Construction of surface facility (including encapsulation plant) and of underground installations, including equipment

Tab. A.2-1: (cont.)

Phase	Time period	Objective	Key activities
Nuclear operating licence L/ILW	2045 – 2049	Granting of nuclear operating licence for L/ILW repository section	Review of the documentation by the authorities, decision of DETEC, preparation of documents for nuclear construction licensing procedure for HLW
Emplacement operations L/ILW	2050 – 2064	Operation of L/ILW repository section	Delivery of L/ILW waste packages, packaging/emplacement in L/ILW pilot and main repositories, backfilling and closure of emplacement caverns, periodic safety analyses/reporting
Nuclear construction licence HLW	2050 – 2054	Granting of nuclear construction licence for HLW	Review by the authorities of the nuclear construction licence application for HLW, decision of DETEC; preparation of documents for nuclear operating licensing procedure for HLW
Repository construction HLW	2055 – 2059	Construction of HLW repository section	Expansion of surface facility (including HLW encapsulation plant) and of underground installations for HLW repository section, including equipment
Nuclear operating licence HLW	2055 – 2059	Granting of nuclear operating licence for HLW repository section	Official review of the documents, decision of DETEC
Emplacement operations HLW	2060 – 2074	Operation of HLW repository section	Delivery of HLW waste packages, packaging/emplacement in HLW pilot and main repositories, backfilling and closure of emplacement drifts, continuous excavation of new HLW emplacement drifts, periodic safety analyses/reporting
Monitoring phase	2065 – 2124	Monitoring phase	Measurements in pilot repository (L/ILW until 2114; HLW until 2124), further monitoring activities, periodic reporting
	2075 – 2080	Decommissioning/dismantling of nuclear components of the surface facility	Decommissioning and dismantling of the L/ILW and HLW encapsulation plants
Closure of main repository	2085 – 2090	Closure of main repository/partial dismantling of surface facility	Closure of main and pilot repositories including accesses no longer required from the surface to the underground, continuation of dismantling of surface facility (conventional) (see also Section 5.4.2)
Closure of entire repository	2125 – 2126	Proper closure of entire repository	Preliminary work, backfilling and sealing of test areas still in use and of open accesses to the underground facilities Marking the repository, complete dismantling of the surface facilities, site recultivation as needed
Long-term monitoring	> 2126	Environmental monitoring	Possible implementation of measures for environmental monitoring until release of the sealed repository from nuclear energy legislation

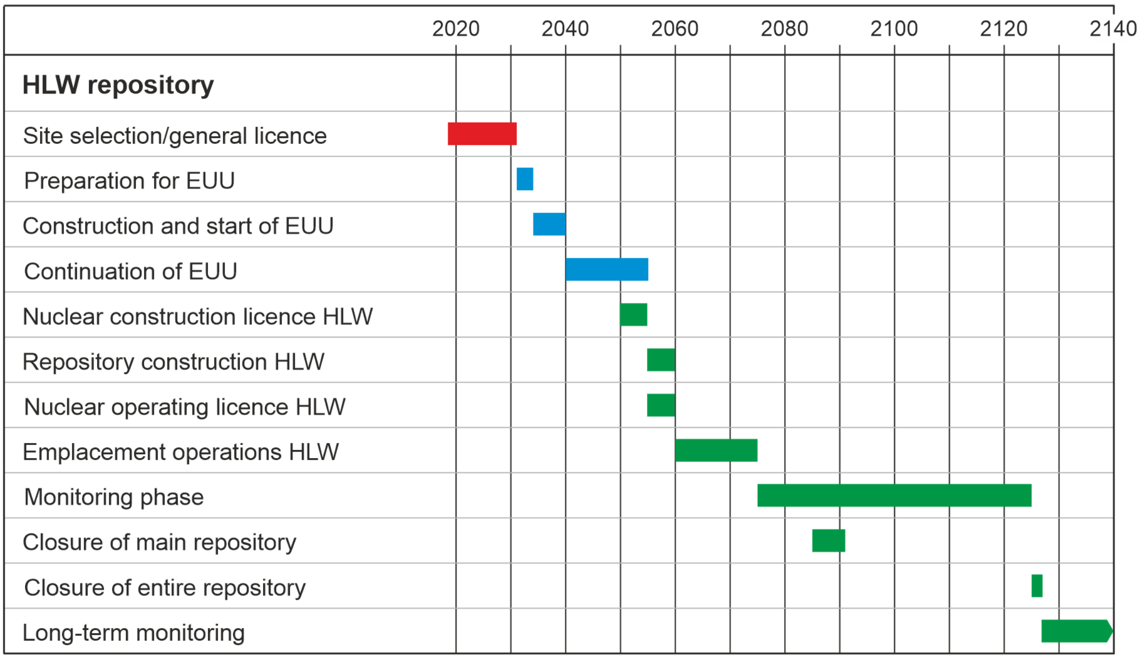

Fig. A.2-1: Realisation plan for the HLW repository based on current planning

Tab. A.2-2: Overview of phases, time periods and key activities for the HLW repository in the various phases outlined in the realisation plan in Fig. A.2 -1

Convention for time periods: from January (start of year) to December (end of year).

Phase	**Time period**	**Objective**	**Key activities**
Site selection	2019 – 2024	Stage 3 of the Sectoral Plan: field investigations, selection of sites for preparation of the general licence application, preparation of general licence application	Execution and evaluation of field investigations, safety-based comparison of the siting regions, siting proposals for the surface infrastructure, preparation of documents for the general licence application
General licence	2025 – 2031	Granting of the general licence	Official review of documents, decision of Federal Council, approval by Parliament, optional national referendum Borehole at the shaft site
Preparation for underground geological investigations (EUU)	2032 – 2034	Approval of underground geological investigations	Construction preparation for the underground geological investigations Review of application for EUU, decision of DETEC
Construction of EUU facilities and start of EUU	2035 – 2040	Construction of EUU facilities and start of underground geological investigations	Construction of EUU facilities and start of EUU (accompanying characterisation during construction of the access structures for the EUU, start of initial experiments in the facilities for EUU; see Tab. A.2-4)
Continuation of EUU	2041 – 2054	Continuation of underground geological investigations	Setup and execution of experiments underground, and observation (see Tab. A.2-4), syntheses, preparation of evidence based on results of EUU for the nuclear construction licensing procedure
Nuclear construction licence HLW	2050 – 2054	Granting of nuclear construction licence for HLW repository	Review by the authorities of the nuclear construction licence application HLW, decision of DETEC; preparation of documents for nuclear operating licensing procedure
Repository construction HLW	2055 – 2059	HLW repository construction	Construction of surface facility (including HLW encapsulation plant) and of underground facilities, including infrastructure
Nuclear operating licence HLW	2055 – 2059	Granting of nuclear operating licence for HLW repository	Official review of the documents, decision of DETEC

Tab. A.2-2: (cont.)

Phase	**Time period**	**Objective**	**Key activities**
Emplacement operations HLW	2060 – 2074	Operation of HLW repository	Delivery of waste packages, packaging/emplacement in pilot and main repositories, backfilling and closure of emplacement rooms, continuous excavation of new HLW emplacement drifts, periodic safety analyses/reporting
Monitoring phase	2075 – 2124	Monitoring phase	Measurements in pilot repository, further monitoring activities, periodic reporting
	2075 – 2080	Decommissioning/dis-mantling of nuclear components of the surface facility	Decommissioning and dismantling of the HLW encapsulation plant
	2085 – 2090	Closure of main repository/partial dismantling of surface facility	Closure of main and pilot repositories including no longer required accesses from the surface to the underground, continuation of dismantling of surface facility (conventional)
Closure of entire repository	2125 – 2126	Proper closure of entire repository	Preliminary work, backfilling and sealing of test areas still in use and of open accesses of the underground facilities Marking the repository, complete dismantling of the surface facilities, site recultivation as needed
Long-term monitoring	> 2126	Environmental monitoring	Possible implementation of measures for environmental monitoring until release of the closed repository from nuclear energy legislation

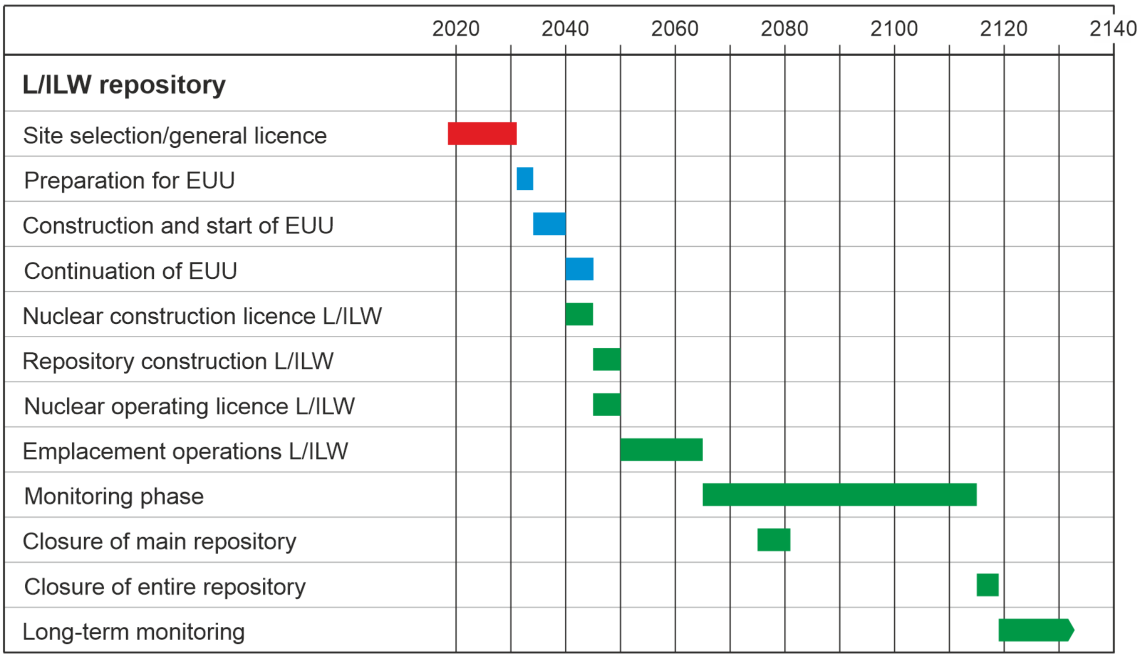

Fig. A.2-2: Realisation timetable for the L/ILW repository based on current planning

Tab. A.2-3: Overview of phases, time periods and key activities for the L/ILW repository repository in the various phases outlined in the realisation plan in Fig. A.2 -2

Convention for time periods: from January (start of year) to December (end of year).

Phase	Time period	Objective	Key activities
Site selection	2019 – 2024	Stage 3 of the Sectoral Plan: field investigations, selection of sites for preparation of the general licence application, generation of general licence application	Execution and evaluation of field investigations, safety-based comparison of the siting regions, siting proposals for the surface infrastructure, preparation of documents for the general licence application
General licence	2025 – 2031	Granting of the general licence	Official review of documents, decision of Federal Council, approval by Parliament, optional national referendum Borehole at the shaft site
Preparation for underground geological investigations (EUU)	2032 – 2034	Approval of underground geological investigations	Construction preparation for the underground geological investigations Review of application for underground geological investigations, decision of DETEC
Construction of EUU facilities and start of EUU	2035 – 2039	Construction of EUU facilities and start of underground geological investigations	Construction of EUU facilities and start of underground geological investigations (accompanying characterisation during construction of the access structures for the EUU, start of initial experiments in the facilities for EUU; see Tab. A.2-4), preparation of documents for nuclear construction licensing procedure
Continuation of EUU	2040 – 2044	Continuation of underground geological investigations	Setup and execution of experiments underground and observation (see Tab. A.2-4), syntheses, preparation of feasibility demonstrations based on results of EUU for the nuclear construction and operating licensing procedures for L/ILW
Nuclear construction licence L/ILW	2040 – 2044	Granting of nuclear construction licence for L/ILW repository	Review by the authorities of the nuclear construction licence application for L/ILW, decision of DETEC; preparation of documents for nuclear operating licensing procedure
Repository construction L/ILW	2045 – 2049	Construction of L/ILW repository	Construction of surface facility (including encapsulation plant L/ILW) and of underground facilities, including infrastructure
Nuclear operating licence L/ILW	2045 – 2049	Granting of nuclear operating licence for L/ILW repository	Official review of the documents, decision of DETEC

Tab. A.2-3: (cont.)

Phase	**Time period**	**Objective**	**Key activities**
Emplacement operations L/ILW	2050 – 2064	Operation of L/ILW repository	Delivery of waste packages, packaging/emplacement in pilot and main repositories, backfilling and closure of emplacement rooms, periodic safety analyses/reporting
Monitoring phase	2065 – 2114	Monitoring phase	Measurements in pilot repository, further monitoring activities, periodic reporting
	2065 – 2070	Decommissioning/dis-mantling of nuclear components of the surface facility	Decommissioning and dismantling of the L/ILW encapsulation plant
	2075 – 2080	Closure of main repository/partial dismantling of surface facility	Closure of main and pilot repositories including no longer required accesses from the surface to the underground, continuation of dismantling of surface facility (conventional)
Closure of entire repository	2115 – 2118	Proper closure of entire repository	Backfilling and sealing of test areas still in use and open accesses, marking the repository, complete dismantling of the surface facilities, site recultivation as needed
Long-term monitoring	> 2118	Environmental monitoring	Possible implementation of measures for environmental monitoring until release of the closed repository from nuclear energy legislation

Tab. A.2-4: Presentation of a potential programme for underground geological investigations for the combined repository (for details, see Nagra 2021a, 2021e)

Convention for time periods: from January (start of year) to December (end of year).

The programme is based on the following assumptions: construction of the EUU facilities is staggered and can proceed without relevant geological surprises; under these circumstances, initial experiments can start from 2038. From 2040, these experiments will be supplemented by further specific investigations with a view to the nuclear construction licence and by long-term experiments. From 2043, safety-relevant technologies will be tested and their functional capability demonstrated with a view to the start of operation of the repository. In addition, long-term experiments are continued in the test areas as required. It is assumed that the investigations in the EUU facilities and the test areas are representative for the repository and that the experiments will not reveal surprises that could question the suitability of the site.

Phase	**Time period**	**Task**	**Key activities with associated objectives (Ch, CS, M, D)** (Ch) Characterisation of the geological situation (CS) Confirmation of suitability with regard to previous assumptions and parameters (M) Monitoring (D) Demonstration
Preparation of EUU application	2029 – 2031	Exploratory borehole at the shaft site	• Characterisation of the geological situation for the construction of the EUU access structures (Ch)
Preparation for EUU	2032 – 2034	Preparation for construction	• No underground activity
Construction of EUU facilities and start of EUU	2035 – 2039	Accompanying characterisation during excavation of underground access	• Characterisation during construction of EUU access structures, central area and EUU facilities (mapping and sampling): includes geotechnical, hydrogeological and hydrogeochemical aspects (Ch) • Monitoring under in-situ conditions (M)
Initial EUU experiments	2038	Start of initial experiments in the EUU facilities	• Characterisation of the underground geological situation at the disposal level, including spatial variability (Ch, CS) • Start of experiments to confirm rock-mechanical parameters and suitability of technical elements (e.g. tunnel support) with a view to repository construction (Ch, CS) • Start of experiments on gas release via the host rock (gas test) (CS) • Start of experiments on migration (diffusion tests) (CS) • Monitoring under in-situ conditions (M)

Tab. A.2-4: (cont.)

Phase	**Time period**	**Task**	**Key activities with associated objectives (Ch, CS, M, D)** (Ch) Characterisation of the geological situation (CS) Confirmation of suitability with regard to previous assumptions and parameters (M) Monitoring (D) Demonstration
Continuation of EUU for L/ILW & HLW	2040 – 2044	Continuation of experiments in EUU facilities with a view to the nuclear construction licences for L/ILW and HLW	• Continuation of ongoing experiments (CS) • Self-sealing (development, geometry and hydraulic properties of the excavation-damaged zone) (CS) • Effects of heat on host rock (heater test) (CS) • Monitoring under in-situ conditions (M) • Demonstration of sealing (D) • Demonstration tests for emplacement (including introduction of backfill materials) and retrieval of L/ILW waste packages (D)
Continuation of EUU for HLW	2045 – 2054	Continuation of experiments in EUU facilities with a view to the nuclear construction licence for HLW	• Continuation of experiments to confirm suitability for HLW (CS) • Monitoring under in-situ conditions (M) • Demonstration tests for emplacement (including introduction of backfill materials) and retrieval of HLW waste packages (D)
Repository construction L/ILW	2045 – 2049	Construction of L/ILW repository section	• Investigation and characterisation accompanying excavation (Ch) • Monitoring under in-situ conditions (M)
Repository construction HLW	2055 – 2059	Construction of HLW repository section	• Investigation and characterisation accompanying excavation (Ch) • Monitoring under in-situ conditions (M) • Potential continuation of long-term experiments

Tab. A.2-5: Operating and decommissioning periods for NPPs and interim storage facilities according to the "60-year NPP operating lifetime" scenario

	Beznau NPP	**Mühleberg NPP**	**Gösgen NPP**	**Leibstadt NPP**	**Zwilag**	**ZWIBEZ** [1]	**BZL-1/2**
Commercial operations from/to	24.12.1969 [2] – 2030	06/11/1972 – 2019	01/11/1979 – 2039	15.12.1984 – 2044	2000 – at least. 2074	2008 – 2074	1992 – 2064
Post-operation from/to	2031 – 2034	2020 – 2024	2040 – 2042	2045 – 2048			
Dismantling from/to [3]	2031 – 2044	2020 – 2034	2043 – 2053	2045 – 2059	2060 [4] – 2081	2075	
Decentralised L/ILW interim storage from/to [5]	1970 – 2034	1972 – 2024	1979 – 2042	1984 – 2048			
Zwilag L/ILW from/to					2020 [6] – 2064		
Zwilag ILW from/to					2000 – 2074		
Zwilag SF/HLW(WA) from/to					2000 – 2074		
ZWIBEZ LLW from/to						2008 – 2064	
ZWIBEZ HLW from/to						2008 – 2074	
Gösgen NPP wet storage facility from/to			2008 – 2045				

1) The Swiss Federal Interim Storage Facility (BZL) and the ZWIBEZ and Zwilag interim storage facilities have independent licences in line with nuclear energy legislation; ZWIBEZ will continue to operate autonomously even after the decommissioning of NPP Beznau.

