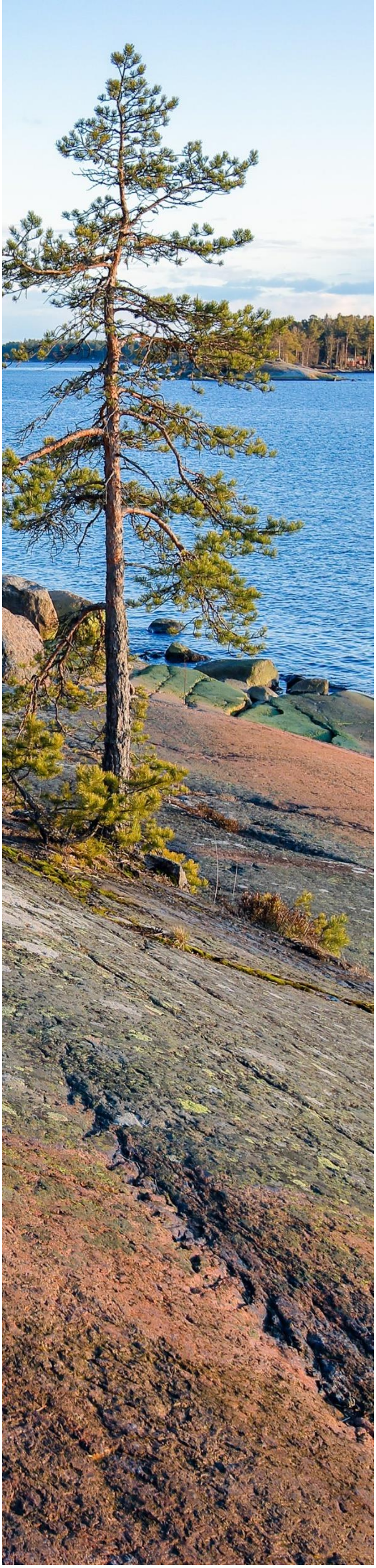

Technical memorandum

Development process for the Norwegian National Facility

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1 Background and introduction

1.1 Background

Since 1999, LLW and ILW radioactive waste have been stored and disposed of in the Combined Disposal and Storage Facility (KLDRA) in Himdalen. KLDRA is gradually filling, and the remaining capacity is not sufficient for projected future waste volumes in Norway.

In 2017, Ministry of Trade, Industry and Fisheries (NFD) requested Statsbygg to prepare a siting and cost analysis for a new KLDRA in Norway. The task was performed by WSP Norway with subcontractors.

The premises for the process of finding a suitable location for new KLDRA changed significantly during 2019. Norwegian Nuclear Decommissioning (NND) had assumed responsibility for the follow-up of the assignment from the NFD and requested that the assignment for the investigation of new KLDRA be terminated. In connection with the conclusion of the assignment, NND is studying different concepts for how to update the Norwegian infrastructure for management of radioactive waste. One concept consists of combining different types of facilities into a National Facility for management of radioactive waste. In this, the radioactive waste will be disposed of in a single disposal location. This nuclear waste facility, called Norwegian National Facility, consists of underground repositories as well as a landfill repository and auxiliary facilities above ground.

The National Facility would contain the following repository types for the waste:

- Intermediate depth repository for very low, low- and intermediate-level waste,
- Deep geological repository (DGR) for high-level waste,
- Deep borehole repository (DBR) for high-level waste as an alternative to the DGR,
- Landfill-type repository as an option for non-radioactive decommissioning waste and potentially for very low-level radioactive waste, mainly soil and concrete.

NND's entire radioactive waste management programme is in an early phase ("initiation phase"). NND is in charge of all aspects related to the final disposal of the waste. These include disposal concept development site selection for the National facility, safety assessments, waste treatment and encapsulation and decommissioning of the reactors.

1.2 Scope, boundary conditions and assumptions

This work concentrates on the development process related to the final disposal technical design activities of the Norwegian National Facility of NND's. This development process describes a phased development process, phases and steps, outputs, milestones, and decision points.

There are many alternatives for pre-disposal conditioning, treatment, and encapsulation, as well as for disposal. Considerations and questions for the encapsulation plant, decommissioning of the reactors, the interim storage of the nuclear waste, and R&D needs for nuclear waste management are out of scope of this work. These are however briefly mentioned where applicable in the development process.

The work pulls experiences from several on-going radioactive waste management programmes. Especially lessons learnt from spent fuel management projects in Finland (Posiva) and in Sweden

(SKB) are used to facilitate and streamline the programme in Norway. Similarities in methodologies and solutions are applied to the situation and conditions in Norway. Additionally, the process description relies on the IAEA guidelines and terminology. The development process has been developed jointly with Håvard Kristiansen, NND.

The main focus in this study is on the technical development through the design stream of the waste management programme. Technical development means the engineering design activities to realise the National Facility. However, site selection process and development of the long-term safety assessment are discussed as well since these are coordinated together closely.

Main focus of the development process is on the activities from the Initiation phase (now) until to the construction licence submission of the National Facility.

This development process was developed and published in 2021. It is recommended to revise the process annually to reflect on the latest developments in the overall waste management progress and decisions in Norway.

Generic assumptions for the development process are presented below. The assumptions do not represent a formal description of Norway's waste management strategy. They are made for the purpose of simplifying the interfaces with pre-disposal activities. If future decisions contradict these assumptions, then the development process should be revised. More detailed assumptions and their implications to the work are discussed in Chapter 4.

- Planning of the decommissioning of the reactors in Halden and Kjeller starts in 2022.
- Interim storage for decommissioning waste will be constructed.
- Interim storage for spent fuel will be constructed.
- Scheduling assumes that all phases and activities are executed back-to-back in a continuous manner (variations to this are noted separately where applicable)
- All radioactive waste will be disposed in the National Facility in a single location with two schedule variations are presented in the memorandum. These are scenarios S1 and S2.
- In addition it will be briefly discussed if two separate sites will be developed: one site for the disposal of HLW, and another site for the other waste streams. Scenario S3.

1.3 Structure of the report

An overview of general nuclear waste repository design principles and relevant stages is presented in Chapter 2. The description is based on International Atomic Energy Agency (IAEA) recommendations and guidelines.

Chapter 3 introduces the current stage of the radioactive waste management in Norway. Design phase of the disposal facility, current facilities for spent fuel and radioactive waste and stage for the site selection of the disposal facility are included. Also, a very general overall schedule is shown in this chapter.

The development process for the National Facility is in Chapter 4, including scenarios.

Development of the repositories and timelines for the development have strong interaction with site selection, licensing, long-term safety assessment, and research & development, as discussed in Chapter 5. Finally, summary and recommendations are presented in Chapter 6.

2 IAEA main design principles and approaches

The International Atomic Energy Agency (IAEA) has published an overview of repository design principles and approaches that can be used to address radioactive waste disposal needs (IAEA 2020). This chapter summarises the design principles and stages from the IAEA publication.

A typical repository programme life cycle timeline is illustrated in Figure 2-1. The timeline identifies the main phases and stages of a repository programme, together with typical licensing points. Also shown, are the five stages in the design process. Milestones, such as the identification of potential candidate sites and construction licence authorization, represent key decision points and are supported by specific design stages with associated design outputs used to help inform these decisions.

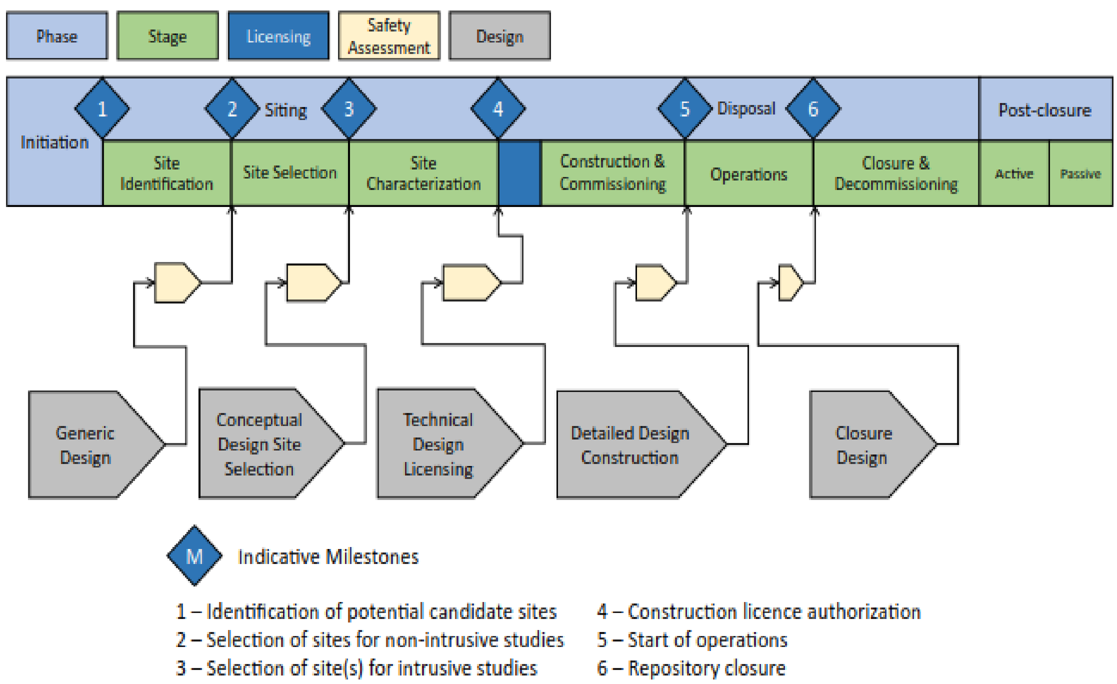


Figure 2-1. Generic repository programme life cycle and associated design stages aligned with indicative project milestones (IAEA 2020).

<u>Main stages</u> for the generic repository programme life cycle are:

- Site identification
- Site selection
- Site characterization
- Construction and commissioning
- Operations
- Closure & Decommissioning
- Active and passive post-closure

The five <u>design stages</u> for the generic repository programme are:

- Generic design, Chapter 2.1

- Conceptual design for site selection, Chapter 2.2
- Technical design for construction licensing, Chapter 2.3
- Detailed design for construction and operation, Chapter 2.4
- Design for closure, Chapter 2.5

Design stages are introduced in the following subsections.

2.1 Generic design

The first design stage is carried out during the initiation phase (Figure 2-1) of the programme, when generic designs will be developed to support the repository siting process. At this stage, the designs are likely to be conceptual in nature, as only the broad nature of potential siting options might be known. The flow of information into and out of a generic design process is illustrated in Figure 2-2. Generic design concepts broadly address the requirements, assumptions, and constraints detailed in an initial functional specification. Work is undertaken to develop the waste inventories and properties, and to identify potential disposal solutions. These form the basis for the initial generic design studies, perhaps for a range of disposal concepts and options for different categories of waste. The premise is to develop a safe and feasible system within existing constraints, such as any requirements already set by regulatory authorities. Usually, this early stage also includes developing an R&D roadmap for disposal technology (IAEA 2020).

The generic designs allow definition of associated generic safety cases (how the concepts being considered would provide safe disposal for the waste inventory) and provide a starting point for programme planning and estimation of duration, costs, and risks (IAEA 2020).

