European Partnership
on Radioactive Waste Management

DI 4.1.1 Site Descriptive Model

EURAD Roadmap

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The **EURAD Roadmap** is a representation of a generic radioactive waste management (RWM) programme that shall enable users and programmes to access existing knowledge and active work or future plans in EURAD-2 and elsewhere. The content is focused on what knowledge, and competencies (including infrastructure) is considered most critical for implementation of RWM, aligned to the EURAD Vision.

All Roadmap documents can be accessed at the EURAD website: https://www.ejp-eurad.eu/roadmap.

The **Theme Overview Series** is part of the EURAD Roadmap, which is 7 high-level introductions to the EURAD Roadmap providing:

Guidance on typical goals and activities for RWM – Activities (which may be of variable importance and scope depending on the nature of the disposal programme) provide generic guidance on how to achieve key programme goals and how priorities evolve throughout programme phases, from advanced programmes perspectives.

Competencies for RWM – Needed competencies (and accessible infrastructure) for successfully managing a disposal program within the different phases of implementation.

The **Domain Insight Series** is part of the EURAD Roadmap, which in totality provides a high-level checklist of generic and typical activities needed for the full radioactive waste management lifecycle, leading to geological disposal including:

Functionality – Contextual information about how activities and knowledge associated with a domain contribute towards achieving generic safety and implementation goals.

Maturity and State-of-Knowledge (SoK) – Links to available SoK are included, providing an Experts' view of the most relevant knowledge and associated uncertainties (including areas of ongoing scientific and technological enquiry) in a specific domain applied in the context of a radioactive waste management programme.

Safety and Implementation Significance – Contextual information about how activities and knowledge associated with a domain impact long-term safety or practical implementation.

The **Domain Insight Series** of EURAD comprises over 70 short documents, prepared by Europe's leading Subject Matter Experts across Radioactive Waste Management. The documents are aimed at early career professionals or new starters interested in best practice and key knowledge sources.

Overview

This Domain Insight report introduces Site Descriptive Model (SDM) and key points to establish and define a model during siting and building a repository. The SDM is a foundational tool in geological disposal of radioactive waste. The SDM integrates geological, hydrogeological, hydrogeochemical, geomechanical, biosphere data and defines properties of the bedrock for radionuclides transport. SDM evolves through all phases of repository development: from programme initiation to post-closure. Provides a simplified but comprehensive representation of site conditions. The SDM is the basis for safety assessments, repository design, and regulatory reviews. A comprehensive SDM stress the importance of multidisciplinary collaboration, predictive modelling, and robust data management. The SDM can be designed to different geological settings and disposal concepts.

Keywords

SDM, site descriptive model, geology, hydrogeology, hydrogeochemistry, rock mechanics, biosphere, radionuclide pathways, surface environment

Key Acronyms

SDM = Site Descriptive Model

DGR = Deep Geological Repository

URL = Underground Research Laboratory

EBS = Engineered Barrier System

DFN = Discrete Fracture Network

FEP = Features, Events and Processes

1. Site Descriptive Models: Overall goals, objectives, activities and strategies

This section describes the overall goal of this domain, extracted from the EURAD Roadmap goals breakdown structure (GBS). Furthermore, the typical activities, for each phase of implementation, required to meet this domain goal are described. The activity descriptions are generic and are common to most geological disposal programmes.

1.1 Goals

The geological setting, both local and regional, and the Site Descriptive Model (SDM) of a potential disposal site form a fundamental basis for all future geoscientific and safety assessments of a Deep Geological Repository (DGR) site. The SDM should also assess in addition to the local site, also data and experience with similar rocks elsewhere and studies, to form a robust geoscientific argumentation and safety assessment. The SDM is closely linked to the overall process of understanding all the characteristics relevant for disposal at the site, i.e. the site characterisation process, and evolves progressively as each phase of characterisation is completed. It is essential that the SDM describes and reflects site conditions with a sufficient level of detail and understanding. The adequacy of this interpretation should be evaluated based on its intended use, whether for safety assessment, repository design, or regulatory review, following a graded approach that aligns the depth of investigation with the complexity and risk associated with the disposal concept.