2) Dates for NPP Beznau I: 24.12.1969, NPP Beznau II: 23.10.1971; for the other dates, an "average" year is used for both blocks.

3) This includes dismantling until completion of decommissioning.

4) Decommissioning of conditioning plants/plasma furnace (at the latest) in the year after the last NPP decommissioning waste arises (2059), dismantling from 2075 onwards.

5) The end of the operating lifetime of the respective L/ILW interim storage facility corresponds with the end of the post-operation of the respective NPP.

6) Emplacement of first decommissioning waste is expected from 2021 onwards.

A.2.2 Topics and activities to be addressed for realisation of the deep geological repositories

Tab. A.2-6: Topics and activities to be addressed to implement the realisation plan from today's perspective

System analyses: These activities contribute to evaluating safety and engineering feasibility within the framework of system analyses and mainly include:

- Performing safety analyses, including the evaluation of safety-relevant phenomena, also as input for facility planning (see below) and the safety-oriented optimisation of the deep geological repositories

The following work is conducted as a basis for the system analyses:

- Refinement of safety, barrier and radiological protection concepts, including the methodology for safety analyses and system analyses
- Characterisation of immobilisation, retardation and transport phenomena for radionuclides (particularly with respect to geochemistry) in the engineered and geological barriers after closure of the repositories, and consideration of these phenomena in the safety analysis models
- Determination of safety-related properties of the engineered barriers and the near-field, including interaction with the surrounding geology and deepening of the process understanding (repository-induced effects) for the engineered barriers and the near-field
- Modelling to calculate personal doses from radionuclide release rates after closure of the repositories
- Dose calculations and accident analyses for the operational phase

With a view to the general licence application, the focus of the activities lies on:

- Performing safety analyses for the overall comparative assessment with regard to site comparison and an deepening and expansion using comprehensive scenario and risk analyses for the selected site in line with Guideline ENSI-G03. Safety analyses deliver the required systematic quantitative investigation demonstrating compliance with the protection criteria and fulfilment of the stipulated safety requirements; these include supporting arguments for the qualitative evaluation of the 13 criteria listed in the Sectoral Plan, e.g. to justify or derive evaluation scales or the relative weighting of indicators and criteria
- Developing stage-appropriate safety demonstrations for the operational phase and the post-closure phase considering the current state of the art (status of facility planning, geosyntheses, input from the RD&D programme)

With a view to subsequent licensing steps, the focus of the activities lies on:

- Performing safety analyses for the application for underground geological investigations as well as for the nuclear construction and operating licence applications. The safety analyses must still be periodically updated after the repository goes into operation.
- Stage-appropriate elaboration and documentation of the required safety demonstrations for the operational phase and the post-closure phase considering the state of the art at that point in time (status of facility planning, geosyntheses, findings from the underground geological investigations and the RD&D programme)

Tab. A.2-6: (cont.)

Geological investigations: These activities include geological investigations and the geological description of the sites with the following focus:

- Site investigations (geometry and properties of relevant rock layers, state parameters, site-specific long-term evolution, etc.)
- Regional geological investigations on general geology and tectonics, hydrogeology and geological long-term evolution as well as studies and model calculations on climate evolution, erosion, neotectonics
- Deepening of process understanding (transport mechanisms, gas release, self-sealing, coupled phenomena, rock mechanics, etc.)
- Syntheses and reporting, including geological datasets for the construction of the repository facilities and for safety assessment

With a view to the general licence application, the focus of the activities lies on:

- Performing, evaluating and interpreting 3D seismic measurements, including but not restricted to determining layer geometry and tectonic dissection
- Performing, evaluating and interpreting deep boreholes to calibrate 3D seismics and to determine the properties and state parameters in the host rock, in the clay-mineral-rich confining geological units and in the adjacent deep aquifers
- Integrating the field investigations and developing geological site models
- Performing site-specific numerical modelling and additional studies to improve process understanding
- Performing, evaluating and interpreting Quaternary investigations (in particular, 2D seismics and boreholes) as a basis for the assessment of the geological long-term evolution
- Developing scenarios on long-term geological evolution and analysing the effects on transport processes
- Summarising the geological findings in a geosynthesis as part of the application documents

Activities can be scaled back accordingly once the general licence has been granted. The focus of activities lies on the basis required for applying for underground geological investigations and the nuclear construction licence application:

- Exploratory borehole at the shaft site to characterise the geological situation for the construction of the access structures for the underground geological investigations
- Geotechnical, hydrogeological and hydrochemical characterisation during the construction of the access structures for the underground geological investigations
- Construction and execution of underground experiments to:
    - Characterise the underground geological situation at the disposal level, including spatial variability
    - Confirm rock-mechanical parameters and the suitability of technical elements with a view to repository construction
    - Investigate the transport processes through the host rock (including gas release)
- Stage-appropriate expansion of the geological dataset and documentation as part of geosyntheses

Tab. A.2-6: (cont.)

Characterisation of radioactive materials: The purpose of these activities is to characterise the radioactive materials and their properties. This mainly includes:

- Continuously updating the waste inventory (activities, volumes, properties) as a basis for planning the repositories and operating procedures, as documented in, e.g., the "Model Inventory for Radioactive Materials (MIRAM)":
  - including improvements in the methods for characterisation and inventorying
  - stage-appropriate reduction of avoidable uncertainties and conservatisms of the radioactive waste inventory
- Studies on handling, loading and packaging radioactive waste, including provision of the entire waste logistics (waste inventory and transport frameworks) for each relevant repository scenario
- Advising the waste producers, in particular with regard to projects such as decommissioning (container development, activation calculations, shielding calculations, etc.)
- Product control of existing conditioning procedures and evaluation of new ones, and performance of procedure for certifying suitability of waste for disposal and preliminary acceptance procedures to ensure that the conditioned radioactive materials correspond with the acceptance criteria
- Evaluation of waste properties and clarification of handling aspects (SF integrity, recycling or potential disposal of transport casks, handling of waste packages in the surface facility)
- Exclusion of criticality both for handling operations during the operational phase and for long-term evolution after closure by means of advanced methods ("burnup credit")
- Research on, e.g., issues related to the integrity of spent fuel assemblies

With a view to the general licence application, the focus of the activities lies on:

- Developing application documents (updating the waste inventory (activities, volumes, properties) and further documentation of the "Model Inventory for Radioactive Materials" (MIRAM), sub-criticality demonstration within the framework of the general licence application)
- Introducing preliminary waste acceptance procedures and performing and documenting illustrative/model-based preliminary acceptance procedures

With a view to subsequent licensing steps, the focus of the activities lies on:

- Supporting the optimisation of the overall system and developing the required databases
- Detailed planning and optimisation of waste logistics (including required developments of, e.g., transport casks)
- Providing waste-specific characteristic data for, e.g., facility planning
- Developing the corresponding application documents (waste inventory, assumptions on waste treatment (transport and storage casks, etc.), waste properties relevant for handling, specifying acceptance criteria)
- Research activities in line with the 2021 RD&D Plan

Tab. A.2-6: (cont.)

Activities with a view to planning and realisation

These activities mainly comprise:

- Timely and stage-appropriate facility planning and construction and operation of surface and underground facilities for the permanent emplacement of all of Switzerland's radioactive waste in a deep geological repository in line with the overarching realisation plan and in compliance with applicable legal and regulatory stipulations and requirements
- Developing the required technologies and engineered barriers
- Monitoring and closure of the deep geological repository and decommissioning and dismantling of the surface facilities

With a view to the general licence application, the focus of the activities lies on:

- Preparing the site-specific underground repository projects, including a structural risk analysis at the preliminary project stage as a basis for the safety-based comparison
- Developing concepts for construction (methods, processes) and repository operation with a view to long-term safety, operational safety and radiological protection
- Developing planning studies for the layout and design of the surface infrastructure, including the underground access structures for the repository
- Developing engineered barrier concepts
- Developing a concept for decommissioning the surface infrastructure and closing the repository, including information on backfilling and sealing of all repository sections that are still open when emplacement operations and the monitoring phase have been completed
- Preparing the Environmental Impact Report as well as the report on reconciliation with spatial planning

With a view to the nuclear construction licence application and subsequent licensing steps, the focus of the activities lies on:

- Developing the construction project in line with the requirements listed in Appendix 4 of the Nuclear Energy Ordinance
- Reviewing the environmental impact with regard to the application for underground geological investigations (Stage 1 of the Environmental Impact Report) and nuclear construction licence application (Stage 2 of the Environmental Impact Report)
- Developing and testing (through development work and demonstration experiments) the required technology for fabricating and installing engineered barriers (disposal containers, backfill materials, sealing)
- Stage-appropriate project development (through development work and demonstration experiments) in connection with repository monitoring, the potential retrieval of the emplaced disposal containers and the closure of the repository, including marking and long-term archiving

Tab. A.2-6: (cont.)

Monitoring: Activities include developing monitoring concepts and carrying out measurement programmes with the following priorities: • Radiological and non-radiological monitoring of the environment • Monitoring of the geological surroundings • Monitoring during construction • Monitoring of the pilot repository • Preparation and periodic updating of an integral monitoring concept With a view to the general licence application, the focus of the activities lies on: • Expanding and continuing existing measurement programmes in the siting regions (permanent GNSS measuring stations, seismometers, long-term monitoring in deep boreholes), including recording of initial zero measurements • Developing an integral monitoring concept that covers all phases of realising deep geological disposal (e.g. zero measurements, environmental monitoring, monitoring in the repository) With a view to subsequent licensing steps, the focus of the activities lies on: • Supplementary zero measurements to monitor the environment and the geological surroundings for the measurement programmes for meteorology, surface waters, springs, shallow groundwater and levelling, including the potential consolidation of measurement programmes already underway • Monitoring during construction • Implementation of radiological zero measurement campaigns • Participation of Nagra in international research projects • Continuation or initiation of experiments relating to technological and methodological issues on monitoring of the pilot repository • Development of a project for the monitoring phase with a view to the nuclear construction licence application (Art. 24 Par. 2 Letter f KEV)
Other aspects, including organisation (management and planning) To successfully perform the work, a suitable management system is maintained (including a certified quality management system), in which planning has a high priority (see Section 5.7).
Information according to the information concept The different elements of the information concept are described in Chapter 8. The effective information activities are adapted to the needs of the stakeholders.

A.3 Fundamental decisions regarding the realisation of deep geological repositories: initial situation, potential for modifications and flexibility with regard to future developments

Tab. A.3-1 outlines the **background** (1st column), the **available scope** for optimising and increasing the robustness of the facilities as well as for handling existing or required flexibility with regard to future developments (2nd column), and information on **decision-making points** where flexibility with regard to future developments or potential for modification can be used to optimise the facilities (3rd column). The following information is based on the "60-year NPP operating lifetime" scenario (see Section 2.1).

Tab. A.3-1: Background, potential for modifications and decision-making points

Disposal principles in Switzerland		
Background	**Available scope for optimisation**	**Decision-making points**
All waste types are to be disposed of in Switzerland in principle.	Until the start of repository construction, flexibility exists with regard to the joint disposal (of a part) of the waste with other countries.	In rare exceptions and under strict conditions, a permit may be issued for the disposal of waste abroad (considered unlikely from today's perspective). The final decision on disposal of (part of) the waste abroad must be made no later than the start of construction of the relevant geological repository.
Interim storage (capacity, operating lifetimes)		
Background	**Available scope for optimisation**	**Decision-making points**
There is sufficient interim storage capacity for all waste types.	Extending the availble interim storage capacity is possible in principle. If necessary, existing interim storage facilities for waste from medicine, industry and research can be further expanded.	If necessary, existing interim storage facilities can be expanded at any time. The required administrative and technical measures must be initiated at an early stage.
The operating lifetimes of the existing interim storage facilities are in line with the realisation plans for the combined repository as well as for the individual HLW and L/ILW repositories.	The operating lifetimes can, in principle, be adjusted to take into account any delays in the realisation of the repositories.	Adjusting the operating lifetimes of the existing interim storage facilities is possible in principle at any time. The required administrative and technical measures must be initiated at an early stage.

Tab. A.3-1: (cont.)

Waste conditioning, characterisation and inventorying		
Background	**Available scope for optimisation**	**Decision-making points**
Conditioning, characterisation and inventorying of the waste arising today according to current procedures or the waste arising in the future according to concepts envisaged today are ensured.	Flexibility exists for adapting conditioning procedures for future waste to take into account new findings (for example as a result of updated decommissioning studies). There is capacity to improve the conditioning processes of waste produced today or, if necessary, to recondition existing waste.	At any time until the nuclear operating licence for the repositories, existing or planned conditioning procedures can be modified or supplemented as needed. If necessary, reconditioning can also be carried out. For both options, the licensing procedures are defined and the methodology and instruments for assessing the suitability for disposal are available.
Disposal capacity and waste types		
Background	**Available scope for optimisation**	**Decision-making points**
The "60-year NPP operating lifetime" scenario (see Section 2.1) shows sufficient disposal capacity for all waste types according to current concepts.	The repository is designed in such a way as to ensure sufficient flexibility to adapt the disposal capacity and to take into account new types of waste.	The general licence specifies the maximum disposal capacity; this must include foreseeable waste types at that point in time as well as planning reserves. Planning reserves must be justified; i.e. technical and operational uncertainties must be presented. The repositories are designed in such a way that, even after the general licence, the disposal capacity can be adapted and new waste types can be considered. Depending on the nature and extent of the extension or modification, a supplement to the general, construction or operating licence or approval by the authorities may be necessary.

Tab. A.3-1: (cont.)

Waste allocation		
Background	**Available scope for optimisation**	**Decision-making points**
Waste allocation is decided by considering the site-specific geological conditions at the respective repository sites in accordance with current concepts.	With regard to the allocation of the waste types to the different repositories, there is capacity to regulate the waste allocation and requirements for the waste to be disposed of on the basis of the site-specific conditions actually found, in accordance with the optimisation requirement, even after the general licence has been granted.	The waste is allocated conceptually within the context of site selection. The categories of the waste as well as the maximum disposal capacity are specified in the general licence and are based on the updated Model Inventory of Radioactive Materials (MIRAM), safety-oriented allocation of the waste and a repository concept adapted to this waste allocation. The detailed requirements for the waste to be disposed of are specified in the nuclear construction and operating licences, taking into account the detailed characteristics (site properties after full exploration, detailed design of the repository and the engineered barriers) and the waste intended for emplacement at that point in time.
Waste inventory (volume, type) – waste from medicine, industry and research (MIR)		
Background	**Available scope for optimisation**	**Decision-making points**
The inventory of MIR waste includes the collection period until 2064; this includes future MIR waste that is produced in a similar way as it is today.	Within the framework of the multi-stage licensing procedure, sufficient flexibility to handle additional MIR waste due to extension of the collection period will be taken into account. The available systems and concepts have the capacity to handle waste from other sources (new types of MIR waste).	In due course, the Federal Government will decide whether, when and to what extent MIR waste is to be taken into account beyond the collection period and volumes foreseen today (see Appendix A.8.10). To consider new types of waste, the licensing procedures are defined correspondingly, and the methodology and instruments for assessing their suitability for disposal are available. In principle, it is also possible to dispose of other types of waste.

Tab. A.3-1: (cont.)

Transports		
Background	**Available scope for optimisation**	**Decision-making points**
The transports required in connection with the treatment of waste or interim storage are routinely carried out; concepts are available for transports to the deep geological repositories required in the future and for the infrastructure required for loading and unloading the transport casks.	Flexibility to take into account new experience, technical innovations and new specifications (infrastructure, transport casks, vehicles) is available.	For each transport, the detailed conditions are specified in the transport permit. At the time of the construction or operating licence for the repositories, the infrastructure required for loading, unloading and transport must be determined definitively (including measures taken by the consignor).
Safety and disposal concept		
Background	**Available scope for optimisation**	**Decision-making points**
The Swiss safety concept foresees a multi-barrier system with barriers consisting of the waste matrix, disposal canisters, backfilling/sealing and the containment-providing rock zone.	Sufficient potential to modify the safety and repository concept is provided during the realisation process to allow new findings (progress in site exploration and experience gained in other programmes) to be considered.	The safety and repository concept is concretised in the construction licence, but can still be modified subsequently. Depending on the nature and extent of the modifications, this will either require an addendum to the general licence or the construction and operating licence or approval by the authorities.