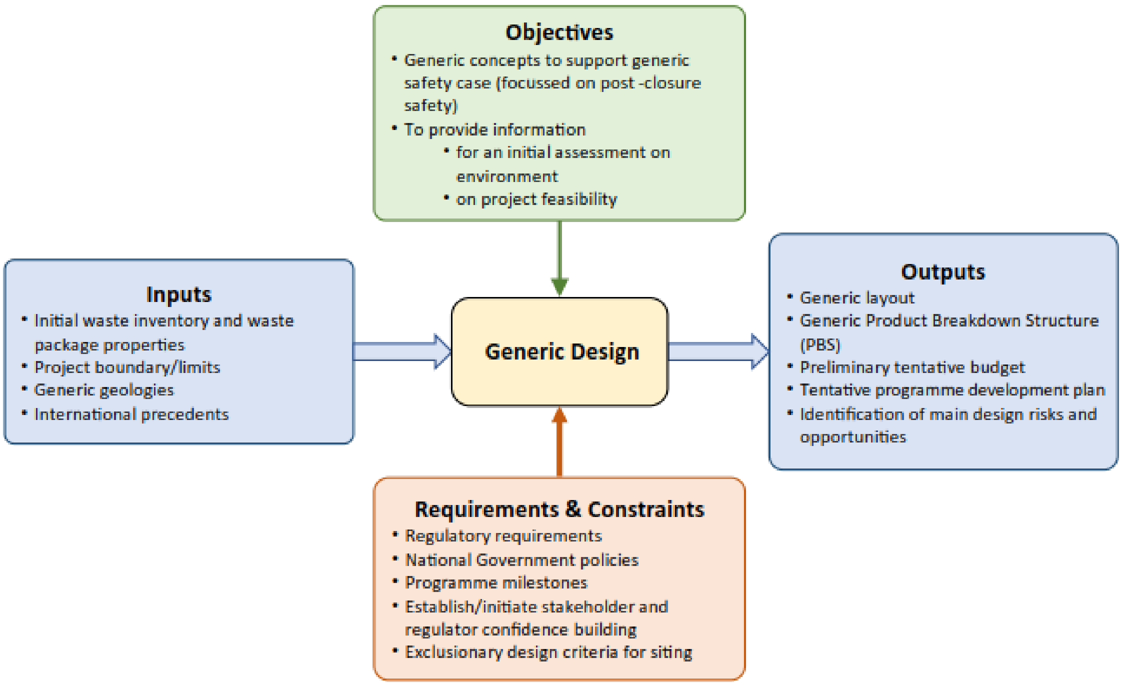


Figure 2-2. Generic design: objectives, inputs, constraints, requirements and outputs (IAEA 2020).

2.2 Conceptual design for site selection

The siting process consists of both technical and societal components. The technical dimension considers geological and environmental conditions of potential sites and the interactions of those conditions with potential design options, which will directly influence the disposal concept and subsequently the design of components. The societal aspect considers a wide range of stakeholder interests and concerns and is ultimately critical to public acceptance of a repository. Stakeholder concerns need to be adequately addressed by the design. International experience has shown that successful siting processes reflect a balance between these two elements (IAEA 2020).

A generally accepted approach to siting could involve an initial site screening process followed by more intensive site characterization at one or more candidate sites. Site screening could include a review of existing geological, geographical and environmental information, together with socioeconomic factors, and might initially be based on exclusion criteria. As screening progresses, potential sites might be investigated at increasing levels of detail and assessed against favourable conditions for a repository. Ultimately the goal of screening is to identify a preferred site that meets a range of requirements, warranting more in-depth site characterization. Site characterization encompasses scientific and technical investigations aimed at providing an in-depth understanding of the geological and physical characteristics of the site and how the disposal system can effectively be integrated (IAEA 2020).

Throughout the siting process, the WMO (Waste Management Organization) will consider and develop design concepts specific to the waste inventory and the siting options emerging, augmented with a preliminary safety case for the design concepts that might be deployed at the sites (see Figure 2-3). Existing disposal solutions for similar waste in other countries can be reviewed. If siting options are all in similar environments, then a single conceptual design might be appropriate for all of them. The conceptual design stage includes preliminary considerations of a basic layout that can accommodate the waste inventory at the sites under consideration (IAEA 2020).

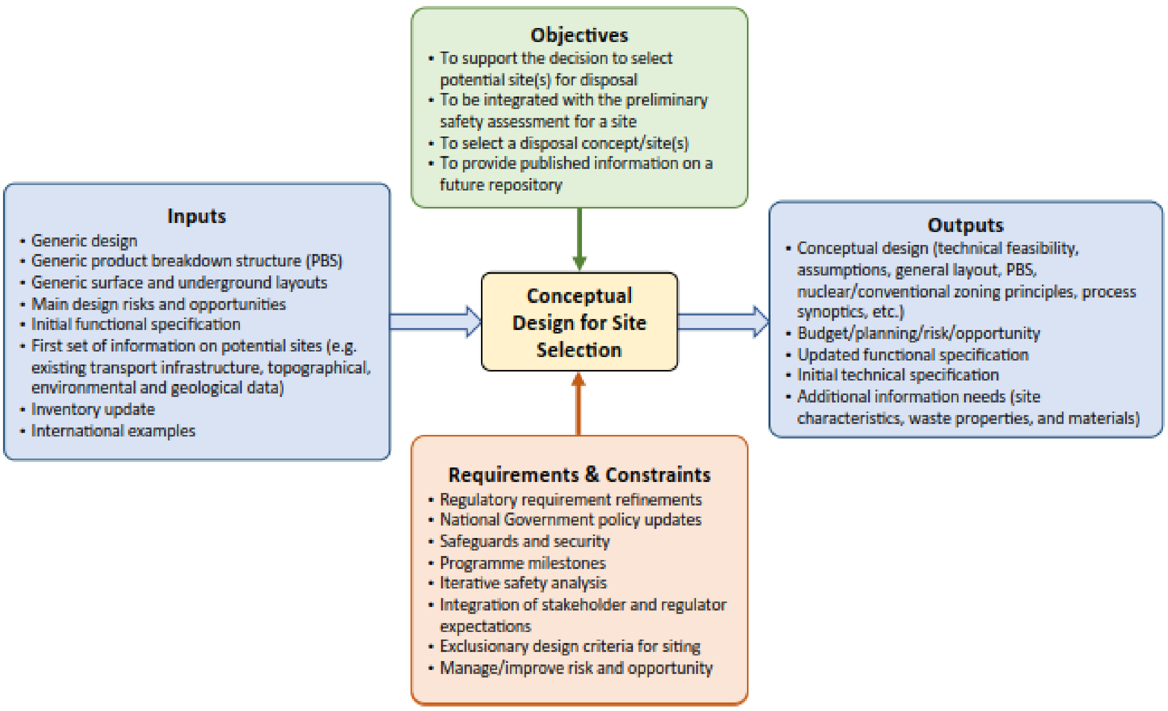


Figure 2-3. Conceptual design for site selection: objectives, inputs, constraints, requirements, and outputs (IAEA 2020).

The WMO will need to compare combinations of repository concepts, designs and siting options in order to decide which solution is the most appropriate for meeting the higher-level programme requirements. Different repository solutions might be feasible, even if there is only one siting option available. Alternative solutions are likely to meet the different requirements to varying extents, although any option being considered must meet all of the critical requirements (e.g. regulatory or legal requirements) adequately. The process of considering and weighing the extent to which other requirements can be met is often termed ‘optioneering’ and the WMO can approach this in a flexible manner, involving other stakeholders as appropriate. A number of formal and less formal methods are available for weighing and ranking options so as to achieve a transparent decision on a preferred conceptual design/site combination. These include multi-attribute analysis and benefits/constraints comparison techniques (IAEA 2020).

The siting phase produces scientific documents such as geotechnical investigation reports and a preliminary environmental impact assessment, and, typically, a preliminary safety analysis report. These documents provide the basis for the selection of a preferred site (and an associated preferred repository concept), which will generally require the approval of regulatory authorities and/or government. At this stage, detailed coordination with local and regional stakeholders occurs, and schedule estimates and quality levels can be better established. The design programme should include a process and schedule for consultation and open discussion with all stakeholder groups (IAEA 2020).

Design stage “Conceptual design for site selection” is also named “Conceptual design for siting” in some parts of IAEA publication (IAEA 2020). The term “Conceptual design for site selection” is used throughout this memorandum.

2.3 Technical design for construction licensing

The technical design for initial construction licensing at the chosen site (see Figure 2-4) follows from the conceptual design. This stage develops the chosen design, based on the specific characteristics of the selected site, sufficiently for construction licensing application; i.e. the design must be sufficiently detailed to comprehensively demonstrate that the system can be constructed at the site and fulfil all licensing requirements imposed by regulation (IAEA 2020).

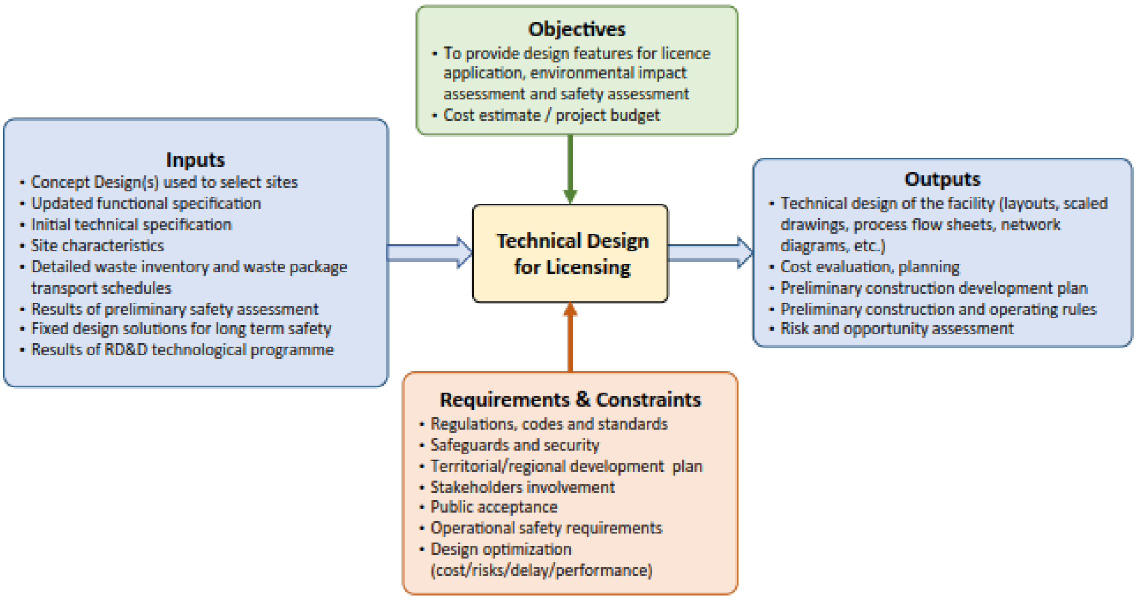


Figure 2-4. Technical design for construction licensing: objectives, inputs, constraints, requirements and outputs (IAEA 2020).

During this phase, models and analyses are developed and drawings, technical reports are completed with design control and quality management protocols in place. Technical bases are confirmed. Timing, scheduling, requisite resources and external interfaces are defined. The technical design expands on the conceptual design and incorporates additional site-specific information obtained during characterization activities. The technical design would also be used to consult with key stakeholders before moving on to the detailed or final design, (IAEA 2020).