Domain Insight 4.1.1 Site Descriptive Model

Domain Goal	
4.1.1 Develop a model of the host rock and surrounding geological environment, including distributions of rock types, geometry and properties of structural features, geotechnical properties and the hydrogeological and hydrogeochemical environment (Site Descriptive Model). The description here regards the technological processes for a SDM, but equally important is the socio-political, economical and public consent processes depending on the approach and cultural framework for each country.	
Domain Activities	
Phase 1: Programme Initiation	**Compile a broad-scale national geological overview with information across the country**, focusing on major geotectonic units. Characterise these units in terms of their structural complexity, geological history (e.g., sedimentation and mountain-building processes), and recent tectonic activity (e.g., vertical displacement, seismic and aseismic movements). Map and define units with low bedrock topography and low fracture frequency on exposed rock surfaces, as well as areas with no occurrence of economical minerals. Present findings in a comprehensive overview report, supported by maps and cross-sectional diagrams. **Compile a broad overview of existing knowledge related to large-scale geological and environmental processes across the country.** This should include patterns and trends in vertical and horizontal crustal movements, seismic activity, glaciation history, volcanic phenomena, and erosion. The initial screening can rely on publicly available large-scale datasets and published sources. The data and maps, that are compiled and acquired during this stage, will be used during next phases. **The identification of potential host rock types and blocks.** Determine the general distribution of rock formations (e.g., uniform composition and structure of the rock mass) that may be suitable for long-term containment, such as low-permeability sedimentary and crystalline rocks. Use existing geological profiles and maps to highlight relevant formations and structural patterns. **Assess the large-scale subsurface suitability.** Identify larger regions where potential host rocks may occur in sufficient extent, at suitable depth with a tectonic overprint not critically affecting radionuclide migration (e.g., units with low water flow rate within the bedrock). The identification of search regions may will base on direct measurements and on knowledge from analogous geological settings. Document the findings to support further site-specific investigations.

Phase 2: DGR Site Identification	**Conduct a more detailed review of existing geological and tectonic information than in the initial phase with focus on the areas that have been identified as potentially suitable in Phase 1.** Further evaluate the geological framework in these regions to narrow down and better define areas with potentially suitable rock formations at desired depth and geometry, considering both geological characteristics and long-term stability factors. **Compiling or updating existing datasets (e.g. geophysical data, lineament interpretations, large-scale geological 3D-models) to define suitable host rock blocks.** Geological, geophysical, and topographical data are used to refine existing geological 3D-models and to inform on the spatial location and dimension of potential host rocks and on the location of major faults. This helps to identify regional deformation zones and delineate potentially stable host rock blocks in desired geometrical configuration (depth, extension, etc.). Define broad regions (e.g., geotectonic units) that warrant further investigation. Narrow down to a manageable number of promising regions with manageable extent for more detailed studies. **Optionally, apply exclusion criteria** to eliminate areas clearly unsuitable for deep geological disposal (e.g., due to tectonic instability, natural preservation areas, ore potential areas etc.) allowing remaining areas to be assessed based on their individual merits. If the site identification, is performed with volunteering sites, it is still important to perform the regional analyses from a wide enough area. **The identification and investigation activities are focused on specific sites.** The investigation includes a comprehensive and detailed evaluation of existing information related to the sites and regions. Where necessary, site-specific field investigations may also be conducted to address remaining uncertainties. **Compile all existing and available information across** a wide range of geoscience disciplines. This includes smaller scale geological maps, data from existing boreholes and results from previous geophysical surveys (e.g., airborne geophysics, reflection seismic surveys) conducted by other organisations for various purposes. If needed, information can be complemented by selective laboratory investigations on existing cores or outcrops and/or by complementary new field investigations.