Tab. A.3-1: (cont.)

Repository conceptual design (design of repository components such as engineered barriers, emplacement rooms, backfilling, disposal containers, sealing)		
Background	**Available scope for optimisation**	**Decision-making points**
The repository conceptual design considers stage-appropriate requirements on safety, technical feasibility, handling of available resources and optimisation measures. The current repository conceptual design is largely generic in nature and the design principles can be applied to all siting regions included in Stage 3 of the Sectoral Plan. In Stage 3, further, site-specific concretisation of the repository conceptual design will take place to develop site-specific repository projects that include information on repository components (e.g. approximate dimensions, selection of materials).	This procedure allows for modifications to the repository conceptual design based on new findings (progress in site exploration and experience gained in other programmes as well as technological state of the art) and to consider other variants.	To meet demonstration requirements, the general licence application includes a model implementation of the repository conceptual design at the preliminary project stage within the framework of site-specific repository projects. In line with Anhang 4 KEV, technical specifications of the repository components are determined in detail considering site-specific conditions (partly based on the underground geological investigations) and the effectively expected waste within the framework of the nuclear construction licensing procedure.

Tab. A.3-1: (cont.)

Technology for construction, operation and closure (surface and underground facilities)		
Background	**Available scope for optimisation**	**Decision-making points**
Technological concepts for the construction, operation and closure of the repositories (surface and underground facilities) are available.	With regard to the technology for construction, operation and closure, there is sufficient potential for modification in the process, so that the design of the facilities can be adapted to new findings (including international programmes) as needed, and alternative concepts can be applied for selected elements.	To meet demonstration requirements, the general licence application includes a model implementation of the technology required for repository construction, operation and closure. The technology will be determined in detail for the nuclear construction licence application, based on the current state of knowledge at that time.
Retrievability and monitoring		
Background	**Available scope for optimisation**	**Decision-making points**
Retrievability and monitoring are integral components of the repository concept; corresponding stage-appropriate concepts for the technology are available.	The designs of the equipment required for waste retrieval, the pilot repository (including instrumentation) and of other elements related to monitoring can still be modified to take into account the increase in knowledge, to design waste retrieval technology based on the state of the art for the nuclear construction licence application, and to use current monitoring technology for phenomena considered to be relevant at the time of the applications for underground geological investigations and for the nuclear construction licence.	The general licence application presents concepts, which may also include variants; these will be concretised as required for the applications for underground geological investigations and the nuclear construction licence.

Tab. A.3-1: (cont.)

Site – layout of underground facilities		
Background	**Available scope for optimisation**	**Decision-making points**
The layout and detailed design of the underground facilities takes into account the waste to be emplaced and the site-specific conditions identified through focused field investigations.	For the detailed layout of the underground facilities, sufficient potential is available to adapt the layout (including technology) to new findings (progress in site exploration, experience in other programmes) and to the waste inventory effectively to be disposed of.	For the purpose of a safety-based comparison within the framework of site-specific repository projects at the preliminary project stage, the general licence application includes a model with the approximate position and layout of the underground repository structures. The detailed layout of the underground structures is presented in the nuclear construction licence application and takes into account the site-specific conditions (obtained, for example, from the underground geological investigations).

Tab. A.3-1: (cont.)

Site – layout and design of the surface infrastructure (including site development)		
Background	**Available scope for optimisation**	**Decision-making points**
Layout and spatial design of the surface infrastructure: Available space for the surface infrastructure is limited; as a rule, there are various options for the layout and spatial design of the surface infrastructure, taking into account aspects of land use and environmental impact. Official procedures lead to coordination with spatial planning and determine the environmental impact for each stage of the project. In Stage 2 of the Sectoral Plan, siting areas for the surface facility were identified and documented as an interim result based on collaboration with the siting regions and cantons.	In Stage 3 of the Sectoral Plan, the decisions from Stage 2 can be reviewed; this also applies to the sites for the encapsulation plants. The definitive surface infrastructure areas are then determined based on collaboration with the siting regions and cantons. Besides the siting areas for the surface facilities, this also includes the areas for the auxiliary access facilities. If an external site is chosen for the encapsulation plant for high-level waste, the required areas are also identified (e.g. at the Zwilag interim storage facility).	In line with nuclear energy legislation, the general licence application includes a description of the facilities in general terms and the approximate position of the key structures. In addition, for land-use planning purposes and to ensure the expedient realisation of the project, the areas required for the surface infrastructure are secured in object sheets. A detailed layout of the surface infrastructure is developed for the application for the underground geological investigations and the nuclear construction licence. This also includes the development infrastructure and installation sites required for construction and operation. In addition, the repository includes sites for the recycling and deposition of material from excavation and dismantling. These sites also form an integral spatial and functional component of the project.
Design of the surface infrastructure according to current concepts	There is sufficient potential in the design of the surface infrastructure to adapt its stage-appropriate layout to new insights (in particular, progress in technology and new experience in other programmes).	In accordance with nuclear energy legislation, the design of the surface infrastructure is described in broad outline in the general licence application. A detailed design of the surface infrastructure is prepared in conjunction with the applications for underground geological investigations and for the nuclear construction licence.

Tab. A.3-1: (cont.)

Site – demonstration of safety		
Background	**Available scope for optimisation**	**Decision-making points**
Long-term safety: In Stage 3 of the Sectoral Plan, the knowledge gained from Stages 1 and 2 was further developed and, taking into account the results of the RD&D programme and the site-specific data with a view to the general licence application, a safety case was prepared for the site(s). *Operational safety*: The safety demonstration for the operational phase comprises a systematic safety analysis both for normal operations and in case of incidents or accidents. Extensive experience is available in this context (operation of nuclear facilities, experience in other programmes).	With each licence, long-term safety and operational safety are re-evaluated in the context of periodic safety reports, taking into account new findings. There is sufficient potential to consider any necessary adjustments to the system and changes in the RD&D Plan based on the results of the safety analysis.	For the various decision-making points, the safety reports must be updated and adapted to the latest findings and decisions (waste, repository conceptual design). The safety-related RD&D programme and the repository conceptual design must take into account the findings from the safety reports and their assessments with a view to optimising the design of the facilities.

Tab. A.3-1: (cont.)

Site – geology		
Background	**Available scope for optimisation**	**Decision-making points**
The Federal Council has approved focusing on the Opalinus Clay as the host rock and decided that the Jura Ost, Nördlich Lägern and Zürich Nordost siting regions were to be further investigated.	Results of the advanced field investigations confirm that all three siting regions provide enough space for a combined repository layout. Site selection must leave sufficient flexibility to modify the available space to consider improved knowledge regarding site-specific conditions (including tectonics, state parameters, long-term evolution) in the context of further realisation.	The site is determined (including the definition of the underground space in which intrusion could impair the safety of the repository) with the general licence and results in the spatial planning of a preliminary protection zone. The operating licence specifies the definitive protection zone of the deep geological repository.

A.4 Realisation of the repository project as part of a holistic optimisation process

The following describes the approach to performing the work arising within the framework of the decade-long, multi-stage licensing procedure in line with KEG (2003) (Section A.4.1) and the principles, objectives and approach to optimising the deep geological repository (Section A.4.2). This includes topics and activities addressed in Section A.4.1 and places them in a temporal context. Appendix A.4 thus addresses the ENSI requirement to document the optimisation procedure in the Waste Management Programme.

A.4.1 Procedure for performing the work within the framework of the licensing procedure according to the Nuclear Energy Act

With a view to the successful realisation of the project, decisions are made within the framework of an optimisation procedure that considers the optimisation objectives and principles (see Section A.4.2) that are relevant for each decision. The licensing procedure according to KEG (2003) already serves as an optimisation process as decisions on project realisation are made in a stage-appropriate manner to allow optimum consideration of future developments with a view to the safe disposal of radioactive waste. The optimisation steps in the development of the repositories are oriented correspondingly and, in line with the legal framework and regulatory requirements, the respective expertise and project development technology are developed for each licensing step.

Fig. A.4-1 schematically outlines the licensing steps in line with KEG (2003) as well as the procedure for handling the work for concretising and realising the repositories in a stepwise manner.

At every licensing step, following the submission of the application documentation by the project planner and the expert review by the responsible authorities, the relevant bodies (Federal Council or DETEC) make formal and legally binding provisions and decisions. Once the corresponding licence has become legally valid and considering potential attached conditions, this provides the baseline for the next licensing step.

The following is a conceptual explanation of the procedure for concretising and realising a deep geological repository oriented towards the individual licensing steps. This allows the optimisation process associated with safety-related decisions to be embedded into **project development** (blue-grey box in Fig. A.4-1). The optimisation process is explained in detail in Appendix A.4.2.

The key factor in project development for the technical assessment of safety and technical feasibility of variants and options are **system analyses** (shown as an orange box in Fig. A.4-1; see also Appendix A.2.2).

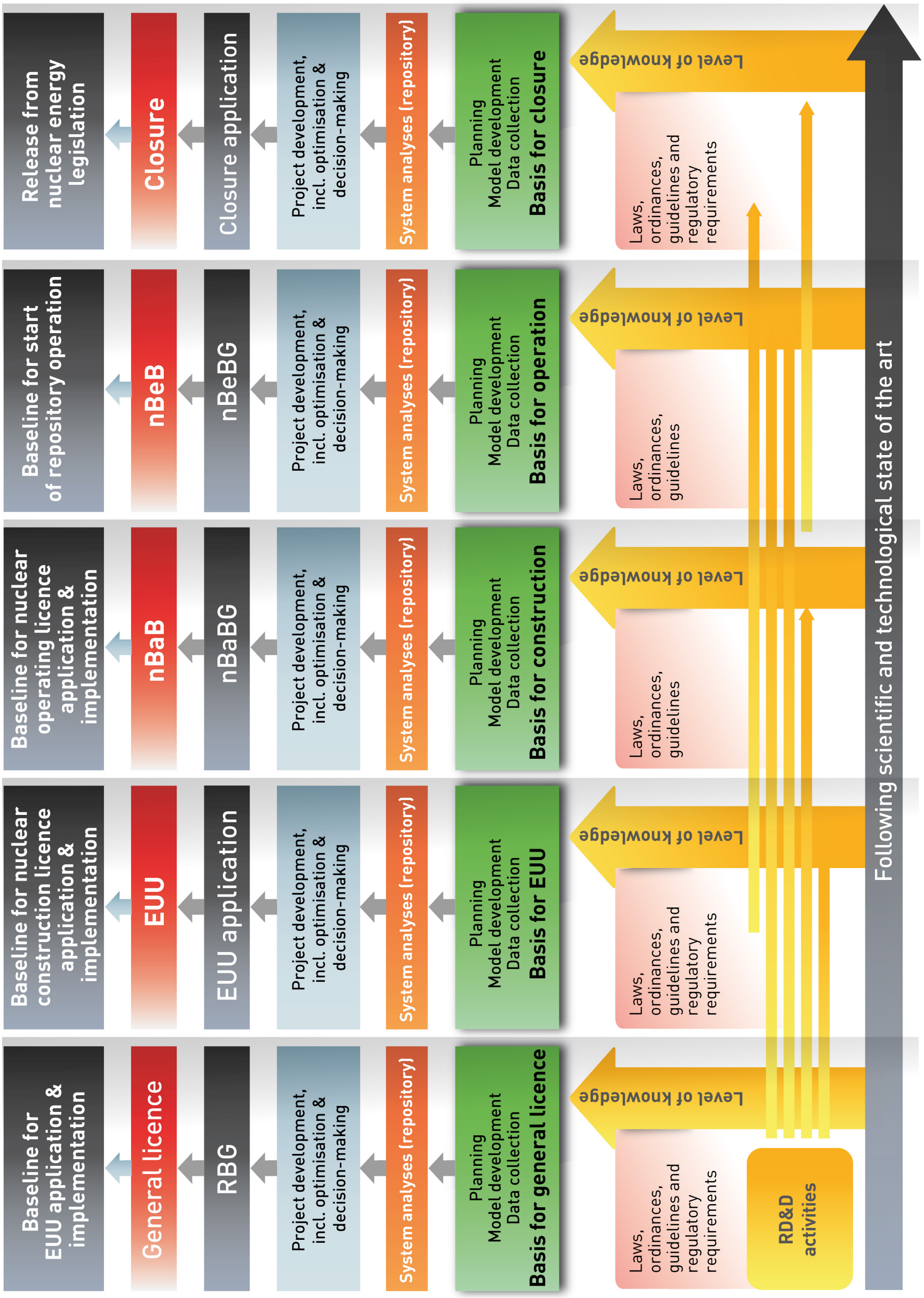

Fig. A.4-1: Procedure for handling the work for stepwise concretisation and realisation of the repositories in line with KEG (2003)

The starting-point for the work is the Sectoral Plan for Deep Geological Repositories which is based on the licensing procedure under the Nuclear Energy Act.

Fundamental principles have to be developed and concretised to ensure that system analyses for the corresponding licensing step are available in a timely manner. These **principles** (shown as a green box in Fig. A.4-1) can be divided into the following topics and activities:

- **Data collection** includes the acquisition and assessment of geoscientific data and further material characteristics and the waste to be disposed of (see also Appendix A.2.2).
- The further development of methods and models (**model development**) for safety analyses and system analyses (see also Appendix A.2.2) also contributes to the stage-appropriate handling of uncertainties and to an adequate process understanding.
- Stage-appropriate **project planning** (see also Appendix A.2.2) is accompanied by stage-appropriate project concretisation and provides the basis for implementation in accordance with the rules, regulations and principles of engineering and facility construction for surface and underground facility elements and structures.

Developing these principles considers applicable laws, ordinances, guidelines, official requirements and boundary conditions (e.g. the waste inventory for disposal, see Chapter 2). They are based on the corresponding baseline and consider the current state of science and technology as well as the knowledge gained from the corresponding technical research and development work with a view to stepwise concretisation and stage-appropriate realisation of the project.

The time frame for the repository project is extremely long, and the **licensing procedure** extends over a period of around one hundred years from the general licence until repository closure. As the project moves forward, the number of decisions to be taken that are relevant to long-term safety will decrease, while optimising implementation aspects will become more important. Tab. A.3-1 outlines the room for manoeuvre for selected topics and, using decision points, shows how this flexibility with regard to future developments is used to optimise the facilities. Considering the long timeframe for the repository project, formal specifications include appropriate reserves to create favourable conditions for taking into account developments at later stages of the realisation process. Specifically, the **licensing steps** are characterised as follows:

- In contrast to the licensing procedure for other nuclear installations, a **Sectoral Plan for Deep Geological Repositories** has been developed in addition. This resulted from past experience which showed that selecting a repository site is a challenging undertaking. For this reason, the conceptual part of the Sectoral Plan (BFE 2008) sets out a transparent and impartial three-stage selection procedure that is now very advanced (see Sections 1.3 and 5.4.1). With the conclusion of **Stage 1,** six siting regions were identified. Within the framework of **Stage 2**, the Federal Council approved focusing on the Opalinus Clay as the host rock and decided that the Jura Ost (JO), Nördlich Lägern (NL) and Zürich Nordost (ZNO) geological siting regions were to be further investigated in **Stage 3**. In addition, and based on very close collaboration with the siting regions and cantons, the siting areas for the surface facilities were identified. At present, Stage 3 of the Sectoral Plan and the preparations for the general licence application are ongoing. Nagra's announcement of the site(s) for which it will prepare general licence applications in line with the Sectoral Plan concept is an important milestone and is expected in the near future (2022). The comparison of the siting regions is conducted within the framework of a safety-based optimisation according to the safety criteria defined in the Sectoral Plan and the requirements specified by ENSI (ENSI 33/649; ENSI 2018c). Site selection will then be recorded in line with requirements from nuclear energy legislation (Art. 62 KEV) and ENSI (2018c) as part of the documents to be submitted along with the general licence application. The **general licence** represents the first step in the licensing procedure for the realisation of a nuclear installation in line with the Nuclear Energy Act and defines the site and the basic features of the project. While the principle of the multi-barrier concept (safety concept; see Section 3.1.2) has already been integrated into the legislation, the most important decisions with regard to long-term safety, aside from site selection for the respective repository type, concern the allocation of the waste. Decisions on the approximate size and location of the most important structures of the surface infrastructure are rated as having no or only minor relevance for long-term safety.