Provisions to address closure requirements are identified at this design stage. Data will be provided for safety assessments and interactions with the regulator will take place. A description of active and passive institutional controls may be required. Provisional proposals can be made in the design for future extension of the site (both surface and subsurface) to accommodate the possible construction of new disposal structures and capabilities. Monitoring provisions for performance confirmation will take shape and define how future information will be evaluated against the existing technical basis. Completion of this phase might be marked by the issuance of an intermediate safety analysis report, (IAEA 2020).

The design stage “Technical design for construction licensing” is also named “Technical design for licensing” or “Technical design for initial construction licensing” in some parts of the IAEA publication (IAEA 2020). The term “Technical design for construction licensing” is used throughout this memorandum.

2.4 Detailed design for construction and operation

The detailed design for construction and operation (Figure 2-5) entails complete drawings and reports containing the final technical design, considering detailed information on site, environment and waste package throughput and capacity requirements. Workshop drawings, equipment specifications and detailed instructions must be appropriate for equipment procurement, commissioning of the facility and construction. Information communication, system integration, schedules and management systems are operationally ready (IAEA 2020).

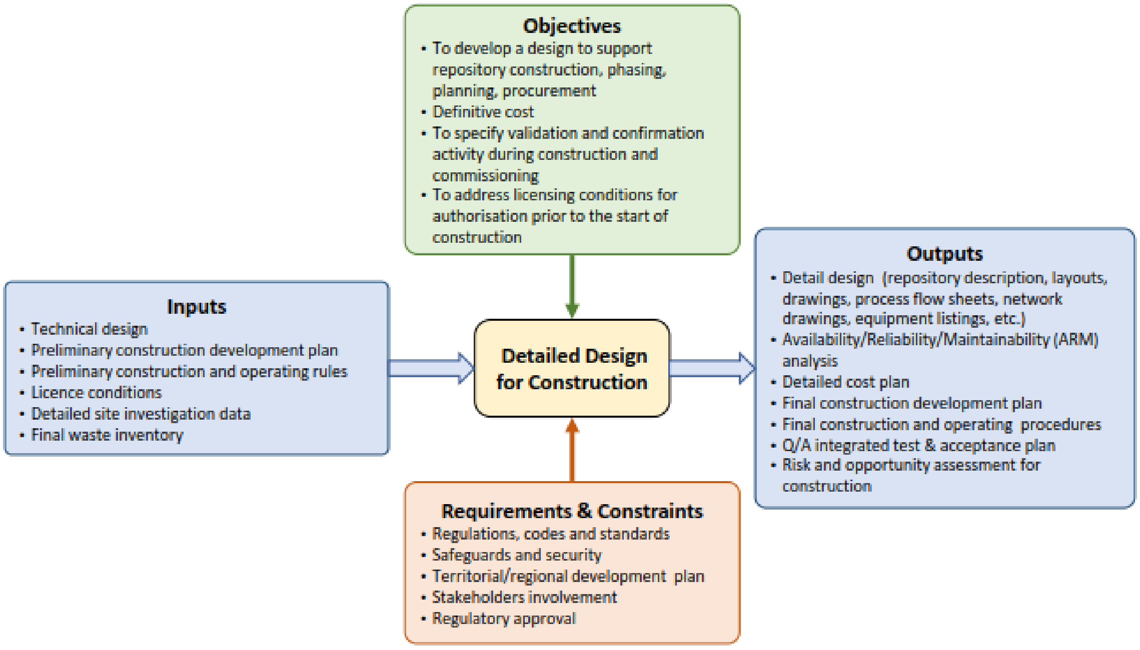


Figure 2-5. Detailed design for construction and operation: objectives, inputs, constraints, requirements and outputs (IAEA 2020).

The main objective of the detailed design stage is to prepare for the construction and operation phases and to provide information to support the safety assessment undertaken for licensing purposes. The safety case and detailed design confirm that the disposal facility can be operated and closed safely and efficiently. Satisfactory interaction with the regulator provides the basis for commencing construction and, subsequently, operations. The regulatory authorities might introduce conditions for certification (IAEA 2020).

During this stage, detailed cost estimates for facility construction, operation and closure are prepared. Environmental surveillance and radiological monitoring programmes to be conducted during operations and after closure of the disposal facility are identified and concerned parties are informed regarding requirements for final closure of the facility. Specified information requirements from construction activities and planned interface arrangements with construction and operations and schedules are finalized, to facilitate requests for bids, particularly in relation to design change management and 'as-built' records (IAEA 2020).

Once sufficient infrastructure and the initial disposal areas of the repository have been constructed and inspected to the regulators' satisfaction, a licence for operations can be issued. Construction documentation to support this process is divided into two groups. The first group shows that the technical requirements from the requirements management system and the design basis have been met by the final design of the constructed system. The second group contains as-built drawings, certificates of materials, equipment, declarations of conformity, changes, protocols, variance from the certified licence and detailed design. Completion of this phase might be marked by the issuance of a final safety analysis report, a licence for construction and contract(s) for work (IAEA 2020).

The design stage "Detailed design for construction and operation" is also named "Detailed design for construction" in some parts of IAEA publication (IAEA 2020). The term "Detailed design for construction and operation" is used throughout this memorandum.

Depending upon the volume of wastes and the rate at which they are delivered to the repository, a staged, modular approach can be an efficient means to manage disposal. It also allows designs for later phases of disposal to be updated, taking into account continuous learning and improvement. This approach can provide improved information on conditions at closure, relevant to long-term safety, while at the same time aiding in control of capital investments versus routine expenditures, (IAEA 2020). In practise this means that the stage for detailed design for construction and operation might continue during the disposal phase and potential stages where the repository is expanded.

2.5 Design for closure

Sections of a repository might have been closed and sealed during its operational lifetime, as operations move to new disposal areas. Final closure occurs after all the waste has been emplaced. The basis to ensure safe closure capability is demonstrated prior to the start of emplacement, possibly using full-scale tests. The final closure design (Figure 2-6) might continue to be refined and tested throughout the disposal phase, as it might not be implemented until many decades into the future. The disposal phase is considered complete following approval of the closure safety report by the appropriate authorities, which will confirm that the long-term, post-closure behaviour of the repository will continue to conform to regulatory requirements. It will be accompanied by agreed arrangements for post-closure institutional control and monitoring and the allocation of long-term responsibilities for the site up to the end of institutional control and beyond (IAEA 2020).

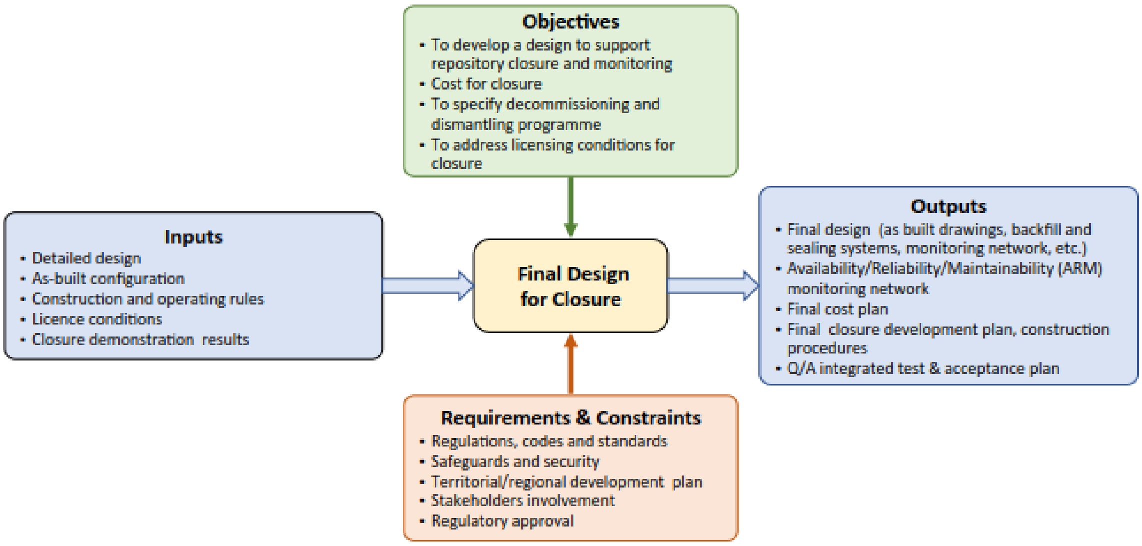


Figure 2-6. Design for closure: objectives, inputs, constraints, requirements and outputs (IAEA 2020).

The design stage “Design for closure” is also named “Final design for closure” or “Closure design” in some parts of IAEA publication (IAEA 2020). The term “Design for closure” is used throughout this memorandum.

3 Current stage in Norway

Norway's inventory of radioactive waste is characterized by high-level waste from the research reactors in Halden and Kjeller, taken out of operation. In addition, there will be non-radioactive waste, very-low-level waste (VLLW), low-level waste (LLW), and intermediate-level waste (ILW) from the planned decommissioning of the research reactors and from other nuclear facilities. Norway has also other low- and intermediate level waste generated by for example the medical sector.

This chapter summaries current stage in Norway divided in a) existing facilities, b) design of new facilities and c) site selection of new facilities.

3.1 Current facilities for spent fuel and radioactive waste

The spent fuel in Norway is stored in two sites: Halden and Kjeller. Repositories for other radioactive waste are located in Himdalen and Gulen. The sites are shown in Figure 3-1.

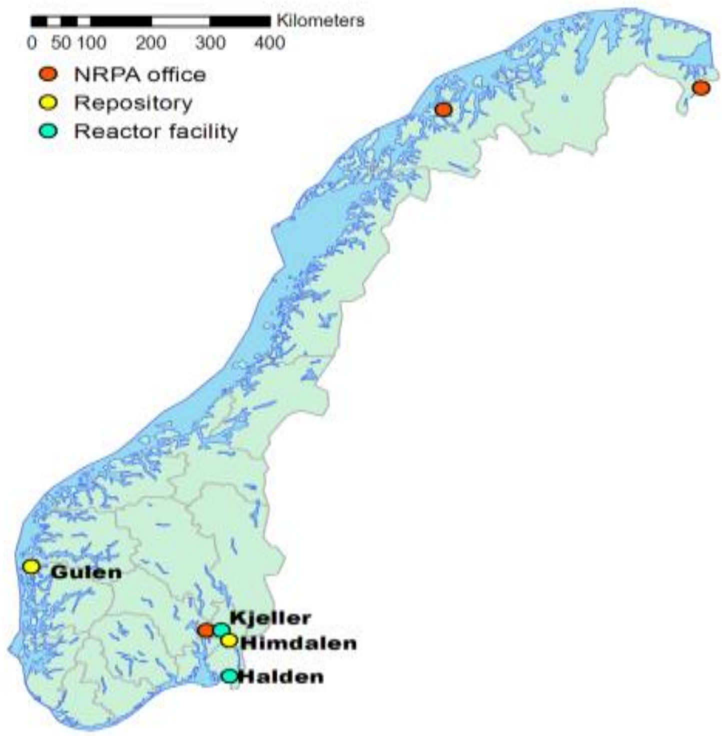


Figure 3-1. Map of Norway with relevant sites (NRPA 2018).