- The licensing procedure for **underground geological investigations (EUU)** is a special case in the licensing of nuclear installations and is regulated in (Art. 35 und 36 KEG). The objective of the underground geological investigations is the extended characterisation and confirmation of the underground geological situation. Corresponding investigations, experiments and demonstrations provide important input for repository construction. Aside from geological investigations carried out during construction and the review of construction procedures, the focus is on assessing suitability criteria. As the facility elements for the underground geological investigations are to be converted into repository components once the nuclear construction licence has been obtained (Chapter 5), the EUU licence also includes decisions on the exact layout and detailed design of the auxiliary access facilities, the EUU access structures in the central area of the main underground connection area as well as of the facilities for underground geological investigations (see Section 3.2).
- The **nuclear construction licence** (nBaB) regulates the conversion of the EUU infrastructure and specifies the technical implementation for the remaining elements. The background for preparing the application is provided by the general licence and site-specific insights gained from the underground geological investigations, experience from international projects and information on newly developed technologies. For preparing the nuclear construction licence application (nBaBG), a stage-appropriate optimisation is carried out with regard to selection of the engineered barriers (disposal container, backfilling, sealing) and the design of underground repository architecture as well as the technical implementation of the project. The nuclear construction licence application also provides the possibility to consider additional regional concerns regarding the realisation of the surface infrastructure.
- With regard to the **nuclear operating licence application** (nBeBG), safety-relevant technologies will be tested and their functionality demonstrated. This particularly concerns the technology for the retrieval of waste packages without undue effort until repository closure and requires demonstration of the introduction and removal of backfill materials. For sealing elements that were not tested in advance, the sealing technology is tested at this point and functionality during repository operation is demonstrated in the test areas. The most important decision relevant to long-term safety is determining the final protection zone of the deep geological repository in the nuclear operating licence application.
- Once the **nuclear operating licence** has been granted, waste emplacement in the repository begins. First, a small, representative amount of radioactive waste is emplaced in the pilot repository. Following this, the radioactive waste packaged for disposal is emplaced in the emplacement caverns (L/ILW) and emplacement drifts (HLW). In the case of a combined repository, additional HLW emplacement drifts are constructed in parallel with L/ILW waste emplacement (see Section 3.2). During operation, safety checks are carried out periodically.
- The **monitoring phase** begins once emplacement is complete. In an initial step, the application for decommissioning of the facilities and structures at the surface is submitted.
- With the **application for repository closure**, the final decision on the preferred closure variant is made. For this, the repository closure plan and an updated project plan for the monitoring phase are to be submitted.

A.4.2 Repository optimisation in connection with safety-oriented decisions: objectives, principles and process

The waste producers have tasked Nagra with realising safe deep geological disposal for all categories of radioactive waste in Switzerland at reasonable cost and in a timely manner. To fulfil this mandate, Nagra must create the corresponding conditions:

- The safety of the deep geological repositories must be demonstrated to the scientific community, the authorities and the public with a solid technical foundation and transparent documentation within the framework of the Sectoral Plan and the licensing procedure in line with KEG (2003).
- Together with other actors, Nagra, must also contribute to achieving sufficient regional and national acceptance for the realisation of the deep geological repositories (see Chapter 8, Collaboration and information concept).
- Finally, Nagra must consider economic factors and ensure that the repository projects are economically reasonable.

To take the above-mentioned conditions into account, the repository project must be realised within the framework of a holistically oriented optimisation that is aligned with the following overarching optimisation goals and principles for long-term safety and implementation:

- Ensuring **long-term safety** for the protection of humans and the environment from ionising radiation without undue burdens for future generations.
- Ensuring **safety and feasibility** in connection with **construction and operation** of the deep geological repositories. This includes occupational health and safety (including an optimisation of radiological protection in line with Art. 4 StSV). Additional topics include security and safety in the case of incidents or accidents in terms of their impact on humans and the environment. Feasibility is defined as achieving reliable implementation of all required work steps with reasonable effort.
- Ensuring the compatibility of the repository with the **environment, spatial planning and society**; this includes realising the facilities within the framework of planning and collaboration with the siting regions to date (as documented, e.g., in planning studies). A successful realisation also requires adequate consideration of environmental and spatial planning aspects.
- Considering **resources and economic efficiency**, i.e. realising the project cost-efficiently and within an appropriate time period.

While the latter three overarching optimisation goals and principles underlie all large-scale infrastructure projects, the optimisation goals and principles of long-term safety refer specifically to deep geological disposal and highlight their particular significance. This is highlighted both in Guideline ENSI-G03 (ENSI 2020b) and the international standards for deep geological disposal (e.g. IAEA Safety Standard SSR-5, IAEA 2011).

Fig. A.4-2 illustrates the schematic optimisation process in connection with the safety-based decisions in project development and provides an in-depth insight into the work procedures for realising the repository project shown in Fig. A.4-1.

For project development, those variants and options were considered (so-called variants and options for further consideration) that can be assessed and judged suitable with regard to their compatibility with the requirements relating to long-term safety as well as to design, construction and operation using system analyses. Variants and options that do not meet these criteria or comprise project options that are difficult to realise are justifiably deferred.

Final overall optimisation is carried out with regard to all optimisation goals and principles. When evaluating potential variants and options that come into question, their proportionality in terms of time and costs is also taken into account and chances and risks are adequately considered. This also includes an evaluation of the flexibility for increasing facility robustness as well as handling of the existing or required flexibility with regard to considering potential future developments (see Appendix A.3). Mutual dependencies are identified, and conflicting requirements are resolved based on the principle of proportionality. In individual cases, it may be necessary to determine in advance which solution is most advantageous overall with regard to safety (ENSI 2020b).

The safety-related decisions are recorded for transparency reasons (ENSI 2020b). The repository project (including corresponding requirements) is defined for the preparation of the required safety demonstrations and the licence application (black box in Fig. A.4-2). This has to be redetermined and confirmed for every licensing step as it represents the basis for respective stage-appropriate verification management.

To implement the repository project in a goal-oriented manner, Nagra must fulfil numerous external and internal requirements:

- Legal requirements (e.g. Nuclear Energy Act, Nuclear Energy Ordinance, Environmental Protection Act)
- Guidelines (e.g. ENSI guidelines)
- Boundary conditions (e.g. types and volumes of radioactive waste)
- Requirements on long-term safety
- Specifications based on the implementation of the process (e.g. Sectoral Plan for Deep Geological Repositories)
- Requirements of various stakeholders (e.g. authorities, general public)
- Internal requirements (e.g. matching of elements, facility operation and economic viability of the project)

To adequately address all these requirements, Nagra has established a **"Requirements and Configuration Management"** (RCM) system. The structured RCM process is part of Nagra’s quality management and includes the development, documentation and management of the requirements and their implementation. The requirements and their implementation are specified in a stage-appropriate manner. RCM is linked with the RD&D programme through ongoing RD&D projects for optimising the deep geological repository. In addition, RCM documents the selection of the repository project, which forms the basis for the safety analysis and verification management.

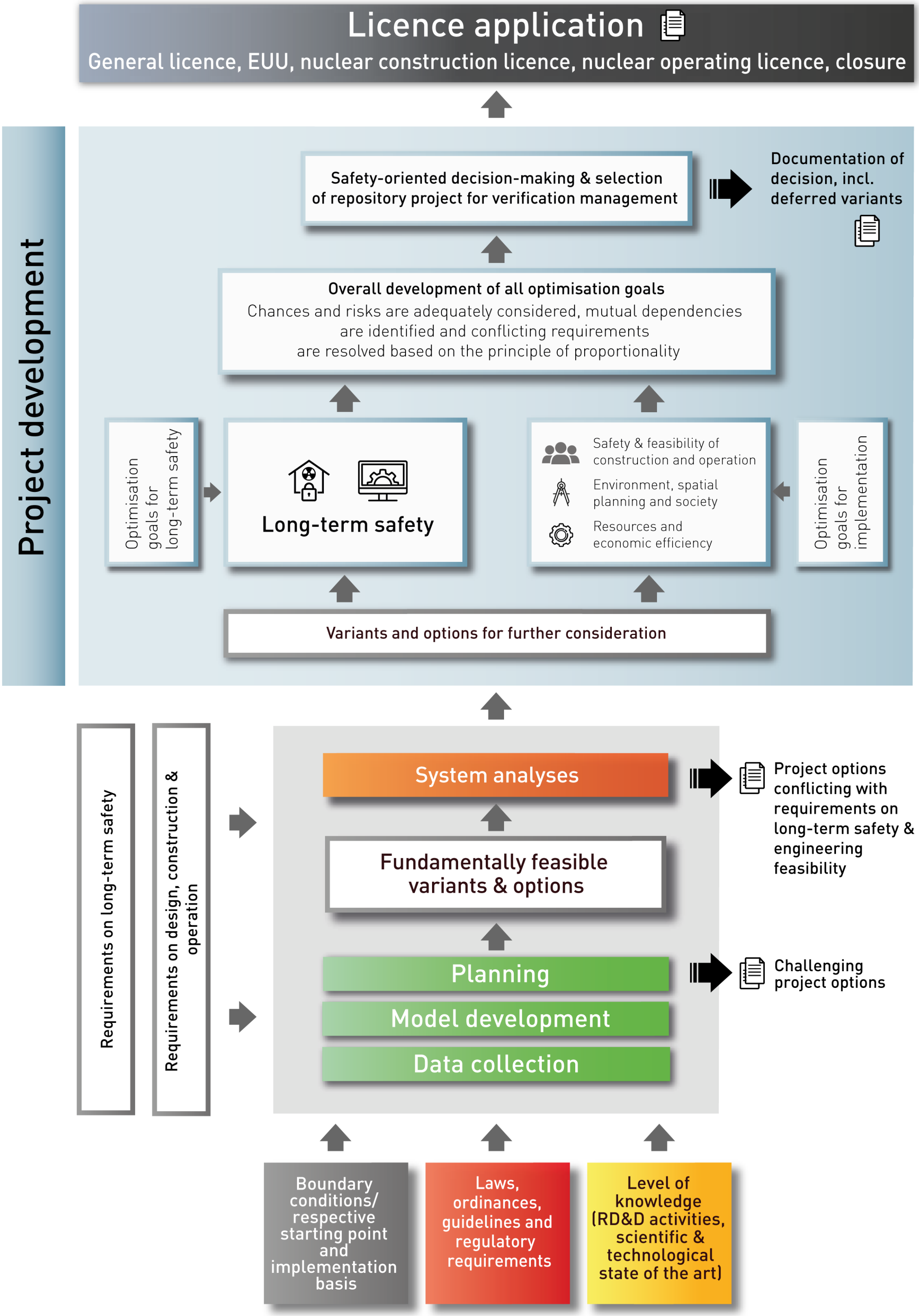

Fig. A.4-2: Schematic presentation of the optimisation procedure in connection with decisions on safety based on stage-appropriate system analyses and fundamental principles (see Fig. A.4-1)

To fulfil, modify and demonstrate requirements relating to feasibility, Nagra has been pursuing an RD&D programme for many years, and will continue this programme into the operational phase of the deep geological repository. In the earlier phases of the RD&D programme, numerous results confirmed the structure and elements of the safety case. RD&D activities to date have demonstrated that the safety requirements can be met. Future RD&D activities are expected to support repository optimisation as a priority but will also support feasibility (as described in the RD&D Plan, Nagra 2021e). These activities thus contribute to the final determination of requirements relating to the design and specifications of structures, systems and components.

Nagra (2021d) and (Nagra 2021e) outline the basic principles on the procedure and implementation of the overall project. In principle, the corresponding information in these reports is consistent with the information in WMP21, thereby fulfilling Federal Council stipulation 4.2 (see Appendix A.7). This outlines how technical topics and work priorities are linked with the milestones and decisions on realising a deep geological repository. The RD&D Plan (Nagra 2021e) also highlights which issues Nagra must resolve within which time period considering which internal and external requirements so that the insights from RD&D help to provide a stage-appropriate foundation for each respective licensing step in a timely manner; this contributes to fulfilling Federal Council stipulation 4.1 (Appendix A.7). As a supporting instrument, (Nagra 2021e) uses so-called roadmaps to illustrate and outline connections and interdependencies. Roadmaps correspond with international practice and are used to plan deep geological repositories (IAEA in prep., RWM 2016, EURAD in prep., IGSC in prep.).

A.5 Supplementary information on origin, types and volumes of radioactive waste based on the "50-year NPP operating lifetime" scenario

For a consistent presentation of the information on waste management in WMP21 and CS21, as well as to ensure comparability of the information on the cost estimate in these two reports with that in previous Waste Management Programmes and Cost Studies, the following provides details on the types and volumes of the waste for the so-called "50-year NPP operating lifetime" scenario. This is based on the following boundary conditions that differ from those of the "60-year NPP operating lifetime" scenario.

- 50-year operating lifetime for the Beznau[43], Gösgen and Leibstadt NPPs, 47-year operating lifetime for the Mühleberg NPP.
- For operational MIR waste, a collection period up to the end of 2063 is assumed.
- The information for the operational waste from the PSI Hotlab are based on the assumption that any waste from the Hotlab containing spent fuel is coupled with the end of the commercial operation of the Leibstadt NPP. With a 50-year operating lifetime of the Leibstadt NPP, the Hotlab will produce waste until 2034.

The waste inventory and volumes for the "50-year NPP operating lifetime" scenario are given in Tab. A.5-1. The table first lists the volume of the delivered and conditioned waste. As the waste will be packaged in disposal containers before being emplaced in the repository (cf. Section 3.2), the volume for waste packaged in disposal containers is given in brackets.

An improved estimate compared to WMP16 regarding the arising waste inventory and volumes as well as modified assumptions regarding packaging result in different figures for the waste inventory and volumes.

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43 The effective operating lifetime of the Beznau I NPP at the time of submission of WMP21 and CS21 is 52 years (s. Tab. A.2-5 in Appendix A.2.1) and, for the first time, thus exceeds the "50-year NPP operating lifetime" scenario on which WMP21 and CS21 are based. This deviation is justified as follows:

- In line with Art. 4 Par. 3 SEFV (Ordinance on the Decommissioning Fund and Waste Disposal Fund for Nuclear Installations), a 50-year NPP operating lifetime is to be assumed to calculate decommissioning and disposal costs of nuclear installations. By outlining the waste inventory framework for the "50-year NPP operating lifetime" scenario, this specification for CS21 is taken into account and ensures a consistent presentation of the information provided in both WMP and CS.
- In addition, including the waste inventory framework for the "50-year NPP operating lifetime" scenario in WMP21 ensures comparability with regard to the information on cost calculations in WMP21 and CS21 with those of previous Waste Management Programmes and Cost Studies.

The terminology used in the following is identical to that used in Section 2.1. The differences for the various waste categories are systematically outlined and the underlying reasons clarified based on the figures for the "packaged volume" as these are relevant for deep geological disposal. The so-called "50-year NPP operating lifetime" scenario (WMP21) and Scenario 1b of WMP16 (Nagra 2016b) form the basis for the comparison. Note that the number of packages assumed for WMP21 has changed slightly compared to the WMP16.

- **Spent fuel (SF):** Slight reduction of the packaged volume by 349 m^3 to (new) 6,780 m^3: The key boundary condition of limiting the maximum permissible heat output of the canisters has not changed compared to WMP16. In contrast, the predictions regarding the number of spent fuel assemblies were updated, leading to a slight increase in the unpackaged volume by 2 m^3 to (new) 1,124 m^3. This more significant change results from the revised design of the disposal canisters. Their volume has decreased slightly, leading to the aforementioned reduction of the packaged volume.
- **High-level waste from reprocessing (WA-HLW):** Slight reduction of the packaged volume by 21 m^3 to (new) 377 m^3: The high-level waste from reprocessing was conditioned in special steel containers (180-litre flasks). As in WMP16, it is assumed that three 180-litre steel flasks can be packaged in a disposal canister to optimise efficient use of volume. This reduction can be explained by a revised design of the disposal canister resulting in a slightly decreased volume; this leads to a slight reduction of the packaged volume.
- **Alpha-toxic waste from reprocessing (WA-ATW):** Slight increase of the packaged volume by 18 m^3 to (new) 432 m^3: The design for the disposal container foreseen for WA-ATW has been concretised; for WMP16, only a conceptual design was available. Concretisation results in a slight increase in the volume (0.4 m^3 per disposal container).
- **Operational waste (BA (NPP)) and rector waste (RA):** Reduction of the packaged volume by 2,705 m^3 to (new) 27,150 m^3: In WMP16, the packaging for the 200-litre container was based on the assumption of a 10.3 m^3 disposal container that can hold twelve 200-litre containers. WMP21 goes back to the significantly "tighter" packaging concept of a disposal container with a volume of 26 m^3 assumed in WMP08 for the disposal-ready packaging of 200-litre containers. This disposal container can hold 36 200-litre canisters. Compared to WMP16, the packaged volume can be significantly decreased. For the first time, WMP21 completely recorded the operational waste from the disposal of the transport and storage casks for HLW(WA) and for SF (BA(TLB)) and allocated it to the operational waste from NPPs (BA (NPP)). The packaged volume of this operational waste from the disposal of the transport and storage casks (BA(TLB)) increases by 2,139 m^3 to 2,648 m^3 compared to WMP16: WMP16 was based on the assumption that the baskets for the transport and storage casks would be decontaminated and conventionally disposed of. As it is probably not possible to successfully decontaminate the casks with reasonable cost and effort, WMP21 also includes the disposal of the baskets for the transport and storage casks.
- **Decommissioning waste (SA) (NPPs/Zwilag):** Reduction of the packaged volume by 2,414 m^3 to (new) 24,976 m^3: The volumes of activated decommissioning waste were fundamentally recalculated. In addition, an optimised packaging concept was developed and, for individual facilities, the arising waste inventory from the controlled zone was re-evaluated. Similar to WMP16, the concept of using low-level contaminated concrete from decommissioning to partially backfill containers filled with metallic waste is considered in WMP21.

- **Medicine, industry and research waste (MIR)[44]:** Reduction of the packaged volume by 3,614 m^3 to (new) 15,939 m^3: WMP16 includes 4,883 m^3 of CERN waste. In line with information provided by CERN and Nagra's estimates and based on coordination efforts between Nagra and the Federal Government in 2018, 2,399 m^3 of waste are now expected. The remaining reduction of around 1,000 m^3 compared to WMP16 results, on the one hand, from a general reduction of the operational waste to arise in the future based on predictions revised in collaboration with PSI, and, on the other hand, from an optimised packaging concept (see Section "BA(NPP) and RA").
- **Surface facility (OFA):** Reduction of the packaged volume by 1,397 m^3 to (new) 571 m^3: Aside from the operational waste arising from the surface facilities (and the encapsulation plants in particular), the waste from decontaminating the transport and storage casks was also listed under this category in WMP16; in WMP21, this waste is now listed under BA(NPP) and RA. In contrast, the category under the heading of "surface facility" in WMP21 lists only site-independent operational and decommissioning waste from the encapsulation plants (primarily for spent fuel assemblies); in WMP16, this waste was referred to as SF/HLW(WA) from the encapsulation plant.

[44] The planning assumption is based on an MIR collection period until the end of 2064 (end of emplacement operation in the L/ILW repository; see Section 5.3). Based on a recommendation by the Federal Nuclear Safety Commission, Appendix A.8.8 contains information regarding the handling of MIR waste after the end of emplacement (as of 2065). The Federal Government is responsible for its disposal. A disposal-ready waste volume of around 4,000 m^3 has to be expected over a period of 90 years. This corresponds to around 5% of the volume of all the L/ILW expected until the end of 2064. As the final decision on how to deal with MIR waste does not have to be made for another 50 – 100 years, this waste is not reflected in any of the waste inventory framework listed in the WMPs.

Tab. A.5-1: Waste volumes in cubic metres (m^3) for a 50-year operating lifetime of the Beznau, Gösgen and Leibstadt NPPs and 47 years for the Mühleberg NPP ("50-year NPP operating lifetime" scenario).

Explanation: Volumes of delivered and conditioned waste and the volume "packaged" in disposal containers in brackets. The information is divided according to the categories defined in the Nuclear Energy Ordinance (KEV 2004) with HLW = high-level waste, ATW = alpha-toxic waste and L/ILW = low- and intermediate-level waste. Additional division according to origin with SF: spent fuel assemblies; WA: waste from reprocessing; BA (NPP): operational waste from the NPPs (including waste produced at the Zwilag interim storage facility) and operational waste from the disposal of transport and storage casks; RA: reactor waste from the NPPs consisting of exchangeable components from the reactor pressure vessel that arise during operation (no SF); SA: decommissioning waste from the NPPs and the Zwilag interim storage facility, including Lucens waste; MIR: waste from medicine, industry and research, including CERN waste; OFA: waste from the operation and decommissioning of the surface facilities.

Spent fuel assemblies (SF) are packaged into disposal canisters without further conditioning before emplacement in the HLW emplacement drifts. The first volume listed refers to non-packaged SF. The number in brackets is the packaged volume, whereby some empty spaces in the canisters have to be taken into consideration due to the limit on the maximum permissible heat output.

The totals of the exact waste volumes given here may show negligible deviations from the sum of the rounded, individual waste volumes.

		Origin							**Total**
		SF (NPP)	**WA NPP)**	**BA (NPP)**	**RA (NPP)**	**SA (NPP)**	**MIR**	**OFA**	
Category acc. to KEV	**HLW**	1,124 [1)] (6,780)	114 [2)] (377)				9 [5)] (11)		1,247 (7,168)
	ATW		99 [2)] (432)			25 (25)	149 (465)		274 (923)
	L/ILW			9,568 [4)] (25,872)	360 (1,278)	19,239 (24,951)	11,718 (15,'463) [6)]	216 (571)	41,101 (68,135) [6)]
	Total	**1,124 (6,780)** [3)]	**213 (809)**	**9,568 (25,872)**	**360 (1,278)**	**19,264 (24,976)**	**11,876 (15,939)** [6)]	**216 (571)**	**42,622 (76,226)** [6)]

1) Corresponds to 2,407 tU.

2) Waste from reprocessing of 1,139 tU.

3) Full loading of disposal canisters (without considering empty spaces) would result in a volume of 6,128 m^3

4) This includes 2,467 m^3 of conditioned waste from the disposal of transport and storage casks, which is equivalent to a packaged volume of 2,648 m^3.

5) Fuel assemblies from the DIORIT reactor and compressed drums from PSI's Hotlab research facility.

6) This figure also includes 2,399 m^3 of CERN waste.

A.6 Interim storage capacities for radioactive waste

This Appendix sets out the concept for interim storage of waste packages and derives information on effective use of existing storage capacity. It is comparable to Appendix A.7 in WMP16, but differences result from the interim storage capacities being reviewed with the updated waste volumes of WMP21. This Appendix therefore provides a solid foundation for the information on interim storage given in Chapter 6. By providing details on the interim storage capacity for high-level waste, Federal Council stipulation 5.8 for WMP21 has been met. In connection with updating WMP16, new concepts for increasing the interim storage capacity for spent fuel assemblies and vitrified high-level waste have to be developed.

Low- and intermediate-level waste and alpha-toxic waste

The range of waste packages containing low- and intermediate-level waste conditioned from the NPPs for interim storage includes casks, cubic and cylindrical concrete containers and thick-walled cylindrical steel containers. Fig. A.6-1 shows the corresponding range of conditioned waste packages from NPPs destined for interim storage.

For interim storage, the waste packages (except for containers LC-84/86) are placed in storage containers (so-called stillage cages) with basic dimensions of approx. 6.10 m × 2.44 m (20 ft × 8 ft) and a height of approx. 2.05 m (stillage cage type 1) or 2.60 m (stillage cage type 2). Package-specific emplacement specifications are outlined in Tab. A.6-1.

The stillage cages are held in assigned storage spaces. For this purpose, the interim storage facilities ZWIBEZ LLW, Zwilag L/ILW and Zwilag ILW have a so-called 20 ft × 8 ft "storage space grid". Depending on the situation, different numbers of stillage cages can be stacked on top of each other. The available interim storage capacity is determined by the respective grid layout and stacking options for the respective storage spaces.

Fig. A.6-1: Waste packages used by the NPPs for conditioning and interim storage of low- and intermediate-level waste

Images are not to scale.

Tab. A.6-1: Package-specific emplacement specifications for interim storage of L/ILW and ATW (see text for details)

Note the increased number of waste packages per stillage cage in the case of the Beznau NPP (72 per rack).

Waste package	**Number of packages per stillage cage (space)**	**Storage in stillage cage (type)**	**Approximate height of stillage cage** [m]
100-litre drum (Beznau NPP package)	72	Type 1	2.05
200-litre drum (Beznau NPP package)	72	Type 1	2.05
200-litre drum (not Beznau NPP)	68	Type 1	2.05
180-litre flask (WA-ATW)	56	Type 1	2.05
1 m^3-BC	11	Type 1	2.05
Mosaik-II	5	Type 1	2.05
KC-T12	3	Type 2	2.60
LC-84	3 or 4.5	-	-
LC-86	3	-	-

The following situations apply to the respective interim storage facilities (ZWIBEZ LLW, Zwilag L/ILW and Zwilag ILW) with regard to the **interim storage of stillage cages**:

- ZWIBEZ LLW:
  - Number of 20 ft × 8 ft storage spaces for stillage cages: 55
  - Maximum permissible stacking of type 1 stillage cages: 8-fold
  - Theoretical capacity of stillage cages in the storage spaces using the available space/volume: 440 type 1 stillage cages
- Zwilag L/ILW:
  - Number of 20 ft × 8 ft storage spaces for stillage cages available in the storage hall for LLW: 143
  - Maximum permissible stacking of stillage cages for type 1: 8-fold (6-fold for type 2 stillage cages)
  - Number of storage spaces for stillage cages available in the storage hall for ILW: 64
  - Theoretical capacity of stillage cages (storage spaces in the storage halls for LLW and ILW): 1150
- Zwilag ILW:
  - Number of 20 ft × 8 ft storage spaces for stillage cages: 40 (these storage spaces are designed as bays covered with concrete slabs)
  - Maximum permissible stacking of type 1 stillage cages: 8-fold
  - Theoretical capacity of stillage cages in the storage spaces using the available space/volume: 320 type 1 stillage cages

Interim storage of LC-84/86 containers is carried out directly without stillage cages. The dimensions are designed in such a way as to allow storage of a collection of three LC containers per storage position. When stacking, however, the maximum permissible weight loads of the floor slabs, calculated for each storage position, must be considered.

The following limits have been set for the respective interim storage facilities (ZWIBEZ LLW, Zwilag L/ILW):

- ZWIBEZ LLW:
  - 3 LC-84/86 / storage space for stillage cages (based on 8-fold stacking)
- Zwilag L/ILW (storage hall for LLW):
  - 4.5 LC-84 / storage space for stillage cages (based on 10-fold stacking)
  - 3 LC-86 / storage space for stillage cages (based on 8-fold stacking)

Tab. A.6-2 shows the distribution of the waste containers to be temporarily stored in ZWIBEZ LLW, Zwilag L/ILW and Zwilag ILW, assuming that the existing storage capacity of Zwilag ILW is almost fully exploited. As a boundary condition, it is assumed that all waste containers from the Gösgen, Leibstadt and Mühleberg NPPs are stored at Zwilag ILW and Zwilag L/ILW. For the Beznau NPP, potentially combustible waste and all containers with a surface dose rate of more than 7.5 mSv/h have to be stored in Zwilag ILW. In addition, the containers from all nuclear power plants conditioned by the plasma furnace remain in Zwilag, as do the KC-T12 already produced at Zwilag and, eventually, the LC-84 containers produced for the nuclear power plants.

Tab. A.6-2: Occupancy (number of waste containers) of ZWIBEZ LLW, Zwilag ILW and Zwilag L/ILW for the interim storage of low- and intermediate-level NPP waste in the "60-year NPP operating lifetime" scenario.

For the Beznau NPP, only the 100-litre and 200-litre waste containers are shown separately due to the different loading of stillage cages (see Tab. A.6-1); "rest" refers to all the other containers from the Beznau, Gösgen, Leibstadt and Mühleberg NPPs as well as from the Zwilag interim storage facility.

Waste package	**ZWIBEZ LLW**	**Zwilag ILW**	**Zwilag L/ILW**
	Beznau NPP	Beznau NPP / rest	Beznau NPP / rest
100 litres / 200 litres	3,582	4,160/15,448	2,132 / 19,883
1 m^3-BC	-	-	88
Mosaik-II	256	-	488
KC-T12	-	-	33
LC-84	190	-	1,256
LC-86	340	-	514
180-litre flasks (WA-ATW)	-	552	-

With the packaging specification in Tab A.6-1, the maximum permissible stacking and the waste packages to be stored in line with Tab. A.6-2, the capacity/use of the interim storage facilities for low- and intermediate-level waste in Tab. A.6-3 is obtained.

Tab. A.6-3: Currently existing and required interim storage capacity (number of storage spaces for stillage cages) and occupancy rate of Zwilag ILW, Zwilag L/ILW and ZWIBEZ LLW for the "60-year NPP operating lifetime" scenario.

Interim storage facility	**Existing capacity (in number of storage spaces for stillage cages)**	**Required capacity (in number of storage spaces for stillage cages)**	**Occupancy [%]**
Zwilag ILW	320	295	93 [1)]
Zwilag L/ILW	1150	890	78
ZWIBEZ LLW	440	278	64

[1)] In the case of a need for additional storage capacity in Zwilag ILW, waste can be conditioned for storage in Zwilag L/ILW at any point in time.

High-level waste

The high-level waste from NPPs (vitrified waste from reprocessing, non-reprocessed spent fuel assemblies) is transferred or transported to the ZWIBEZ HLW or Zwilag SF/HLW(WA) interim storage facilities in transport and storage casks and held there. Each transport and storage cask requires its own storage position. ZWIBEZ HLW and Zwilag-SF/HLW(WA) currently have 60 and 200 storage positions, respectively, i.e. in total 260 storage positions for transport and storage casks are available.

Federal Council stipulation 5.8 in response to WMP16 (see Appendix A.7) requires the operators of the nuclear power plants to develop new concepts for increasing the interim storage capacity for spent fuel assemblies and vitrified high-level waste for WMP21. In compliance with this condition, a concept was developed to increase the number of storage positions for transport and storage casks for SF and WA-HLW. As outlined in Kasemeyer (2021), different variants with regard to the optimised number of storage positions exist to meet the requirement that the individual canisters have to be readily accessible for inspections and any maintenance work. As a result, 69 and 228 storage positions, respectively, are thus available at ZWIBEZ HLW and Zwilag SF/HLW(WA), i.e. 297 spaces for transport and storage casks in total.

In the scenario with a 50-year operating lifetime for the Beznau, Gösgen and Leibstadt NPPs and 47 years for the Mühleberg NPP ("50-year NPP operating lifetime" scenario; see Appendix A.5), a total of 248 storage positions are required, of which 225 are for transport and storage casks containing spent fuel assemblies and 23 are for transport and storage casks containing waste from reprocessing. For these scenarios, the available 260 storage positions are sufficient. A study of ZWIBEZ HLW and Zwilag SF/HLW(WA) shows an occupancy rate of 95%.

A total of 274 storage positions are required for the scenario with a 60-year operating lifetime for the Beznau, Gösgen and Leibstadt NPPs and 47 years for the Mühleberg NPP ("60-year NPP operating lifetime" scenario, see Section 2.1), including 251 storage positions for transport and storage casks containing spent fuel assemblies. When considering ZWIBEZ HLW and Zwilag SF/HLW(WA) together, this leads to an occupancy rate of 105% for the 260 storage positions. If, on the other hand, the number of storage positions is increased to 297 storage positions by optimising the available storage area, the resulting total occupancy rate is 91% for the interim storage facilities for high-level waste.

Federal Government waste from medicine, industry and research (MIR)

With the existing Swiss Federal Interim Storage Facility, BZL-1, and the planned BZL-2, two interim storage facilities with an overall capacity for around 6,300 200-litre containers and 690 KC-T12 containers are available for waste for which the Federal Government is responsible. The waste actually generated also includes 1 m^3 and 1.2 m^3 containers, (small) cylinders with different dimensions and a few large 16 m^3 containers. To consider the effectively occupiable interim storage capacity of 6,300 m^3, the storage casks used are converted into the actually required storage volume. Nine 200-litre containers are held in a storage hall and require 4 m^3 in total. Including the pitch between containers, a KC-T12 container requires a storage volume of around 5.12 m^3. In addition, consideration is given to the fact that:

- while the Federal Government will continue to produce waste that is to be disposed of in the deep geological repository until the end of 2064 based on the "60-year NPP operating lifetime" scenario (2063 in the "50-year NPP operating lifetime" scenario), this waste can be delivered directly to the repository as of 2050, which is why the interim storage facilities (BZL-1, BZL-2) will not face additional occupancy
- as the decommissioning of the PSI West facilities can be planned from 2050 onwards, these interim storage facilities (BZL-1 and BZL-2) will also not result in additional occupancy

These assumptions result in a required repository volume in 2060 of a currently estimated maximum of 6,205 m^3 and therefore an occupancy rate of the BZL-1 and BZL-2 interim storage facilities of around 98.5% (6,205/6,300 m^3).

With regard to the available interim storage capacity for CERN waste, ENSI formulated an application requiring the responsible federal authorities to demonstrate that sufficient interim storage capacity is available for CERN waste, including spare capacity for the decay storage of very low-level radioactive materials. Appendix A.8.10 outlines how the responsible federal authorities have responded to this requirement.