In Himdalen, KLDRA is the Combined Disposal and Storage facility for LILW. It has been in operation since March 1999. The main purpose of the facility is direct disposal of conditioned waste packages. One fourth of the capacity of the facility is today for storage. When the political decision was taken to choose Himdalen for a disposal site it was also decided to allocate a part of the facility for storage where certain waste packages were to be placed. Waste packages placed in the hall for storage are all in "disposal-ready form" and will either be encased in concrete, as is done in the repository part of the facility, or retrieved for disposal at another site (NRPA 2018).

At Gulen, there is a repository for radioactive waste from the oil and gas industry. The repository is situated in an underground rock formation. It consists of an entry tunnel, a tunnel for NORM waste treatment as well as two tunnels for waste disposal. Treatment consists of dewatering waste, filling void space in the barrels with sand or oil absorbent material and sealing between the barrels with a cement matrix. The repository tunnels are to be filled with waste-drums, cemented in concrete mould castings (NRPA 2018). The waste emplaced at Gulen is intended to remain there permanently.

3.2 Design of new nuclear waste facilities

NND is studying several different concepts for how to establish the Norwegian infrastructure for the disposal of radioactive waste. One concept consists of combining different types of facilities into a National Facility for management of radioactive waste. The Norwegian National Facility could consist of underground repository facilities and other underground openings as well as auxiliary facilities above ground.

Over the past two years there has been significant advancement of NND's plans for the final disposal of radioactive waste in Norway. There are several background and reference documents published describing the work for the Norwegian National Facility. Some of these work packages are listed in the following for background information.

The Norwegian radioactive waste inventory is discussed in Loukusa & Nordman (2020). The disposal concepts in the Norwegian National Facility were developed in 2020 and described in Ikonen et al. (2020).

Cost estimate for the entire National Facility is given in Saanio et al. (2021a). Costs were also estimated separately for independent HLW disposal sites in Saanio et al. (2020).

The disposal of high-level waste in a deep borehole was explored and developed further in Fischer et al. (2020). Borehole canister design for National Facility and sealing of deep disposal borehole in crystalline rock were studied in 2021, reports Wunderlich et al. (2021) and Engelhardt et al. (2021).

The host rock target properties form the basis for the site selection of the National Facility. The target properties are defined by the long-term safety of the site for disposal of radioactive waste. The target properties are described in Hagros et al. (2021a).

Related work is the collection of the safety and technical requirements for the different repository types in the National Facility. The work lists the important Norwegian and international documents (regulations, standards, recommendations, etc.) and is to be published as Hagros et al. (2021b).

Site selection process and site selection criteria for the Norwegian National Facility were proposed in two separate projects. These are described in Saanio, Hagros & Wanne (2021b) and Saanio et al. (2021c).

The reference design for a Norwegian National Facility is proposed to consist of the following separate disposal systems:

- Intermediate depth repository for VLLW, LLW and ILW,
- HLW repository: either an excavated deep geological repository or a deep borehole repository,
- Landfill repository for non-radioactive waste from decommissioning of the nuclear facilities in Halden and Kjeller.

The published studies so far can provide the following:

- tools for communicating current planning stage to stakeholders, e.g., the authorities and general public,

- initial data for the scheduling and cost estimates for setting out the financial provisions for waste management,
- initial data for the further preliminary design of facilities,
- input for planning research and development activities regarding the different areas of disposal technology,
- guidance for bedrock surveys carried out in potential sites,
- guidance for assessing the feasibility of disposal,
- a part of the overall description of the entire project.

In the National Facility, all the repository types are located in a single site. Alternatively, the repositories could be stand-alone repositories (independent disposal facilities) in different sites. Stand-alone alternatives for high-level waste repositories are described by Saanio et al. (2020).

In the concept description for the National Facility (Ikonen et al. 2020), non-radioactive waste from decommissioning of the nuclear facilities is disposed in the landfill. Alternatively, non-radioactive waste could be located in underground waste halls. This concept is presented by Ikonen et al. (2021). Non-radioactive waste could also be delivered to facilities for conventional (non-radioactive) waste.

The above-mentioned concept descriptions are prepared for communication, preliminary scheduling and cost estimating, input for preliminary design and R&D planning, guidance for bedrock surveys and feasibility studies. The first design stage presented by IAEA (2020) is Generic design. Outputs from the Generic design are: Generic layout, generic Product Breakdown Structure (PBS), preliminary tentative budget, tentative programme development plan, identification of main design risks and opportunities. The produced concept descriptions are important elements of the Generic design phase. Generic layout is presented in the concept description (Ikonen et al. 2020), preliminary tentative budget is presented in the cost estimation report (Saanio et al. 2021a). Still some areas should be studied and reported further to gain the level Generic design. E.g., preliminary drawings for the facilities should be drafted, systems for the facility should be sketched and backfilling and closure technology and materials should be investigated. Product Breakdown Structure (PBS) provides a hierarchical structure of products that make up the project. The main elements for PBS of the National Facility are presented in the concept description (Ikonen et al. 2020).

3.3 Site selection

NND is in Initiation phase with regards to the development process for the final disposal of radioactive waste in Norway and partly in the Site identification stage. This is also the preparatory phase for the upcoming site selection process in Norway. Currently proposed Site selection process and site selection criteria have been developed (Saanio et al. 2021b).

Target properties for the site of the National Facility have been developed (Hagros et al. 2021). The published target properties formed the basis for the Site selection criteria. Main focus is the long-term safety of National Facility.

Compared to the generic repository programme life cycle (Figure 2-1), the Norwegian project is in the Initiation phase and partly in the Site identification stage, as explained in Chapter 3.1, Figure 3-2.

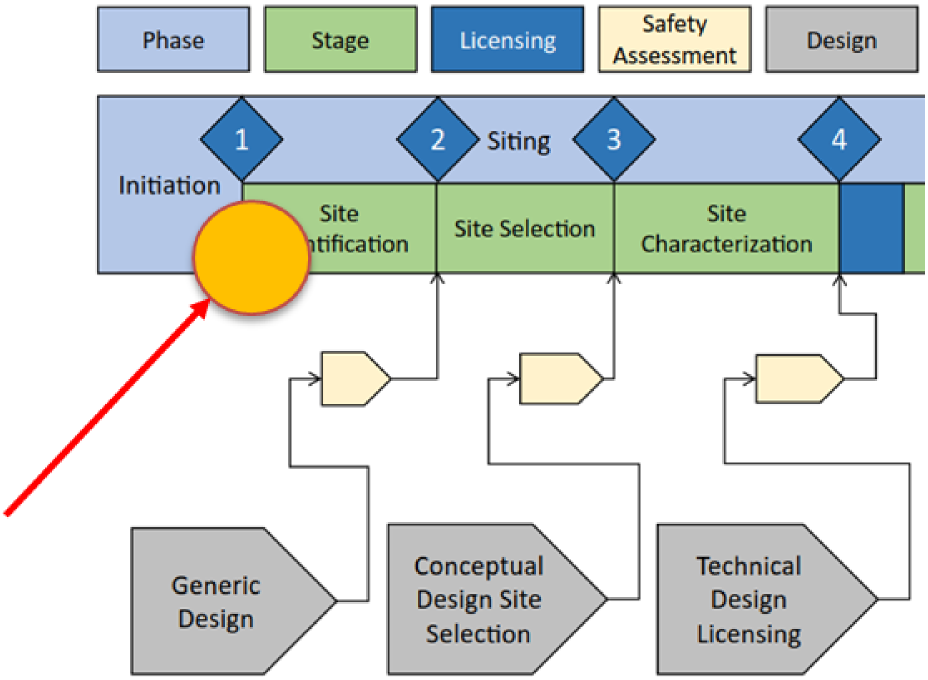


Figure 3-2. Current stage in the site selection process, yellow circle.

3.4 Overall schedule

NND has prepared a preliminary general schedule for construction and commissioning of the National Facility, Figure 3-3. According to the general schedule, it is assumed that around 25 years are needed for preparations, construction, and licensing of the facility. Preparations include e.g. political decisions, development of the concept and safety case. After construction and testing, the operation can start.

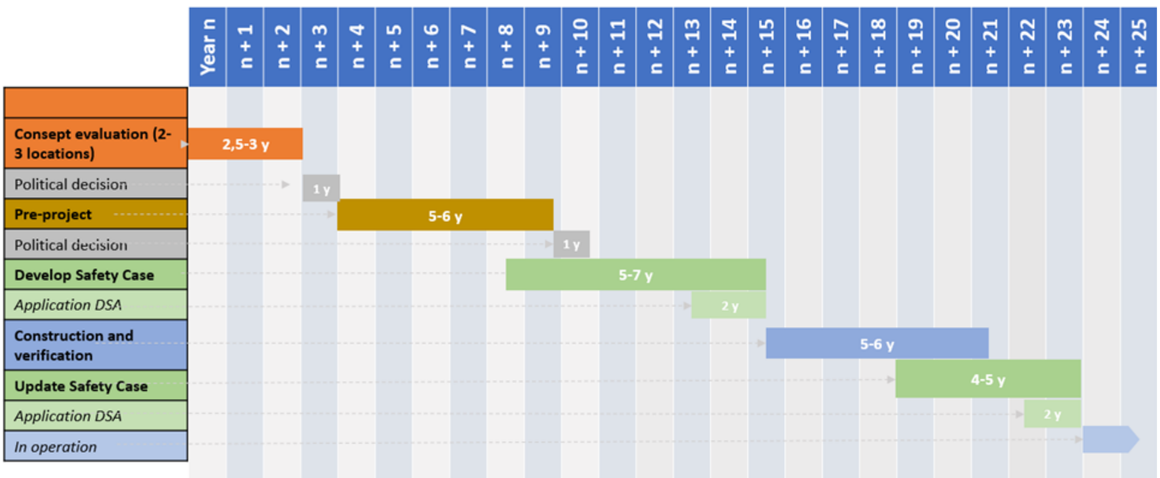


Figure 3-3. The general schedule for planning, construction, and commissioning of the National Facility. Source: NND.

Based on the general schedule, an overall schedule for the project was presented in the concept description (Ikonen et.al.2020), Figure 3-4.

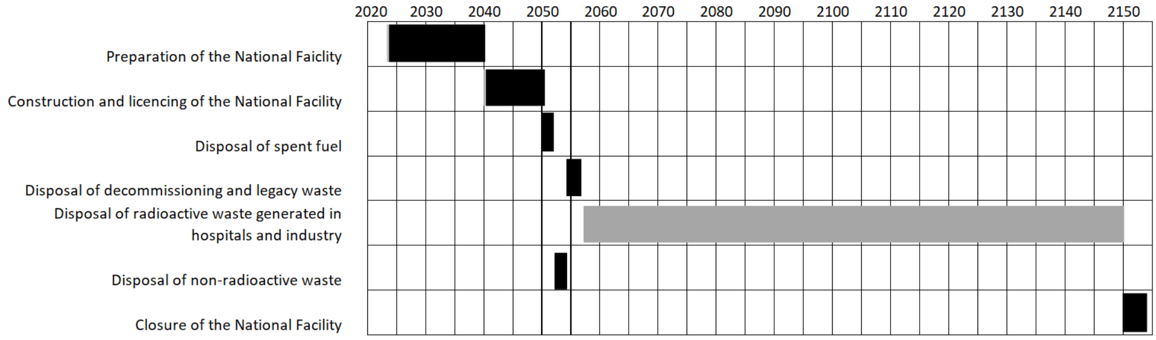


Figure 3-4. Overall schedule for the National Facility.

4 Proposed development process for the National Facility

Based on the IAEA terminology and guidelines, and the experiences from Finnish and Swedish disposal programme, the proposed development process for NND for the development of the National Facility is presented in this chapter.

Preliminary contents for the first three main stages of the development process are described. These stages are:

1. Project initiation and site identification stage
2. Site selection stage, Siting process Phases A-C
3. Site characterization, Siting process Phase D

Outputs, activities, milestones, decisions, risks and opportunities are discussed for each stage. It is also mentioned at various points how the process has been adapted to the Norwegian circumstances. General schedule is presented in the following chapter.

The proposed process and corresponding IAEA stages are shown in Figure 4-1. This assumes single site for the National Facility. This is also Scenario 1 (base case), see Chapter 4.4 for more details on scenarios.

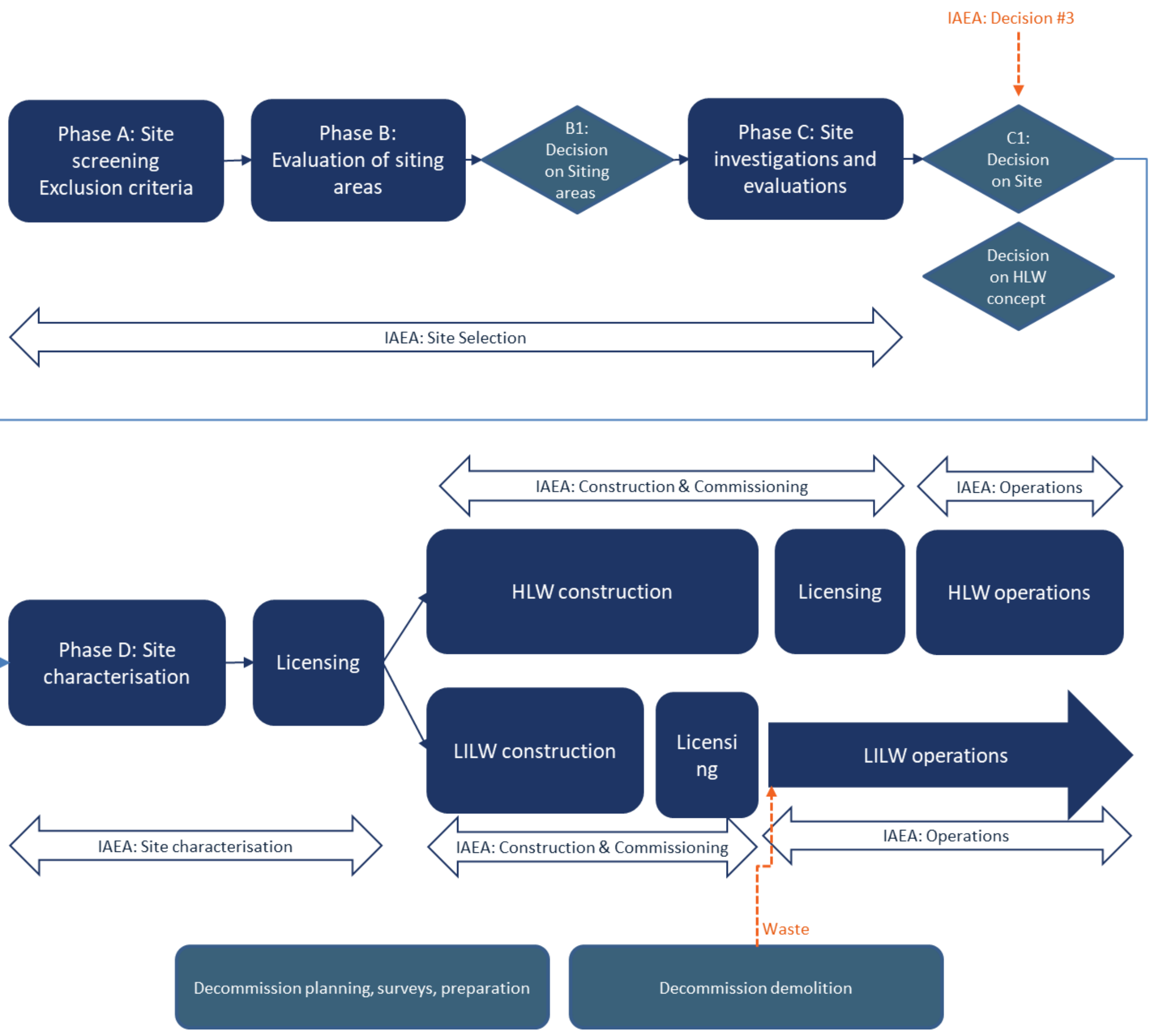


Figure 4-1. Proposed process for the National Facility. Corresponding IAEA stages are shown in arrows. Project initiation phase is not shown.

4.1 Project initiation and site identification stage

First main stage of the project in Norway is the initiation and site identification stage. This is where NND is currently. In the initiation stage all prerequisites for advancing the programme are identified. The stage also includes generic design (term concept design is also used) studies of the National Facility. In addition to developing concepts for the National Facility, the site selection process is prepared. This includes deciding on the siting strategy, developing the site selection process and the site selection criteria. The goal of the project initiation and site identification stage is to decide on the siting process for the site selection and to identify and start to communicate with possible sites for the site selection.

Currently generic design has been completed for the National Facility (see Chapter 3.1). A proposal for site selection process for the Norwegian National Facility was developed in two separate projects. These are reported as Saanio, Hagros & Wanne (2021b) and Saanio et al (2021c). Please refer to the original source material for details of the site selection process in Norway. IAEA generic repository programme and associated design stages are presented in Figure 4-2, comparative phase/stage is presented in the red box.

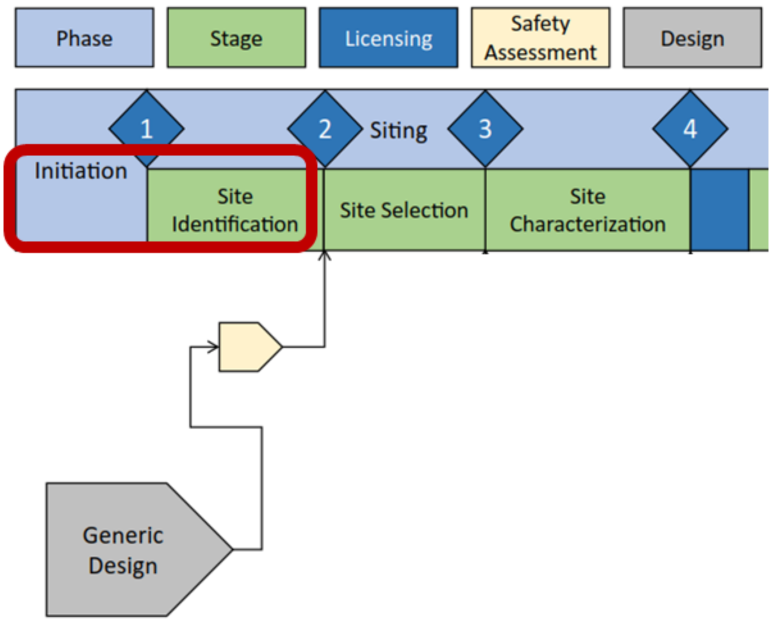


Figure 4-2. Above: IAEA generic repository programme and associated design stages until construction licensing aligned with indicative project milestones 1…4. Below: proposed site selection process for Norway. This equals "Site Selection" in IAEA diagram. Full IAEA diagram was presented in Figure 2-1.

Development of the following topics should also be considered during the Initiation and site identification stage.

- Decommissioning schedule of Kjeller and Halden. This schedule affects the need for the interim storage for the decommissioning waste. Decision of the decommissioning schedule should be done during the Initiation and site identification stage.
- Concept for spent fuel disposal. Deep geological repository or deep borehole repository. This decision may affect the target properties of the site and may affect the site selection. This decision is taken the latest (for basic scenario) at the same time as the decision C1.

4.1.1 Milestones and outputs

Initiation and site identification phase can be considered complete when the site selection process is officially launched. The main milestones of the site selection process in the project initiation and site identification stage are:

- siting strategy and
- detailed site selection plan.

For the facility design, the milestone is to develop a Generic design for the National Facility. Outputs from the Generic design (IAEA 2020) are:

- generic layout,
- generic Product Breakdown Structure (PBS),
- preliminary tentative budget,
- tentative programme development plan, and
- identification of main design risks and opportunities.

National Facility concept description (Ikonen et al. 2020 and Fischer et al. 2020) is the generic design of the facility as defined by IAEA terminology. In addition, following topics need further development:

- preliminary drawings for the facilities,
- systems descriptions and schematic designs for the ventilation, smoke extraction, electrical, automation, water and drainage systems of the facility, and
- backfilling and closure technology and materials.

4.1.2 Risks and opportunities

The main risk for the schedule is that the decision on siting strategy (e.g. voluntarism, white map,…) is delayed for example because there is not enough common understanding of how to proceed.

If the siting strategy is based strongly on the activeness of the communities, there is a risk that this process could take a very long time and there is a risk that there are no communities that are willing to offer a site. It is also a risk for the realisation of next stage “Site selection”, especially if only a few communities are willing to offer a site.

If the decision for the National Facility or independent repositories for different waste types could be done during this stage, it would be beneficial for the progress of the next stage. In that case, the target for the site selection phase would be clear: Select one site for the National Facility or two (or more) sites for independent repositories.

If the decision for the spent fuel repository concept could be done during this stage, it would be beneficial for the next stage. Target properties for the site may differ in case of the deep geological repository compared to the deep borehole disposal but differences in the target properties between the alternatives may be small.

4.2 Site selection stage, Phases A-C

Proposed site selection process is described in (Saanio et al. 2021b). Goal of NND’s site selection process is to find a suitable site for the Norwegian National Facility. The goal is that the location will fulfil all the necessary requirements set for such a facility. Generally, it is expected that there may be several locations satisfying the requirements. The final selection of the facility site is supported by evaluating various non-technical factors.

Proposed site selection process is divided into three phases: Phases A-C. Site selection strategy is hybrid mode with “white map” of Norway combined with voluntarism. There are two main decision points: B1 and C1. At B1 it is decided which sites will move to Phase C that includes intrusive site investigations. Phases A and B are desktop studies. Decision C1 is the decision on the site for National Facility, Figure 4-3. Phase D is Site characterisation (Chapter 4.3 in this report).

Parallel to site selection activities, design of the repositories at the National Facility are further refined and developed. These conceptual design updates can be used to adapt the disposal concepts to the sites under consideration. The information also assists the site selection. Preliminary safety assessment updates on selected sites are performed during this stage.