A.7 Overview of the decree and stipulations of the Federal Council for the Waste Management Programme 2021 and their application in this report

Decree	
1. With the Waste Management Programme 2016 (Nagra 2016b, NTB 16-01), Nagra has fulfilled the legal mandate of the waste producers in line with Art. 32 KEG and Art. 52 KEV.	
2. The next Waste Management Programme is to be submitted in 2021 together with the 2021 Cost Study.	
3. Together with the construction licence application for a deep geological repository, Nagra has to submit to DETEC a report estimating the costs of retrieving the waste from an L/ILW repository, an HLW repository or a combined repository during the monitoring phase and after closure. In both cases, the costs of delivering this waste to an interim storage facility also have to be estimated.	
4. Stipulations for the Waste Management Programme 2016 and 2021 s	**Addressed in:**
Item 6.3 Waste volumes: As part of future Waste Management Programmes, Nagra must outline the waste volumes that are currently expected and document that these are bounding. Nagra must also describe the methodology on which this prediction is based, what differences there are compared to earlier predictions and how these differences are to be justified and evaluated. *To evaluate the interim storage capacity and the radiological inventory and waste volumes to be emplaced in the deep geological repositories, the Waste Management Programme refers to the "60-year NPP operating lifetime" scenario that forms the basis for the repository conceptual design and the safety case. For further information illustrating the method used to predict the waste volumes, WMP21 refers to corresponding documentation (Nagra 2014c). The database for the Model Inventory for Radioactive Materials (MIRAM) is updated with a view to the general licence application.* *The maximum disposal capacity is determined with the general licence (Art. 14 Par. 2 KEG). Considering the time horizon for the realisation and operation of the deep geological repositories, it is necessary to include planning reserves in the maximum disposal capacity.*	Chapter 2 Chapter 4 Chapter 6 Appendix A.5 Tab. A.3-1
Item 6.4 Realisation plan: In future Waste Management Programmes, Nagra must outline its preparations for the long-term archiving of information on the deep geological repositories. To prepare the construction licence application, nuclear energy legislation and Guideline ENSI-G03 (ENSI 2020b) require a project for the monitoring phase, a facility closure plan and concepts for retrieval, marking and temporary closure in times of crisis. The corresponding preliminary work must also be presented in future Waste Management Programmes. *WMP21 contains information on long-term archiving of documentation and on marking the repository and demonstrates ongoing work with regard to passing on information to future generations.* *Quality management measures and the implementation of all project phases up to closure of the entire repository are also outlined in WMP21.* *With regard to the preliminary work on closure, see Appendix A.8.4, Nagra (2021f) and the RD&D-Plan 2021 (Nagra 2021e).*	Section 5.1 Section 5.7 Section 5.8 Section 5.9 Appendix A.2.2 Appendix A.8.4 Nagra 2021e Nagra 2021f

4. Stipulations for the Waste Management Programmes 2016 and 2021 (cont.)	**Addressed in:**
Item 6.5 Taking into account experience and the current state of the art in science and technology: In future Waste Management Programmes, Nagra must demonstrate that, based on current experience and the state of the art in science and technology, all necessary measures have been taken to meet the legally stipulated protection objectives that apply during the construction and operation of a deep geological repository as well as after its closure. With regard to enhanced safety, appropriate optimisation measures must be outlined and verified, and their practicality must be evaluated in an overall context (i.e. operational safety, long-term safety, transport safety, personal doses, arising of new waste, etc.). *WMP21 outlines the existing potential for optimising the facilities and the required flexibility for taking into account future developments. The purpose of this is to ensure that all necessary measures are taken to comply with the specified protection objectives during construction and operation and after closure.* *In addition, and as required in ENSI (2020b), Appendix A.4 demonstrates the optimisation procedure based on which safety-relevant decisions are made in the repository project. For basic principles relating to the process and overall planning as well as temporal implementation in line with the Nagra Roadmap, see Nagra (2021d) and Nagra (2021e).* *The 2021 RD&D Plan (Nagra 2021e) also explains in detail how experience and the current state of the art of science and technology are taken into consideration.*	Chapter 1 Chapter 2 Appendix A.3 Appendix A.4 Nagra 2021e Nagra 2021d
5. Stipulations for the Waste Management Programme 2016 modified for the Waste Management Programmes 2021 and future programmes	
4.1 Research programme: Together with the Waste Management Programme, Nagra must submit a Research, Development and Demonstration (RD&D) Plan that documents the purpose, scope, type and temporal sequence of future RD&D activities. Future RD&D Plans should include a comprehensive list of all important open issues, together with information on how and within what time frame Nagra plans to resolve these issues. The list should also indicate which questions are critical for reaching the next milestones and how the required solutions can be achieved in a timely manner. In addition, it should describe the consequences that would arise if the milestone targets are not or not fully met. *WMP21 is restricted to a presentation of the most important RD&D activities and their temporal link to the realisation plan and refers to the RD&D Plan and other relevant reports for more details.* *The 2021 RD&D Plan (Nagra 2021e) outlines the purpose, scope, nature and temporal sequence of currently ongoing and future RD&D activities. In addition, based on roadmaps, the 2021 RD&D Plan illustrates for the first time how the individual research and development activities are connected with each other and with the milestones and decision-making process for realising a deep geological repository.*	Appendix A.2 Appendix A.4 Appendix A.8.7 Nagra 2021e

5.	Stipulations for the Waste Management Programme 2016 modified for the Waste Management Programmes 2021 and future programmes (cont.)	Addressed in:
4.2	**Overall repository system**: In future Waste Management Programmes, Nagra must outline how the overall deep geological disposal system is to be implemented technically and temporally and how the individual research and development activities are connected with each other and with the milestones and decisions related to realising a deep geological repository. With regard to its decisions, Nagra must demonstrate when and why it will undertake which research projects and developments, and where and when it will set which priorities. For safety-relevant decisions, different alternatives must be considered, and a project must be selected that is beneficial to overall safety. Any decisions reached must be documented together with their justification in a manner that remains valid in the long term so that also they remain transparent in the future. *WMP21 (Appendices A.3 and A.4) presents how outstanding elements of waste management (particularly deep geological disposal) will be approached, what must be decided/realised within what time frame and within what legal/regulatory framework, as well as how the potential for optimisation and the flexibility to take into account future developments can be maintained. In addition, and as required in ENSI (2020b), the optimisation process has been outlined based on which safety-relevant decisions are made in the repository project.* *For basic principles relating to the procedure and to present planning in the overall repository system, see Nagra (2021d) and Nagra (2021e). The latter report uses roadmaps to outline how technical topics and work priorities are connected with the milestones and decisions for realising a deep geological repository.* *The 2021 RD&D Plan (Nagra 2021e) also outlines which significant issues are resolved by Nagra and within what timeline, so that the insights help to provide a stage-appropriate basis for each respective licensing step in a timely manner.*	Appendix A.3 Appendix A4 Nagra 2021d Nagra 2021e
6.	**Stipulations for the Waste Management Programme 2021**	
5.1	**Reduction of potential gas production:** In the Waste Management Programme 2021, Nagra must present whether it is necessary to further reduce potential gas production from metallic waste and whether changes should be made to resulting requirements on repository-specific waste properties with a view to the realisation of deep geological repositories. *WMP21 demonstrates the current technological state of the art with regard to waste conditioning. For many years, the focus has been on the possibility of melting metals and reducing the content of organic materials. At present, Nagra is preparing the safety case for the general licence application, and within this framework, the gas synthesis report (Diomidis et al. 2016) is being updated.*	Chapter 2 Appendix A.8.1 Diomidis et al. 2016

6. **Stipulations for the Waste Management Programme 2021** (cont.)	**Addressed in:**
5.2 Pilot repository In the next Waste Management Programme, Nagra must further concretise the scope and content of the measurements for monitoring a pilot repository for HLW or L/ILW and outline current knowledge with regard to the interpretation or interpretability of the measured data as well as ensure that the knowledge gained can be applied to the main repository. *The pilot repository monitoring programme is developed in parallel with the realisation steps of a repository. Within the framework of a background report (Nagra 2021c,) an initial site-independent concept for monitoring a pilot repository is documented. The report outlines Nagra's methodology with regard to selecting measurement parameters for monitoring the pilot repository. It also shows currently ongoing research work on managing and interpreting measurement data as well as on the requirements for the transferability of data from the pilot repository to the main repository.*	Section 3.1 Appendix A.8.2 Nagra 2021c
5.3 Consequences of a combined repository: In the Waste Management Programme 2021, Nagra must outline the existing variants for a combined repository solution with a view to avoiding potential safety-relevant impacts on the individual repository sections. In addition, the relative spatial requirements and the variants targeted from a safety perspective must be included. *For further information, see Appendix A.8.3. In addition, Nagra has prepared two reports evaluating the interactions between the L/ILW and HLW sections of a combined repository: NAB 19-15 (Nagra 2020a) includes information on the interactions related to construction and operation, NAB 20-31 (Nagra 2021b) deals with long-term safety. These reports show that safety is not negatively impacted by these interactions.*	Section 3.1.1 Section 3.2 Appendix A.8.3 Nagra 2020a Nagra 2021b
5.4 Closure variants: In the Waste Management Programme 2021. Nagra must outline and compare potential closure variants as preliminary work for creating a concept for the general licence application. *As preliminary work for the required concept for the general licence application, Nagra prepared a report (Nagra 2021f) in which factors impacting the operation and realisation time during the closure phase are outlined. The report compares and evaluates potential closure variants. For a summary of the most important insights, see Appendix A.8.4.*	Section 3.1 Appendix A.8.4 Nagra 2021f
5.5 Zero measurements: In the Waste Management Programme 2021, Nagra must document preliminary work activities concerning zero measurements. These should include a justified explanation of which processes and parameters are important for monitoring the environment and the zero measurements and how these will be recorded. *Nagra's preliminary work on zero measurements is documented within the framework of a background report (Fanger et al. 2021). The report shows which parameters are important for monitoring the environment and the geological surroundings as well as for zero measurements and how these are measured. For further information, see Appendix A.8.5.*	Section 3.1 Appendix A.8.5 Fanger et al. 2021
5.6 Stages of using the facilities for underground geological investigations: When updating the Waste Management Programme, Nagra must outline the requirements for the different stages in which the facilities for underground geological investigations will be used. In addition, Nagra must explain what kind of technical demonstrations are planned for converting these facilities at a later point in time and within what time frame this is expected to take place (Cloet et al. 2014). *For further information, see Appendix A.8.6. Nagra has prepared a background report (Nagra 2021a) outlining the current concept for underground geological investigations in a stage-appropriate manner. As part of this concept, the stages of using the facilities for the underground geological investigations are shown and their eventual conversion is explained.*	Section 3.2 Chapter 5 Appendix A.8.6 Nagra 2021a

6.	**Stipulations for the Waste Management Programme 2021** (cont.)	**Addressed in:**
5.7	**Experience gained in repository conceptual design:** Within the framework of the Waste Management Programme 2021, Nagra must outline whether and, where applicable, through which additional feasibility-related investigations specific knowledge can be gained as early as possible to optimise the repository conceptual design. *Appendix A.4 outlines the optimisation procedure, including optimisation of the repository conceptual design within an overall timeframe. For detailed information on planning the overall deep geological disposal and implementation system based on roadmaps, see Nagra (2021d) and Nagra (2021e).*	Appendix A.4 Nagra 2021d Nagra 2021e
5.8	**Number of storage positions for interim storage:** When updating the Waste Management Programme, the operators of the nuclear power plants must develop new concepts for increasing the number of storage positions for interim storage for spent fuel assemblies and vitrified high-level waste. These concepts must consider that individual canisters have to be readily accessible for inspections and potential maintenance work. *The waste producers have prepared a background report (Kasemeyer 2021) presenting different variants for increasing the number of storage positions for the interim storage of spent fuel assemblies and vitrified high-level waste. The requirement that the individual containers have to be readily accessible for inspections and potential maintenance work is considered in the concept report. For more information on the interim storage facility of transport and storage casks, see Chapter 6 and Appendix A.6.*	Chapter 6 Appendix A.6 Kasemeyer 2021
7.	**Stipulations for the Waste Management Programme 2021 and following**	
6.1	**Research, Development and Demonstration Plan:** Nagra must incorporate research activities regarding the ageing of spent fuel assemblies and dry storage in future Research, Development and Demonstration Plans. The results of the research projects and experiments listed in the previous version of the RD&D Plan must be outlined. *Appendix A.8.7 shows results from research projects and experiments as well as the scientific and technological state of the art with regard to long-term stability of spent fuel assemblies during interim storage. For detailed information, see Axpo (2015) and Nagra (2021e).*	Chapter 2 Appendix A.8.7 Nagra 2021e Axpo 2015

A.8 Supplementary information on specific Federal Council stipulations and on handling additional recommendations for the Waste Management Programme 2021

The purpose of Appendix A.8 is to provide an overarching explanation of how the waste producers have responded to specific stipulations made by the Federal Council (Bundesrat 2018) regarding WMP21 and subsequent Waste Management Programmes (A.8.1 – A.8.8), as well as additional recommendations for WMP21 (A.8.9 and A.8.10). For detailed information, see the corresponding background reports for WMP21 (see Section 1.1) and/or other reference material.

A.8.1 Stipulation 5.1 on reducing potential gas production

In the Waste Management Programme 2021, Nagra must present whether it is necessary to further reduce potential gas production from metallic waste and whether changes should be made to resulting requirements on repository-specific waste properties with a view to the realisation of deep geological repositories.

The technological state of the art for waste treatment is re-evaluated periodically and developed further as appropriate. For many years, the focus has been on the possibility of melting metals and on reducing the content of organic materials. The latter is achieved for some of the waste using the plasma furnace at the Zwilag interim storage facility.

In its expert opinion on WMP16, ENSI noted that it follows Nagra's argumentation and that reducing and melting metallic waste offers a higher safety-based optimisation potential than reducing organic substances. ENSI has also recognised that the melting procedure can be applied at any point in time until the waste has been emplaced in the deep geological repository.

In WMP16, the waste producers stated that they consider the treatment of already conditioned waste as disproportionate. The authorities were able to follow this line of argument and cautioned not to irreversibly condition the metallic waste elsewhere. According to the Federal Nuclear Safety Commission (KNS 2018), this statement is particularly important with a view to the requirement in Art. 54 Par. 1 KEV calling for the quickest possible conditioning of radioactive waste.

Pyrolysis is a fundamentally feasible option, but, due to the low relevance of organic materials in a deep geological repository and an overall assessment based on the current state of the art, it is not appropriate. However, as ENSI considers reducing the amount of organic waste as a sensible option in connection with other aspects (radionuclide complexation), the waste producers will continue their efforts to reduce bitumen when conditioning certain types of operational waste. In contrast, the waste producers do not consider a corresponding follow-up treatment of already conditioned organic waste to be useful.

At present, Nagra is preparing the safety case for general licence application, and in this context, the gas synthesis report (Diomidis et al. 2006) is being updated. The safety analysis is based on the site-specific understanding of the geological conditions and integrates new insights with regard to gas production and pressure build-up. Based on the current state of the art, Nagra expects that it is possible to demonstrate with a significant safety margin that the expected pressure build-up from gases will not have a negative impact on the favourable properties of the Opalinus Clay in terms of the expected development of the repository system. The safety analysis for the general licence application also includes a demonstration that, in the very unlikely event of a pressure-induced gas escape through the host rock, the radiological impact on the biosphere will either be minimal or practically non-existent. As a result, it can be concluded that, to date, no information exists that would make a further reduction of gas production necessary. Optimising the safety of a deep geological repository is achieved using a stepwise approach in line with the decommissioning projects of the remaining NPPs; their decommissioning will provide an important source of metallic waste. Should it become apparent in the context of the multi-stage licensing procedure in line with KEG (2003) that a further reduction of gas production might be required, this option could, in principle, be realised by the time emplacement of radioactive waste begins.

A.8.2 Stipulation 5.2 on the pilot repository

In the next Waste Management Programme, Nagra must further concretise the scope and content of the measurements for monitoring a pilot repository for HLW or L/ILW and outline present-day knowledge with regard to the interpretation or interpretability of the measured data as well as ensure that the knowledge gained can be applied to the main repository.

Within the framework of a background report for WMP21 (Nagra 2021c), and in connection with Federal Council stipulation 5.2, Nagra presented its preliminary work on monitoring the pilot repository.

The pilot repository monitoring programme is developed in parallel with the realisation steps of a repository. Along with the general licence application, an initial integral monitoring concept will be submitted; this also includes a concept for monitoring the pilot repository. The project for the monitoring phase must be submitted along with the construction licence application.

Nagra participated in the EU research project "Development and Demonstration of Monitoring Strategies and Technologies" (Galson Sciences Limited 2019) that developed strategies for selecting monitoring parameters for different deep geological disposal concepts. The focus lay on monitoring the engineered barrier system and the near-field rock during the operation of a deep geological repository. As part of Modern2020 (Galson Sciences Limited 2019), Nagra developed a methodology for the Swiss concept, which identifies monitoring parameters that can be measured technologically, do not negatively impact the safety of the pilot and main repositories and play an important role in demonstrating long-term safety. With this methodology, it is possible to regularly evaluate and modify the monitoring parameters for a pilot repository by applying new developments in the area of measurement technology.

Nagra is participating in the new EU research programme "Monitoring Equipment and Data Treatment for Safe Repository Operation and Staged Closure" (MODATS), which, over the next three years, will develop methods for managing and interpreting monitoring data that can be used in the pilot repositories. Nagra will use monitoring data from the FE Experiment conducted at the Mont Terri Rock Laboratory to develop its methods.

The design, emplacement method and backfilling of the pilot repository will be comparable to those for the main repository, and a small, representative amount of waste will be emplaced in the pilot repository (Art. 66 Par. 3c and 3d KEV). The pilot repository will be positioned in such a manner that its geological and hydrogeological conditions will be comparable with those of the main repository (Art. 66 Par. 3a KEV), at the same time ensuring spatial and hydraulic separation (Art. 66 Par. 3b KEV). This is investigated during the excavation of the pilot and main repository drifts. These measures ensure that the monitoring results can be transferred from the pilot repository to the main repository (Art. 66 Par. 2 KEV).

A.8.3 Stipulation 5.3 on the consequences of a combined repository

In the Waste Management Programme 2021, Nagra must outline the existing variants for a combined repository solution in terms of avoiding potential safety-relevant impacts on the individual repository sections. In addition, the relative spatial requirements and variants sought from a safety perspective must also be documented.