Development of the following linked processes of the nuclear waste management programme should also be done during the site selection stage even though some of the decisions can be done later:

- Plans for decommissioning waste and spent fuel interim storage should be developed during site selection stage.
- Reprocessing/treatment of the spent fuel. Decision affects the encapsulation, which may have an effect on where the spent fuel will be capsulated. This decision should be done during the site selection stage. The decision is linked to the decision on the DGR/DBD disposal. Both decisions should be made prior to the site characterisation (Phase D) of HLW disposal site (see Chapter 4.4 Scenarios). Decisions on the reprocessing/treatment and the DGR/DBD disposal can be postponed but more alternatives increase time and costs needed in the subsequent stages. It is possible to design, license and construct the facility to accept all different HLW types.
- Concept for the spent fuel disposal. Deep geological repository or deep borehole disposal. Decision may affect the target properties for the site and thus the site selection. Decision of the schedule must be done before moving to Phase D “site characterisation”. See above point.
- Waste acceptance criteria. WAC has an effect on the detailed construction design of the facility. Typically, waste acceptance criteria specify the radiological, mechanical, physical, chemical and biological characteristics of waste packages and unpackaged waste. Waste acceptance criteria might include, for example, restrictions on the activity concentration or total activity of particular radionuclides (or types of radionuclides) in the waste, on their heat output or on the properties of the waste form or of the waste package. Waste acceptance criteria are based on the safety case for the facility or are included in the safety case as part of the operational limits and conditions and controls.

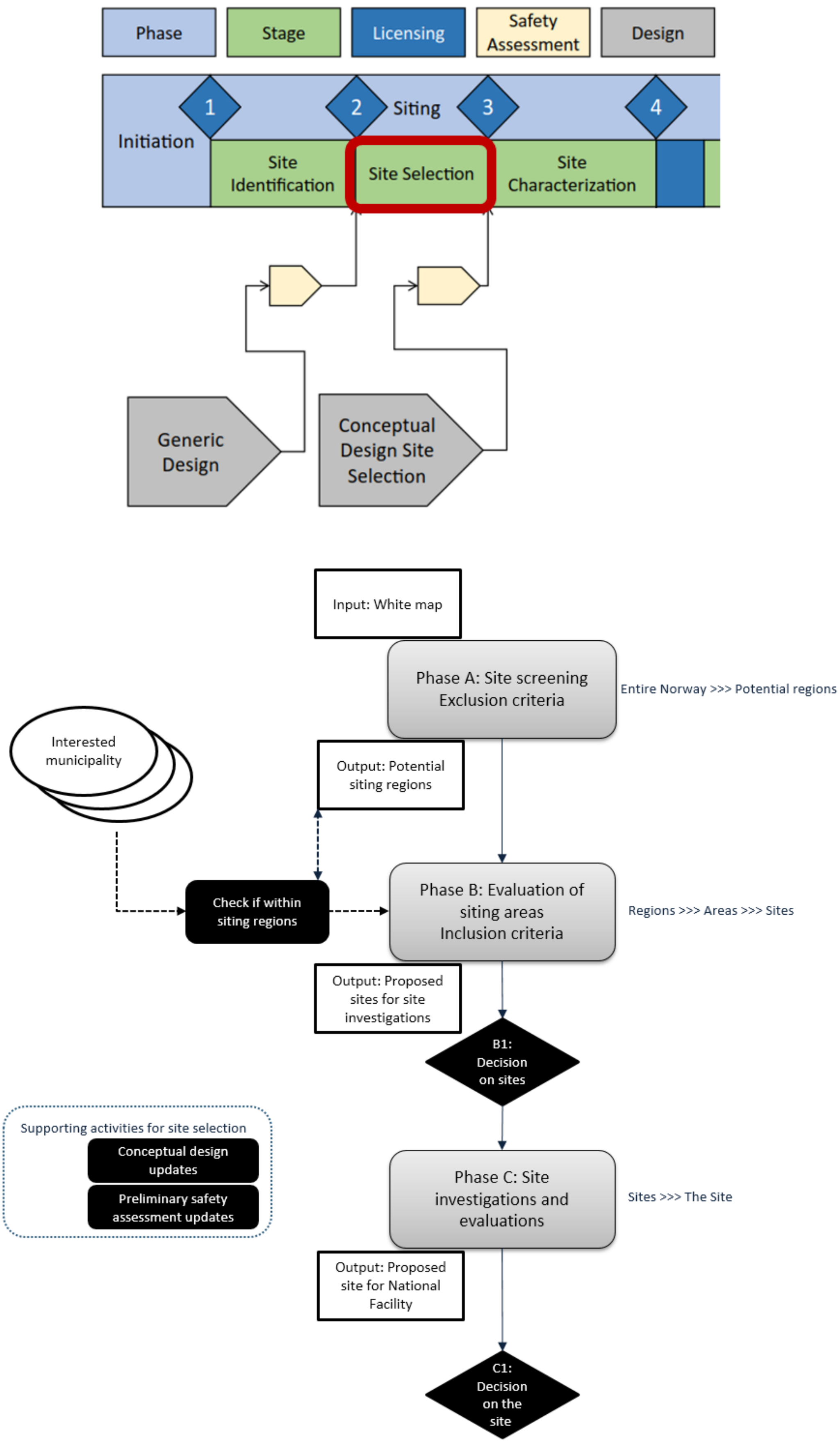


Figure 4-3. Above: IAEA generic repository programme with Site Selection highlighted. Below: Site selection phases A-C as proposed for Norway. This is inside the IAEA Site Selection box.

4.2.1 Milestones and outputs

The main decision of the site selection stage is C1 “Decision on site for the National Facility”.

For the facility design, milestone is to develop “Conceptual design for site selection”. Outputs from the conceptual design (IAEA 2020) are:

- conceptual design (technical feasibility, assumptions, general layout, PBS, nuclear/conventional zoning principles, preliminary process descriptions, etc.),
- budget/planning/risk/opportunity,
- updated functional specification,
- initial technical specification, and
- additional information needs (site characteristics, waste properties, and materials).

For the site selection, enough information should be gathered to be able to evaluate alternative sites. Simplified activities are:

1. investigation programmes for site investigations,
2. site investigations and analysis of data,
3. conceptual design of the facility including adaptation of the facility to sites,
4. long-term safety assessments, and,
5. cost estimations for the National Facility at alternative sites.

Some of the numbered activities above can be performed partly in parallel, but most of the tasks 1-4 must be done is series one after another. Duration of site selection stage (Phases A-C, until decision C1) can be roughly estimated to take 4…6 years. It is more of a question how to allocate resources and budget for the technical work.

4.2.2 Risks and opportunities

The main risk for the stage is that the site cannot be selected due to politics or because of lack of local community support. Technically, based on experiences from other countries, there is a high probability of finding suitable site for the National Facility. Success of the site selection will depend more on the municipality’s willingness and public acceptance. Therefore, communication plays a very important role in the site selection process.

4.3 Site characterization, Phase D

The third main stage in the design process is Phase D “Site characterization”.

The goal for the site characterization is to prepare for the construction licence for the National Facility, Figure 4-4. The activities in Phase D is to gather information for detailed disposal solution design, and for safety assessments and to the safety case to support the official licensing procedures. These together confirm the site suitability. One or more applications are needed, depending on the decision regarding the National Facility or independent repositories, see Scenarios, Chapter 4.4.

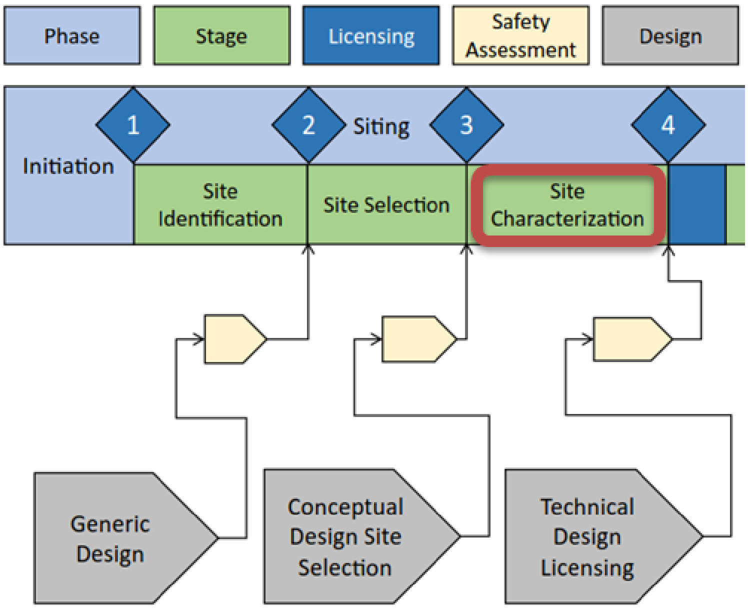


Figure 4-4. Generic repository programme life cycle and associated design stages until construction licensing aligned with indicative project milestones 1…4 (IAEA 2020).

Parallel to site selection activities, the design of the repositories at the National Facility are developed further and long-term safety should be assessed based on new information from the site investigations.

4.3.1 Milestones and outputs

Main decision at the end of the site characterization stage is “Construction licence application” or “construction license for the National Facility”.

For the facility design, the milestone is to develop “Technical design for construction licensing”. Outputs from the technical design (IAEA 2020) are:

- technical design of the facility (layouts, scaled drawings, process flow sheets, network diagrams, etc.),
- cost estimation, planning,
- preliminary construction development plan,
- preliminary construction and operating rules, and
- risk and opportunity assessment.

For the construction licence application, enough information should be gathered. Simplified activities are the same as in the previous stage:

1. Investigation programmes for site investigations
2. Site investigations
3. Conceptual design of the facility to the selected site
4. Long-term safety assessment
5. Cost estimation of the National Facility at alternative sites.

Some of the numbered activities above can be performed partly in parallel, but most of the tasks 1-4 must be done in series one after another. Duration of the site characterization stage (characterisation activities and licensing related activities) was estimated to be 5 years (Saanio, Hagros & Wanne. 2021b).

4.3.2 Risks and opportunities

Technical development and decisions for the concept and location for encapsulation poses a risk for the disposal schedule. If the technology is not developed, designed, and approved, the start of the construction of the spent fuel disposal needs to be postponed. But even in this case, the National Facility could be constructed without the spent fuel repository, and disposal activities could be started with existing low and intermediate level waste. The National Facility can be constructed in two phases. First intermediate depth repository and then deep geological repository in the second phase, see Scenarios.

4.4 Scenarios

Three scenarios of the development process are presented in this chapter. The scenarios provide three options to separate HLW disposal and the disposal all other radioactive waste. The separations are either temporal or physical. Temporal separation meaning the HLW disposal is done independently and separated in time from the other waste, but still within the National Facility site. Physical separation meaning that the two waste streams are not disposed in a single National Facility.

The scenarios are:

- Scenario S1 – One National Facility, one construction license for all waste repositories (Base case, most previous work on the technical framework has been based on this assumption). One siting process (Phases A – D).
- Scenario S2 – One National Facility, two construction licenses: LILW + HLW. Motivation is that LILW license can be obtained easier/faster than HLW license. However, it is unclear if an on-going construction/operation of LILW repository would have negative effect on obtaining construction/operation licenses for HLW. One siting process (Phases A – C) with separation from Phase D onwards (within the National Facility site).
- Scenario S3 – Separate facility sites: LILW + HLW, two completely independent separate siting and licensing processes. HLW process is exactly the same as for S1 (but without the LILW repository).

4.4.1 Assumptions and uncertainties

Chapter 1.2 presented boundary conditions and assumptions for the development process (also base case, Scenario S1) that has been discussed in the report so far. The additional assumptions presented below are related to the developed scenarios, which are variations from the base case.

For the purpose of the scenarios, term “LILW repository” is used to include also landfill repository. In Scenario 3, two separate siting and licensing processes are shown. That could have been three, where siting process for a landfill repository is separated from “LILW repository”.

It is assumed that process steps are executed back-to-back without breaks, unless otherwise noted.

Licensing: one construction licence for the entire National Facility and separate repository specific operational licences due to significant difference in operational timeframes between HLW and LILW.

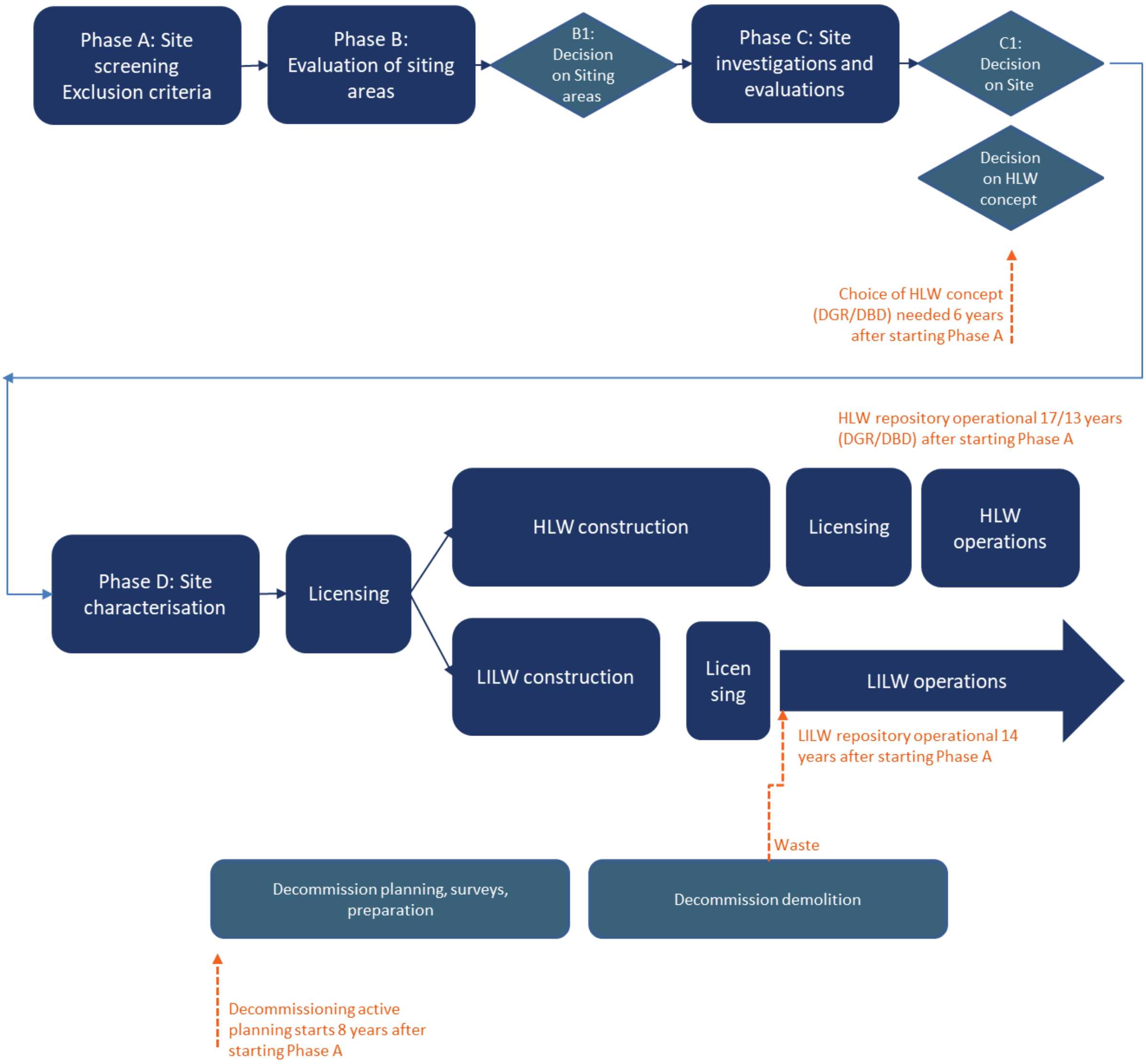
Decommissioning durations assumed: Planning (2 y), Surveys (1 y), Contracting (1y), Site preparation and demolition (4 y): total 8 years. For direct disposal LILW needs to be operational 6 years after decommissioning project starts (from planning stage), assuming maximum two years of on-site temporary storage of demolition products.

Construction durations:

- National Facility was described in Ikonen et al. (2020). The cost estimate (Saanio et al. 2021a) presented construction time, which was 10 years. The construction time was used for costing and was a conservative estimate. The reference work does not include information about sequencing construction (such as which parts will be built first) or how the LILW/HLW repositories could be constructed separately.
- At National Facility site, LILW repository shares underground infrastructure with HLW-DGR repository. Therefore, their construction planning and scheduling are linked. HLW-DBD is independent from LILW repository within National Facility. Therefore, their construction planning and scheduling are not linked, apart from some shared surface infrastructure. These aspects are not covered in the development process.
- Construction times for independent HLW-DGR and HLW-DBD were presented in (Saanio et al. 2020). This was another cost estimate where the durations were estimated in order to estimate cost. The durations were not based on construction planning. For HLW-DGR it was estimated 6 years and for HLW-DBD 2 years.
- There does not exist concept description for National Facility with separated HLW and LILW repositories nor construction duration estimates for National Facility in which HLW/LILW repositories are not constructed as one entity. For this development process it is assumed that LILW repository could be constructed in 5 years and then after LILW repository is finished, HLW-DGR repository in 5 years or HLW-DBD repository in 1 year.
- There do not exist concept description and construction duration estimates for an independent LILW repository. For this development process it is assumed that LILW repository could be constructed in 5 years.

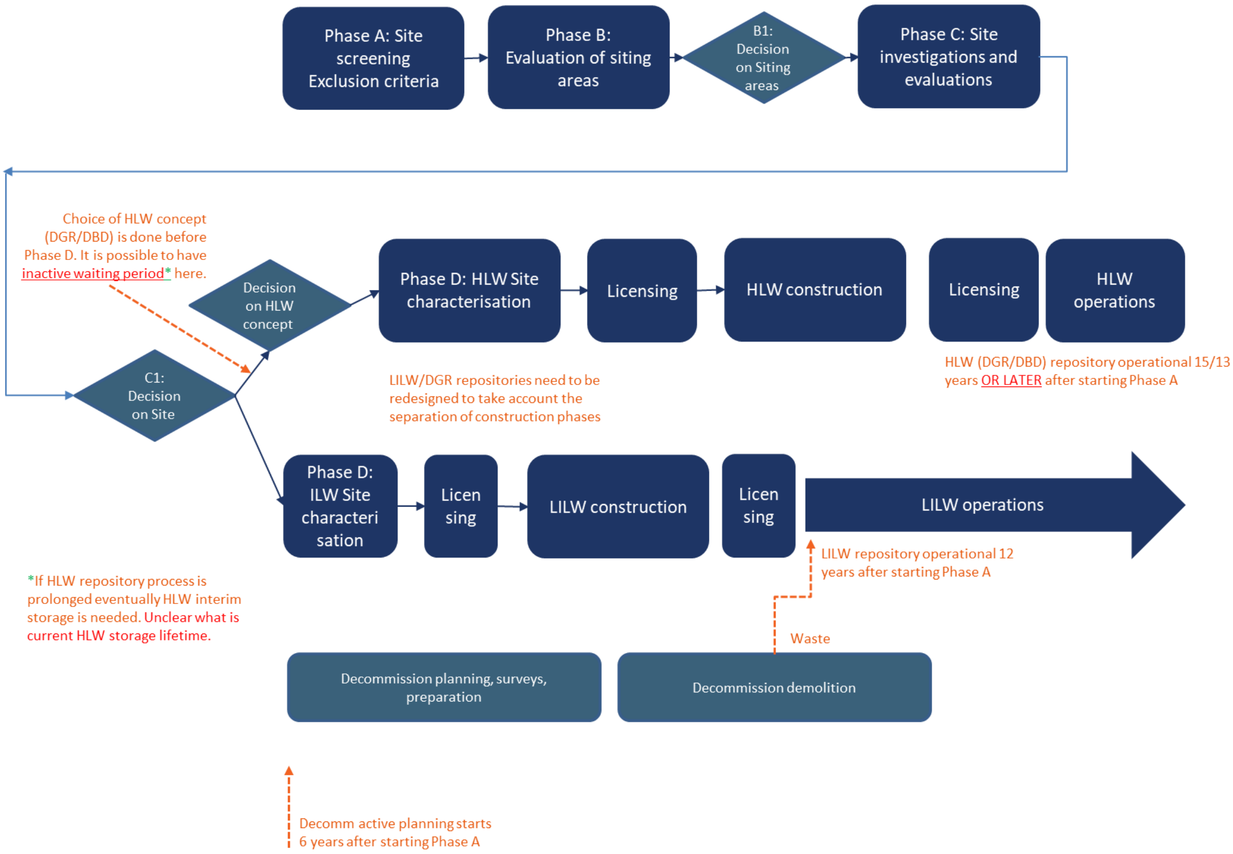
4.4.2 Scenario S1: National Facility – single construction license

The shown years are only indicative. The sizes of the boxes reflect roughly the relative durations of each activity or phase. Interim storages for HLW and decommissioning waste are not presented.



4.4.3 Scenario S2: National Facility – two separate construction licenses

The shown years are only indicative. The sizes of the boxes reflect roughly the relative durations of each activity or phase. Interim storages for HLW and decommissioning waste are not presented.

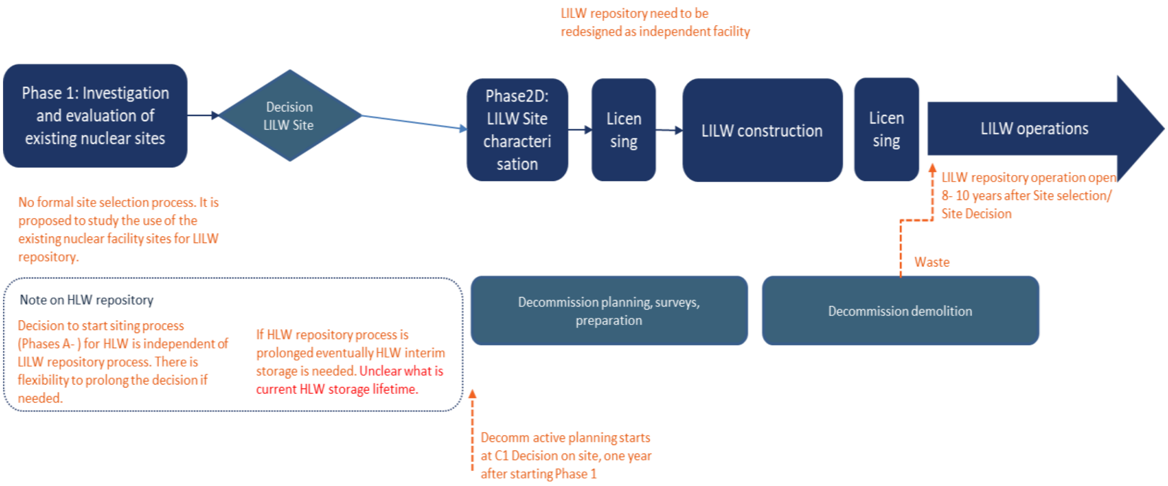


4.4.4 Scenario S3: Two separate independent facilities

The scenario only shows LILW repository process. HLW repository process would follow Scenario S1 without LILW component. The start time for HLW process is independent from LILW repository process. Therefore, decision on HLW disposal can be postponed.