A combined repository consists of spatially separated sections for HLW and L/ILW in the same geological siting region. If the area for the HLW repository has been defined and there is still sufficient space for an L/ILW repository, and the L/ILW and HLW repository sections do not impact each other negatively from a safety perspective (e.g. construction, operational and long-term safety), and if the final overall safety evaluation allows, constructing a combined repository is clearly preferred to the option of constructing two individual repositories (see Section 3.1.1). In connection with ENSI's requirement, the above-mentioned stipulation for WMP21 can be interpreted as a requirement to demonstrate any existing interactions between the L/ILW and HLW repository sections of a combined repository and to explain why these interactions have no relevant impact on repository safety.

Nagra has prepared two background reports for WMP21 evaluating the interactions between the L/ILW and HLW repository sections of a combined repository: NAB 19-15 (Nagra 2020a) contains information on the interactions related to construction and operation, NAB 20-31 (Nagra 2021b) deals with long-term safety.

Nagra (2020a) compares a model combined repository with two individual repositories (L/ILW repository and HLW repository). Similarly to the individual repositories, a combined repository consists of the surface infrastructure (e.g. surface facility, auxiliary access facilities), access structures (e.g. access shaft, ventilation shaft) and structures at the disposal level (e.g. central area, disposal area accesses, HLW main repository and L/ILW main repository). As the combined repository is an overall facility, many elements of the surface infrastructure and some of the underground structures (access structures and central area) necessary for the construction of the emplacement rooms and for emplacement of the L/ILW and HLW waste can be jointly used, including during the monitoring phase. Joint use results in synergies such as the exploration of the geological underground and continuity and know-how of the operating staff. In addition, compared with two individual repositories, a combined repository has a lower overall impact (e.g. area, energy and resource consumption, construction volumes and volumes of the excavated materials, emission of greenhouse gases); both aspects are arguments in favour of realising a combined repository.

The report explains that the same processes are foreseen in a combined repository as in the respective individual repositories. It can be assumed that the same or equivalent facilities and security systems are in place for all repository types and that the level of operational safety is thus identical.

The realisation plan for the combined repository includes two phases during which activities have to be separated from a safety perspective. This concerns L/ILW emplacement operations and the concurrent construction of the HLW repository section and the sequential emplacement of HLW and L/ILW. However, also here, the activities correspond with those for the individual repositories and can be decoupled in terms of time and space, thus providing the same level of operational safety.

A deep geological repository must be planned and constructed in such a way as to ensure that the protection objectives regarding operational safety are met, i.e. the precautions for nuclear operational safety, radiation protection, occupational health and safety, escape routes, rescue, evacuation and intervention as well as security have to comply with legal and regulatory provisions. This principle applies regardless of the repository type and the associated facility elements and operational procedures. A suitable design and layout of the individual repository sections and suitable operational procedures ensure that the structural and operation interactions between the L/ILW and HLW repository sections of a combined repository do not result in any safety-relevant impacts.

Nagra Work Report NAB 20-31 (Nagra 2021b) outlines safety-relevant interactions between the L/ILW and HLW repository sections of a combined repository in connection with assessment of long-term safety. Starting with a comprehensive summary of regulatory requirements and expectations, a method was developed to derive site-specific, safety-based requirements that have to be met with regard to the design of the HLW and L/ILW repository sections of a combined repository. This includes, in particular, the minimum distance to be maintained between the repository sections to ensure that potential thermal, hydraulic, rock-mechanical and chemical (THM-C) interactions between the repository sections through the host rock or any radiological interactions through the host rock do not present any safety-relevant impacts. In addition, site-specific aspects were analysed regarding the mutual design of the repository sections (e.g. alignment of the emplacement rooms, variants of the L/ILW cavern cross-sections for moderate or large overburdens) and the resulting impacts on the space available at the repository site. Further analyses relate to potential THM-C interactions along the access structures to the two repository sections as well as the transport of dissolved and volatile radionuclides along the backfilled underground structures. Based on the example of a model combined repository project, the safety-relevant interactions were quantitatively estimated by applying a model-based indicator methodology. This method is used for an overall safety evaluation of the combined repository as opposed to two individual repositories for HLW and L/ILW in different siting regions within the framework of the safety-based comparison for Stage 3 of the Sectoral Plan.

Should the safety-based comparison not reveal any differences, in line with ENSI (ENSI 2018c), the waste producers have the choice whether to include further aspects in their considerations and overall evaluation. As no negative interactions result for either construction and operation or for long-term safety that cannot be solved with an appropriate design and layout as well as construction and operational procedures, the aspects presented in Nagra (2020a) and Section 3.1.1 clearly support the realisation of a combined repository.

A.8.4 Stipulation 5.4 on closure variants

In the Waste Management Programme 2021, Nagra must outline and compare potential closure variants as preliminary work for creating a concept for the general licence application.

In line with Art. 23 KEV, a site-specific concept is required for the closure of the repository in Switzerland. However, according to Art. 16 Par. 1 Letter e KEG and Art. 24 KEV, closure plans are not required prior to preparing the construction licence application. The closure concept includes the development of a system based on the technological and scientific state of the art. It must be robust and, with a view to the long timespan until final closure, must offer an appropriate degree of flexibility to consider future optimisation.

Complying with and ensuring long-term safety is the most important requirement on the concept and thus also on the closure system. The successive backfilling and sealing of the emplacement drifts and caverns, access structures and the final overall closure of the repository are important components of the multi-barrier system and contribute to preventing or minimising the transport of radionuclides from the underground facility elements.

As preliminary work for the concept required for the general licence application and with a view to Federal Council stipulation 5.4, Nagra has produced a background report (Nagra) describing a site-independent closure concept. This report explains the most important legal provisions for closure and describes the closure requirements on long-term safety in a stage-appropriate manner. Design and dimensioning principles are derived based on overarching design requirements for closure. These principles are applied to develop concepts for all sealing structures and to roughly dimension these for the corresponding place of application (emplacement rooms, disposal areas and access structures). Different structural variants are developed for sealing to cover a broad spectrum of potential geological boundary conditions and to comply with the safety functions for long-term safety. The approach to geotechnical hazards thus avoids negative impacts on long-term safety.

In line with Federal Council stipulation 5.4, the planning of the time schedule for closure, for which variants are to be investigated in accordance with Federal Council stipulation 5.4, must fit into the realisation plan for the combined repository (Fig. 5.3-1) and take into account the requirements on long-term safety, operational safety and radiological protection. From the perspective of long-term safety, passive safety should be provided as soon as possible, i.e. by backfilling the repository and constructing the sealing structures. This is also advantageous with regard to radiological protection and operational safety. For the HLW emplacement drifts, ENSI (Guideline ENSI-G03, Section 7.3a, ENSI 2020b) specifies sealing immediately after the end of emplacement. For safety reasons, an identical procedure is foreseen for the L/ILW emplacement caverns. The requirement to ensure retrievability until closure "without undue effort" is also accounted for. As long as the repository remains accessible, the effort to remove installed backfilling and sealing is small when compared to the overall effort involved in waste retrieval.

The monitoring phase stipulated in the Nuclear Energy Act (planning assumption: 50-year duration) serves to monitor selected aspects of the safety demonstration. In general, monitoring takes place in the observation drifts of the HLW and L/ILW pilot repositories, which must remain accessible during the entire monitoring period. Closure variants therefore only include different closure dates for HLW and L/ILW disposal area accesses and for the accesses to the pilot repositories.

An initial monitoring phase is foreseen for which the planning assumption in WMP21 is a duration of 10 years. During this initial phase, the disposal area accesses are kept open until the emplacement rooms have been sealed, and these seals are then monitored. After the successful completion of this initial phase, the disposal area accesses are backfilled and sealed. Extending or reducing the initial monitoring phase is possible in principle and should not impact on long-term safety. With the timely closure of the emplacement rooms, radiological protection is ensured at all times. Regular maintenance of the underground structures that remain open contributes to operational safety.

In the background report, and in accordance with Federal Council stipulation 5.4, the planning assumptions outlined in WMP21 are compared with variants. Based on current assumptions, the closure process of the repository as outlined in the realisation plan (Nagra 2021) presents the best solution to date as it provides a well-balanced consideration of the various requirements. During continued concept development until the general licence application and beyond, further variants will be investigated and the concept optimised.

A.8.5 Stipulation 5.5 on zero measurements

In the Waste Management Programme 2021, Nagra must document its preliminary work activities concerning zero measurements. Documentation should explain which processes and parameters are important for monitoring the environment and the zero measurements and how these will be recorded.

Within the framework of a background report for WMP21 (Fanger et al. 2021), and in connection with Federal Council stipulation 5.5, Nagra has presented its preliminary work on zero measurements.

Monitoring the environment and the geological surroundings as well as the associated zero measurements constitute part of the integral monitoring concept for the deep geological repository. The data from monitoring the environment and the geological surroundings form the basis for differentiating natural alterations and fluctuations in the environment and geological surroundings of the repository from changes potentially resulting from the construction, operation and closure of the deep geological repository. Based on conceptual and site-independent considerations, Fanger et al. (2021) generically describe examples of measurement programmes that are planned and conducted by the operator of the repository as well as current planning for long-term data management and archiving of the samples. After site selection, and before the general licence application is submitted, the measurement programmes are concretised in accordance with the selected site.

The concept for monitoring the environment and the geological surroundings foresees the following measurement programmes, sample collections and analyses:

- meteorology (meteorological measurement station, sampling using air filters and dust collector panels as well as precipitation and radiological analyses of the samples)
- soil (soil vapour measurement stations for radon, soil samples, radiological analyses of the samples)
- surface water bodies (channel measurement locations, surface water samples, hydrochemical and radiological analyses of the samples)
- springs (measurement locations at springs, springwater samples, hydrochemical and radiological analyses of the samples)

- groundwater (shallow piezometers and long-term monitoring systems in deep boreholes, groundwater samples, hydrochemical and radiological analyses of the samples)
- geodynamics and geotechnology (deformation monitoring of structures as well as monitoring of the disposal areas and the siting region by means of levelling measurements and permanent GNSS measurement stations)
- seismicity (seismometers)

Zero measurements to record the undisturbed initial state constitute one of the central aspects of monitoring the environment and the geological surroundings as they form an important basis for the entire lifecycle of a deep geological repository, from site characterisation via preservation of evidence to the orderly closure of the repository and its release from nuclear energy legislation. They also provide a basis for determining intervention values. For reliable collection, zero measurements have to be started well in advance of constructing the access facilities for underground geological investigations and prior to waste emplacement, and they must also cover statistical, seasonal and annual fluctuations.

Some measurement programmes have already been initiated in the potential siting regions (permanent GNSS measurement stations, seismometers, long-term monitoring in deep boreholes) and initial zero measurements have been recorded. The start of zero measurements for the measurement programmes on meteorology, surface water bodies, springs and shallow groundwater as well as summarising ongoing measurement programmes are planned on completion of the expert review of the general licence application (around 7 years prior to constructing the access structures) or, for levelling, seismometers and deep groundwater, at the beginning of the "preparation for underground geological investigations" phase (around 3 years prior to constructing the access structures). Intensive radiological zero measurement campaigns are planned prior to constructing the access structures and starting emplacement operations.

A.8.6 Stipulation 5.6 on stages of using the facilities for underground geological investigations

When updating the Waste Management Programme, Nagra must outline the requirements for the different phases for which the facilities for underground geological investigations will be used. In addition, Nagra must explain what types of technical demonstrations are planned for the future conversion of these facilities along with the corresponding time schedules.

In connection with Federal Council stipulation 5.6, Nagra has prepared a background report for WMP21 (Nagra 2021a). This report outlines the current concept for underground geological investigations in a stage-appropriate manner and takes the stipulation into account.

Nagra's geoscientific investigations strengthen the database for evaluating long-term safety and for planning the repository. The underground geological investigations provide the site-specific information required for developing the nuclear construction licence application, verifying the safety case for the selected site and preparing and optimising repository construction.

To realise the underground geological investigations, an extensive infrastructure is required that consists of facility components at the surface, access structures and dedicated areas for experiments and demonstrations. Starting from the area for the planned auxiliary access facility for the future repository, all access structures and access tunnels are constructed during the "construction of the EUU facilities and start of the underground geological investigations" phase (see Section 5.4.2) and are designed to allow for their future conversion and integration into the repository.

The requirements on the infrastructure for the underground geological investigations and especially for the facilities for underground geological investigations are determined by different driving factors. For operational safety, for example, two separate underground accesses have to be constructed. For long-term safety, the facilities are to be constructed in such a way as to not impact the suitability of the site for a repository. The layout of the facilities must also allow implementation of all investigations required for the site-specific verification of the safety case. To this end, the experiments have to be conducted in undisturbed areas and it must be possible to apply the findings to the disposal areas. Finally, it must be possible to include the results of the underground geological investigations in the preparations for the nuclear construction and operating licence applications.

During the "continuation of underground geological investigations" phase (see Section 5.4.2), the safety-relevant properties of the host rock with regard to the mechanical system behaviour, self-sealing, thermal impact, gas transport capacity and diffusion and retention behaviour will be studied in detail to demonstrate safety for the emplacement rooms. To obtain reliable measurement series, the experiments will be carried out over a period of up to five years.

In addition, the construction of emplacement drifts and caverns as well as the functionality of the safety-relevant technologies for emplacement, including the introduction and removal of backfill material, as well as retrievability, are demonstrated for the nuclear construction licence application insofar as the required demonstrations cannot be carried out in surface facilities. Finally, sealing methods will be tested in the demonstration structures and their functionality confirmed. The requirements on the documents for the nuclear construction and operating licence applications (Appendix 4 of the Nuclear Energy Ordinance) foresee a hierarchical order for the documents (hierarchical levels H1 – H4). Differentiating between levels H1 and H2 in accordance with the Nuclear Energy Ordinance allows enough time to carry out the underground geological investigations. The experiments can be conducted in parallel, and experiments that have to run for several years to verify the safety case can be started in the "construction of facilities and start of underground geological investigations" phase (see Section 5.4.2). Converting the facilities for underground geological investigations into test areas mainly includes an application for conversion from the initial purpose of carrying out geoscientific investigations to the future purpose of operating test areas as a component of a nuclear facility.

A.8.7 Stipulation 6.1 on long-term stability of spent fuel assemblies

Within the framework of Federal Council stipulation 6.1, Nagra is tasked with presenting the results of research projects related to the ageing of spent fuel assemblies and dry storage.

In the case of spent fuel assemblies, suitable boundary conditions are applied to ensure (see requirements in Guideline ENSI G05; ENSI 2008) that the cladding tubes are not damaged during interim storage. However, it cannot be completely ruled out that, due to damage of individual cladding tubes, radioactivity might be released from the fuel or components of structural materials (so-called "debris") in the transloading cell of the encapsulation plant for spent fuel assemblies. Fuel assemblies with damaged cladding tubes can still be handled in this encapsulation plant (see Section 3.2). Intact cladding tubes are not a prerequisite for long-term safety and their barrier function has not been considered in long-term safety analyses to date (Section 3.1.2). The behaviour of fuel assemblies during long-term dry storage is the subject of several investigations and of various international programmes and studies (e.g. SPAR II-IV of the IAEA; IAEA 2012) and regulatory working groups (e.g. WENRA, the West European Nuclear Regulators Association).

The Swiss waste producers carried out a study (Axpo 2015) on the international state of the art and current research programmes on the integrity of fuel assemblies after long-term storage and transport. Key conclusions are that, during dry storage, integrity is assured for the vast majority of the fuel assemblies as no significant corrosion is expected due to the inert atmosphere and as secondary damage due to hydride reorientation can be excluded if no primary damage occurs. Even if individual cladding tubes were to be damaged, this should not compromise the integrity and manageability of the entire fuel assembly.

Independently of this study, Nagra has initiated its own experimental programme together with international experts from the EU and the USA (Nagra 2021e). In this programme, real (high burnup) spent fuel rods are tested for their integrity under different loading situations. Nagra's programme also investigates how to remove debris from a transport and storage cask in the event of fuel damage. International technologies and stage-appropriate technical concepts are already available for decontaminating the unloaded transport and storage casks and releasing and recycling them (or some of their components) after appropriate decay storage.

In summary, and based on the current state of the art, no significant damage to the fuel assemblies is to be expected from ageing and dry storage, and the safe handling and disposal of waste can be ensured.

A.8.8 Handling MIR waste after the end of the emplacement period (recommendation of the Federal Nuclear Safety Commission for WMP21)

Recommendation: The Federal Nuclear Safety Commission notes that the issue of handling waste from medicine, industry and research (MIR) that will arise after the emplacement of radioactive waste in the L/ILW repository – currently planned as 2065 – has not yet been resolved. As the Federal Government is responsible for the disposal of MIR waste in line with the Nuclear Energy Act, the Federal Nuclear Safety Commission recommends that the responsible federal authorities promptly establish corresponding specifications, particularly with regard to the ability to identify the existing need for regulation and to close any regulatory gaps.