In the scenario it is proposed and assumed that streamlined site selection for LILW repository can be done. The existing nuclear municipalities (Halden, Kjeller, Himdalen) or nearby should be studied as potential sites for LILW repository if one of them could be chosen as the site. Presented process starts with site investigations (Phase 1) in that chosen municipality. This is the streamlined site selection process, which should be suitable for LILW type of repository in Norway. If it is not possible to choose one of these sites, then investigations should be continued in other regions.

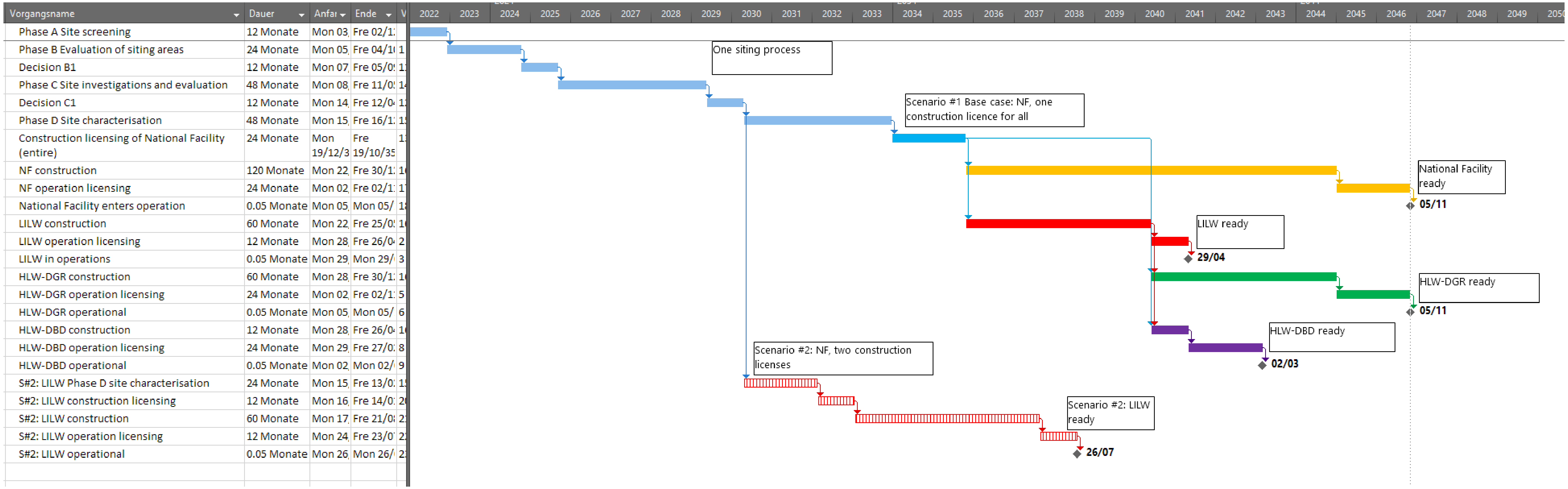
Time needed for licensing and construction of LILW repository is roughly 10 years in the Scenario 3 compared to 15-20 years in Scenarios 1 and 2. Depending on the schedule for the decommissioning of the reactors, it is possible that interim storage for decommissioning waste is not needed. HLW repository schedule in Scenario 3 is independent of LILW repository schedule.



In this scenario, LILW and HLW repositories are separate and independent facilities, meaning that this is not a National Facility concept. It is therefore out of the scope for this process. The possible benefits of this scenario, reducing some of the interdependencies for example, makes it relevant to investigate this scenario further.

4.4.5 Scheduling the scenarios

The Scenarios S1 and S2 are visualised in a simple Gantt chart. The schedule is based on the durations listed in Chapter 4.4.1. As there are several uncertainties in the estimation of durations, the presented schedule should only be considered illustrative giving generic impression of the differences between the two scenarios. What is evident from the schedule is that in S2 LILW repository will be operational about three years earlier (only) compared to the base case. For Scenario S2 only LILW is scheduled. As presented in Chapter 4.4.3, HLW repository is constructed after an undefined time period following Decision C1.



Vorgangsname	Dauer	Anfar	Ende	V
Phase A Site screening	12 Monate	Mon 03	Fre 02/1	
Phase B Evaluation of siting areas	24 Monate	Mon 05	Fre 04/1	1
Decision B1	12 Monate	Mon 07	Fre 05/0	1
Phase C Site investigations and evaluation	48 Monate	Mon 08	Fre 11/0	1
Decision C1	12 Monate	Mon 14	Fre 12/0	1
Phase D Site characterisation	48 Monate	Mon 15	Fre 16/1	1
Construction licensing of National Facility (entire)	24 Monate	Mon 19/12/3	Fre 19/10/35	1
NF construction	120 Monate	Mon 22	Fre 30/1	1
NF operation licensing	24 Monate	Mon 02	Fre 02/1	1
National Facility enters operation	0.05 Monate	Mon 05	Mon 05/	1
LILW construction	60 Monate	Mon 22	Fre 25/0	1
LILW operation licensing	12 Monate	Mon 28	Fre 26/0	2
LILW in operations	0.05 Monate	Mon 29	Mon 29/	3
HLW-DGR construction	60 Monate	Mon 28	Fre 30/1	1
HLW-DGR operation licensing	24 Monate	Mon 02	Fre 02/1	5
HLW-DGR operational	0.05 Monate	Mon 05	Mon 05/	6
HLW-DBD construction	12 Monate	Mon 28	Fre 26/0	1
HLW-DBD operation licensing	24 Monate	Mon 29	Fre 27/0	8
HLW-DBD operational	0.05 Monate	Mon 02	Mon 02/	9
S#2: LILW Phase D site characterisation	24 Monate	Mon 15	Fre 13/0	1
S#2: LILW construction licensing	12 Monate	Mon 16	Fre 14/0	2
S#2: LILW construction	60 Monate	Mon 17	Fre 21/0	2
S#2: LILW operation licensing	12 Monate	Mon 24	Fre 23/0	2
S#2: LILW operational	0.05 Monate	Mon 26	Mon 26/	2

5 Development process schedule

Schedule and summary of the main milestones and main decisions for each process are presented in Figure 5-1. Milestones (M) and decisions (D) (numbers are indicated in Figure 5-1) are:

Site selection

1. Siting strategy and detailed site selection plan, M1
5. Selection of the site for the National Facility, D5, (Decision C1, Scenario S1, chapter 4.4.2.)

Disposal facility development

2. Generic design of the disposal facility, M2
   Decision D2: National facility or independent repositories
6. Conceptual design for site selection, M6
   Decision D6: Disposal concept; deep geological repository or deep borehole repository, in conjunction with Decision D5
9. Technical design for construction licensing, M9

Safety assessment

3. Development of safety assessment process, generic safety assessment for DBD and LILW, M3
7. Preliminary safety assessment for selected site(s) to support site selection, M7
10. Final safety assessment for construction licensing, M10

Encapsulation of the spent fuel

4. Feasibility of encapsulation for different spent fuel inventory alternatives, M4
8. Outsourced or own process, D8
11. Encapsulation plan for the spent fuel, M11

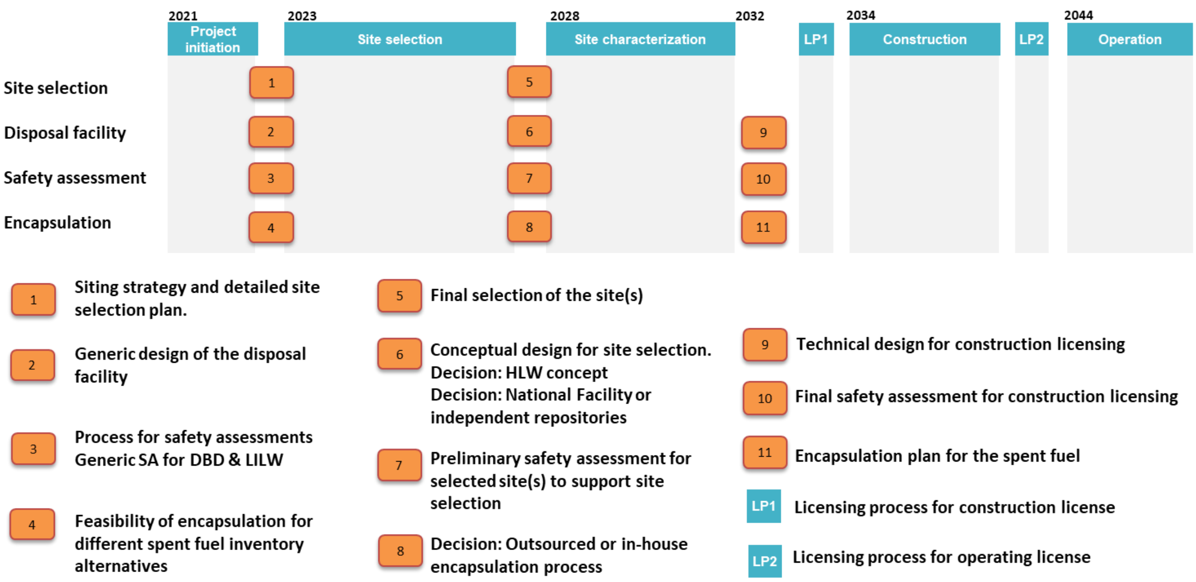


Figure 5-1. Summary schedule for the base case (Scenario S1)

6 Summary and recommendations

Based on the developed process description, the critical path of realising the National Facility is the site selection. The summary schedule collects processes showing readiness for construction license application for the disposal facility in 2032, Figure 5-1.

Waste inventory, decision of possible reprocessing of the spent fuel should be decided in the near future. Decision affects the encapsulation, canister design and long-term safety assessments for the disposal.

The main focus of the work was the development process for the site selection and design of the disposal facility. When similar development processes have been made for the other main activity streams (the long-term safety assessment, decommissioning of the reactors in Kjeller and Halden, interim storage facilities, encapsulation, etc.) master plan can be created showing all major linkage between the processes.

Then an overall decommissioning strategy can be established, followed up by an overall programme and schedule. Project plan and more detailed action plan for each process could then be decided.

This development process indicates that considering technical design of the disposal facility, NND is at the ready to start the siting process for the facility. To conclude, three main decisions are needed before the official launch of the site selection stage (Chapter 4.2) in Norway:

1. Decision on the concept for the Disposal facilities (KVU)

    a. National Facility - one site for all radioactive waste (Scenarios S1 and S2: one site – one siting process) – move to decisions #2 and #3

    b. Separate sites for HLW and LILW disposal facilities (Scenario S3: two sites – two separate siting processes)

    c. Long-term storage (siting process for interim storage facility, no siting process for final disposal) -> this development process does not apply

2. Decision on the site selection process to be followed

3. Decision on the site selection criteria that will be applied.

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