After the emplacement phase of the repository has been completed, L/ILW waste from the areas of medicine, industry and research (MIR) will continue to arise. The Federal Government is responsible for its disposal. To this end, and in accordance with recommendation 1 of the Federal Nuclear Safety Commission (KNS 2018), the Swiss Federal Workgroup for Nuclear Waste Disposal (Agneb) has prepared a report (Agneb 2019) in response to the Waste Management Programme 2016, outlining options for potential disposal paths for the time period following the emplacement period in the repository. The report is based on an expected disposal-ready waste volume of around 4,000 m^3 over a time period of 90 years (2065 – 2155). This is equivalent to around 5% of the amount of all L/ILW predicted by the end of 2064 (see Appendix A.2.1). The waste can be expected to have limited radiotoxicity with a shorter half-life compared to present-day MIR waste.

Options include emplacing the waste in the planned deep geological repository at the end of the monitoring phase, after which the repository will be permanently closed, emplacing it in geological layers close to the surface or storing it at the surface. An international solution is also conceivable. Some of these options would require changes to existing legislation.

From Agneb's point of view, future generations should decide how to dispose of the waste after 2065. However, the prerequisites have to be created today so that all potential options remain possible and can be freely selected. This applies in particular to the potential disposal of MIR waste arising between the end of the monitoring phase following the completion of emplacement and prior to the final closure of the repository. The decision on whether to implement this will not have to be taken for another 50 to 100 years.

To allow this option to remain feasible, adequate spatial reserves already have to be included in the general licensing procedure. Corresponding decisions also must be made for later applications in order to maintain flexibility with regard to implementing this option. Should the Federal Government decide to realise this option, it would have to finance potential additional measures.

The option is limited and, as a result, the advantages and disadvantages of this variant have to be reviewed in detail in the future.

The MIR waste produced today must be disposed of in the same way as other radioactive waste in accordance with current legislation.

A.8.9 Findings and deliberations of the Federal Council with regard to the responsibility of the operating companies of the nuclear power plants and their shareholders concerning site selection and waste management

As part of the regulatory review of WMP16 (Nagra 2016b), the Swiss Federal Office of Energy (BFE) (BFE 2018a) judged Nagra's information concept to be adequate and to comply with requirements, and it welcomed the fact that, in the upcoming years, Nagra will focus on public outreach in the siting regions.

However, it found that the owners of the nuclear facilities could improve their communication efforts, as was already mentioned for WMP08. In its review of WMP16 (BFE 2018a), the Swiss Federal Office of Energy criticised the fact that the operating companies of the nuclear power plants and their shareholders were only barely perceived as waste producers in the public eye. The BFE continues to believe that acknowledging political responsibility for radioactive waste disposal is of great importance. Only by doing so can Nagra be perceived as the technical-scientific competence centre. With a view to WMP21, and due to the importance of this issue, the Swiss Federal Office of Energy continued to insist on its requirement that the nuclear power plant operators and their shareholders assume political responsibility and communicate this more clearly.

As the Federal Council cannot issue a corresponding stipulation, it has decided to waive the inclusion of the demand of the Swiss Federal Office of Energy in its decree of 21st November 2018 in reaction to WMP16 (Bundesrat 2018). However, it has called attention to the responsibility of the nuclear power plant operators and cantons for the site selection process and waste management and requires that they fulfil their role pragmatically and adequately.

To describe how the waste producers have responded to the considerations of the Federal Council for WMP21, the following outlines the responsibilities of the nuclear power plant operators with regard to decommissioning and waste management. This is followed by the corresponding communication by the nuclear power plant operators.

Responsibilities of the operating companies of the nuclear power plants in the areas of decommissioning and waste management

The responsibilities and competencies of the nuclear power plant operators in the areas of decommissioning and waste management include:

- In technical terms, the waste producers, i.e. the NPP operators and the Federal Government (which is responsible for MIR waste), have tasked Nagra with developing the scientific-technical foundation for site selection and with initiating the necessary steps to realise the deep geological repository in line with nuclear energy legislation (KEG 2003).
- In the Zwilag (community of Würenlingen) and ZWIBEZ (grounds of the Beznau NPP), interim storage facilities, existing low-, intermediate- and high-level waste is safely held by the operators.
- Under the supervision of the Federal Government, the operators prepare a Cost Study every five years documenting the expected costs for decommissioning and disposal of the radioactive waste. The Cost Studies are reviewed by ENSI and independent experts.
- The waste management costs that arise during the operation of the nuclear power plants are paid by the operators on an ongoing basis. These costs include expenditure for interim storage, transports, transport and storage casks and preparing the radioactive waste for eventual emplacement in the deep geological repository, as well as Nagra's ongoing costs. In addition, the operators make payments into two funds supervised by the Federal Government. These contributions, together with the returns on the fund assets, cover the overall costs for decommissioning and waste management. The operators thereby ensure that the monies needed for the resulting decommissioning and waste management efforts following the shutdown of the NPPs are secured.
- Switzerland has a unique inventory system for radioactive materials. This quantifies and characterises all of Switzerland's radioactive waste that already exists and is expected to arise in the future. Based on this, well-founded data can be provided to conduct analyses of long-term safety and to plan the deep geological repository. The NPP operators collaborate very closely with Nagra on this model inventory.

In summary, the nuclear power plant operators fulfil their obligations with regard to decommissioning of the installations and disposal of the radioactive waste arising from the operation, decommissioning and dismantling of Switzerland's nuclear power plants in line with the Nuclear Energy Act (KEG 2003); this is done in both technical and financial terms. In contrast, the nuclear power plant operators do not bear political responsibility as they do not make political decisions.

Communication of the nuclear power plant operators

Nagra and the Swiss Federal Office of Energy bear the primary responsibility for communication regarding the Waste Management Programme and the Sectoral Plan process. In principle, the NPP operators do not communicate on the individual steps of the Sectoral Plan process, research results or Nagra's reports. Nagra must be able to conduct its scientific-technical activities independently and be the central voice for communicating the individual steps. Should the nuclear power plant operators on rare occasions wish to communicate, this is done in close collaboration with Nagra.

The nuclear power plant operators and their industry association, swissnuclear, communicate actively on the aforementioned topics that fall into their areas of responsibility:

- The NPP operators are responsible for communicating on the financing of decommissioning and waste management. They actively inform by means of Cost Studies published every five years. The objective of this communication is to inform the public and the media that the NPP operators are fulfilling their financial obligations and disclose how they do so.
  - Communication takes place through active media relations and by publishing articles on swissnuclear's website. Interested members of the public can also subscribe to swissnuclear's electronic newsletter.
- In addition, swissnuclear communicates via www.swissnuclear.ch and www.kernenergie.ch where it addresses the need to maintain competence for decommissioning and waste management by promoting the training and development of the workforce in the nuclear energy sector. swissnuclear also regularly prepares and published corresponding studies.
- In the educational sector, swissnuclear contributes to producing teaching materials and, for example, provides free (and highly popular) school lessons on nuclear energy and on operating nuclear power plants. In addition, it shares an information and knowledge platform with the Nuclear Forum.
- The visitor centres of the NPPs and the Zwilag interim storage facility offer exhibits on decommissioning and waste management that are usually prepared and updated in close collaboration with Nagra. They provide background information on disposal issues, deep geological repositories and the site selection process. The NPP operators also share information on their websites, i.e. under www.swissnuclear.ch and particularly under www.kernenergie.ch.

A.8.10 Interim storage of dismantling waste from CERN and from the high-intensity proton accelerator, HIPA (PSI)

Petition by ENSI for applicable requirements (Bundesrat 2018): Within the framework of the next Waste Management Programme, the responsible federal authorities must demonstrate that sufficient interim storage capacity is available for CERN waste (waste from the European Organization for Nuclear Research).

ENSI's petition affects several federal authorities. Planning the interim and decay storage facilities for CERN waste has not yet been completed. The responsible federal authorities are represented in the Swiss Federal Workgroup for Nuclear Waste Disposal (Agneb) and, accordingly, this petition should be seen as an open issue to be followed up on by Agneb.

Current status of planning for CERN dismantling waste (information provided by the responsible federal authorities for WMP21)

The Paul Scherrer Institute (PSI) operates the Federal Government's waste collection point. This includes facilities for the conditioning of radioactive MIR waste as well as the Swiss Federal Interim Storage Facility (BZL-1). In 2023, a second interim storage facility (BZL-2) will be completed. The inventory in the interim storage facilities may have to be limited due to volume or activity limits. BZL-2 was planned to accommodate, together with BZL-1, the entire volume of known and expected MIR waste requiring interim storage.

The waste from dismantling PSI's high-intensity proton accelerator, HIPA, does not require interim storage as it will arise at a point in time when it can be directly disposed of in the deep geological repository.

In terms of volume, BZL-1 and BZL-2 will not be able to accommodate all of the dismantling waste from CERN (as opposed to operational waste from CERN). This is due to the fact that the planning and licensing procedures for BZL-2 had been completed before the dismantling volumes from CERN had been established. At present, plans are being discussed regarding the disposal of CERN dismantling waste in Switzerland, and it is too early to construct an additional interim storage facility. However, CERN is also not yet planning complete decommissioning of the accelerator complex (LHC, pre-accelerator and experiments).

With regard to potential CERN dismantling waste, a working group consisting of the Federal Office of Public Health, CERN and PSI is investigating preconditioning at CERN and interim storage at an interim storage facility (CERN-ZL) to be constructed on the grounds of PSI. This would be positioned close to BZL-1 and BZL-2 and realising it would take around 10 to 15 years. However, the question as to whether the Federal Government will provide advance funding for the construction of this additional infrastructure remains unresolved.

A.9 List of acronyms

Agneb	Swiss Federal Workgroup for Nuclear Waste Disposal
AltlV	Ordinance on contaminated sites (*Altlastenverordnung*)
ATW	Alpha-toxic waste
BA	NPP operational waste
BAG	Swiss Federal Office of Public Health (*Bundesamt für Gesundheit*)
BBI	Federal Gazette (publication organ of the Federal Council, Federal Administration and Parliament)
BEUU	Facilities for underground geological investigations
BEVA	Encapsulation plant for SF and HLW(WA) / "SF encapsulation plant"
BFE / SFOE	Swiss Federal Office of Energy (*Bundesamt für Energie*)
BZL	Swiss Federal Interim Storage Facility (*Bundeszwischenlager*)
CERN	European Organization for Nuclear Research
ChemRRV / ORRChem	Chemical Risk Reduction Ordinance
CS11	2011 Cost Study
CS16	2016 Cost Study
CS21	2021 Cost Study
DETEC	Federal Department of the Environment, Transport, Energy and Communications (*Eidgenössiches Departement für Umwelt, Verkehr, Energie und Kommunikation*)
EDRAM	International Association for Environmentally Safe Disposal of Radioactive Materials
EIA	Environmental Impact Assessment
EIAO	Ordinance on the Environmental Impact Assessment
EKRA	Expert Group on Disposal Concepts for Radioactive Waste
ENSI	Swiss Federal Nuclear Safety Inspectorate
EURAD	European Joint Programme on Radioactive Waste Management (EU research programme)
EUU	Underground geological investigations (*erdwissenschaftliche Untersuchungen untertag*)
FMT	Mont Terri Rock Laboratory (*Felslabor Mont Terri*)
GNSS	Global Navigation Satellite System (satellite-supported precision measurement network of swisstopo)
GNW	Cooperative for Nuclear Waste Management Wellenberg (*Genossenschaft für nukleare Entsorgung Wellenberg*)
GSchG	Water Protection Act (*Gewässerschutzgesetz*)
GSchV	Water Protection Ordinance (*Gewässerschutzverordnung*)

GTS	Grimsel Test Site
HIPA	High-intensity proton accelerator (PSI)
HLW	High-level waste
HSK	Principal Nuclear Safety Division (from 1.1.2009: ENSI)
IAEA	International Atomic Energy Agency
IDKM	Information, Data and Knowledge Management (project of the OECD/NEA)
ILW	Long-lived intermediate-level waste
JO	Jura Ost siting region
KEG/NEA	Nuclear Energy Act (*Kernenergiegesetz*)
KEV/NEO	Nuclear Energy Ordinance (*Kernenergieverordnung*)
KKB	Beznau NPP
KKG	Gösgen NPP
KKL	Leibstadt NPP
KKM	Mühleberg NPP
KNS	Federal Nuclear Safety Commission (*Eidgenössische Kommission für nukleare Sicherheit*), since 2007 (replaces the Commission for the Safety of Nuclear Installations KSA)
KSA	Commission for the Safety of Nuclear Installations (*Kommission für die Sicherheit von Kernanlagen*, till 2007)
L/ILW	Low- and intermediate-level waste
LHC	Large Hadron Collider (CERN)
LLW	Low-level waste
LRV	Ordinance on Air Pollution Control (*Luftreinhalte-Verordnung*)
LSV	Ordinance on Noise Protection (*Lärmschutz-Verordnung*)
MIR	Waste from medicine, industry and research
MIRAM	Model Inventory of Radioactive Materials
MODATS	Monitoring Equipment and Data Treatment for Safe Repository Operation and Staged Closure (EU research programme)
Modern2020	Development & demonstration of monitoring strategies and technologies for geological disposal (EU project)
MOX	Mixed oxide
nBaB	Nuclear construction licence (*nukleare Baubewilligung*)
nBaBG	Nuclear construction licence application (*nukleares Baubewilligungsgesuch*)
nBeB	Nuclear operating licence (*nukleare Betriebsbewilligung*)
nBeBG	Nuclear operating licence application (*nukleares Betriebsbewilligungsgesuch*)
NEA	Nuclear Energy Agency of the OECD

NHG	Federal Act on the Protection of Nature and Cultural Heritage (*Bundesgesetz über den Natur- und Heimatschutz*)
NHV	Federal Ordinance on the Protection of Nature and Cultural Heritage (*Verordnung über den Natur- und Heimatschutz*)
NL	Nördlich Lägern siting region
NPP	Nuclear power plant
NZA	Auxiliary access facility (*Nebenzugangsanlage*)
NZA-B	Auxiliary access facility for operations
NZA-BL	Auxiliary access facility for operations and ventilation
NZA-L	Auxiliary access facility for ventilation
OECD	Organisation for Economic Co-operation and Development
OFA	Surface facility (*Oberflächenanlage*)
OFI	Surface infrastructure (*Oberflächeninfrastruktur*)
ONKALO	Finnish underground rock laboratory at the Olkiluoto site
OPA	Opalinus Clay
PSI	Paul Scherrer Institute
R&R	Reversibility and Retrievability (Project of the OECD/NEA)
RA	Exchangeable reactor core components of the NPPs (reactor waste)
RBG	General licence application (*Rahmenbewilligungsgesuch*)
RCM	Requirements and Configuration Management
RD&D	Research, Development and Demonstration
RK&M	Preservation of Records, Knowledge and Memory Across Generations (Project of the OECD/NEA)
RPG	Spatial Planning Act (*Raumplanungsgesetz*)
RPV	Spatial Planning Ordinance (*Raumplanungsverordnung*)
SA	Decommissioning waste (*Stilllegungsabfälle*)
SAPIERR	Support Action: Pilot Initiative for European Regional Repositories (EU project)
SEFV	Ordinance on the Decommissioning and Waste Disposal Funds for Nuclear Installations (Funds Ordinance)
SEFV	Decommissioning and Waste Disposal Funds Ordinance (*Stilllegungs- und Entsorgungsfondsverordnung*)
SF	Spent fuel
SFR	Repository for short-lived radioactive waste in Forsmark, Sweden
SGT	Sectoral Plan for Deep Geological Repositories (*Sachplan geologische Tiefenlager*)
SPAR IV	Spent Fuel Performance Assessment and Research (IAEA)

STENFO	Decommissioning Fund for Nuclear Installations and Waste Disposal Fund for Nuclear Power Plants
StFV	Major Accidents Ordinance (*Störfallverordnung*)
StSG	Radiological Protection Act (*Strahlenschutzgesetz*)
StSV	Radiological Protection Ordinance (*Strahlenschutzverordnung*)
SUVA	Swiss National Accident Insurance Fund (*Schweizerische Unfallversicherungsanstalt*)
TFS	Technical Forum on Safety of ENSI
THM-C	Thermal, hydraulic, rock-mechanical and chemical (interactions)
TLB	Transport and storage cask
UO_2	Uranium oxide
USG	Environmental Protection Act (*Umweltschutzgesetz*)
ÜUG	Monitoring of the environment and the geological surroundings (*Überwachung der Umwelt und des geologischen Umfelds*)
VA	Encapsulation plant
VBBo	Ordinance relating to impacts on the soil (*Verordnung über Belastungen des Bodens*)
VLJ	Repository for low- and intermediate-level waste at Olkiluoto, Finland, in operation since 1992
VVEA	Ordinance on the Avoidance and the Disposal of Waste (*Verfügung über die Vermeidung und Entsorgung von Abfällen*)
VwVG / APA	Federal Act on Administrative Procedure (*Verwaltungsverfahrensgesetz*)
WA	Reprocessing waste
WA-ATW	Alpha-toxic waste from reprocessing
WA-HLW	High-level waste from reprocessing
WA-ILW	Intermediate-level waste from reprocessing
WENRA	West European Nuclear Regulators Association
WMP08	Waste Management Programme 2008
WMP16	Waste Management Programme 2016
WMP21	Waste Management Programme 2021
ZNO	Zürich Nordost siting region
ZWIBEZ	Interim storage facility at the Beznau NPP
Zwilag	Zwilag interim facility (*Zwischenlager in Würenlingen*)