Phase 3: DGR Site Characterisation	**This stage is the most important phase to compile a robust and reliable Site Descriptive Model (SDM).** The SDM is continuously updated and refined as new data are gathered, and site information evolves. **The site characterisation investigations will employ a combination of geophysical data (e.g. 2D/3D seismic surveys, high-resolution airborne geophysics), and deep borehole drilling.** These activities will support assessments of long-term safety, repository design, and construction feasibility. The choice of methods depends on geological conditions: in areas with exposed crystalline host rock, surface mapping and airborne surveys are emphasised, whereas in areas where the host rock lies beneath Quaternary and/or sedimentary bedrock cover, reflections seismic and subsurface investigations are prioritised. The required level of geoscientific understanding also varies by setting and by host rocks. Crystalline rock sites typically demand more boreholes than sedimentary rock sites due to the limited data acquired by reflections seismic methods and due to the more important role of tectonic structures as efficient flow paths in the host rock. **SDM must cover following important aspects: lithology, structural geology, hydrogeology, hydrogeochemistry, biosphere, geomechanics and thermal properties.** Preferred host rock blocks are identified based on their geological characteristics. This includes evaluating the broader geological setting and avoiding tectonic structures with dimensions and properties that could endanger the long-term stability for the DGR. **Based on the regional investigations and national policy, one or more potential sites are proposed for detailed site-scale investigations.** These areas may range from a few to several tens of square km, depending on the geological setting and the size of the planned repository. The final selection of the site needs to consider long-term geological stability. **Depending on the geological environment, this stage of the programme can also involve the definition of a 'host rock suitability classification' system.** This system identifies specific geological and geotechnical criteria for accepting or rejecting a volume of rock for waste emplacement. It will be applied and possibly refined during the subsequent construction phase. **The SDM should either be part of a geosynthesis report or should be combined with a separate geosynthesis report that serves as a key reference document.** This includes the geo-datasets used for long-term safety analysis and repository layout and construction planning. One of the aims of the geosynthesis report is to demonstrate the consistency of models and data across different geoscientific disciplines. Moreover, a geosynthesis report should integrate offsite data and knowledge and should demonstrate the understanding of key geological processes with regard to long-term safety.

Phase 4: DGR Construction	**Detailed mapping of all underground structures** is essential and can be acquired from boreholes, ramps, tunnels and shafts. The SDM is continuously updated and refined as new data are gathered, and site understanding evolves. This process includes testing model predictions against observed data to ensure accuracy and reliability. **Detailed site characterisation**, confirmation and testing of discipline specific models, and model updates. The emergence of new data from underground excavations helps to quantify uncertainties with greater resolution within discipline-specific models The availability of higher resolution data enables modelling of smaller-scale features important for identifying optimal volumes for placement of radioactive waste and meet the requirements for a long-term safety of repository. Measurements and monitoring related to disturbances are also conducted to assess long-term stability, repository layout and construction planning as the work proceeds. **Confirmation of key properties of host rock volume.** This may follow specific geological and/or geotechnical criteria for accepting or rejecting a volume of rock for waste emplacement and will be deployed and possibly refined during the subsequent construction phases.
Phase 5: DGR Operation and Closure	**The continuous updating of the SDM and the geoscientific data.** These geo-datasets are crucial for long-term safety analysis and for monitoring the site during operation and after closure, forming a key part of a robust safety case. **Monitoring the surroundings of the repository and comparisons to discipline specific models and baseline studies.** Define and confirm the final conclusions regarding the long-term safety rely on baseline, operational and post-closure results that have been gathered in the SDM through the entire life cycle of the repository. Preserve the data and documentation gathered on the SDM throughout the life cycle of the repository to protect and secure the DGR site for future generations.

1.2 Objectives

The SDM is built on the integration and synthesis of all available data, including geological and geophysical, and with relevant information from geomechanics, hydrogeology, hydrogeochemistry, and any other geoscientific disciplines, including the biosphere. At the early stages of the modelling process, the data acquisition and models are often performed separately within each discipline. Integration of these is ideally performed early and at least a close collaboration is needed between the separate disciplines. The data are processed and analysed using discipline-specific methods that are generally accepted within their respective scientific communities. The complete geosphere description within a SDM, can be considered as a simplified representation of geological (lithology, stratigraphy, tectonic setting, deformation zones, fracture network, etc.), hydrogeological, and geochemical conditions within a specified rock volume. SDMs should aim to be useful for describing natural characteristics, listed above, whilst also being amenable to numerical computations and if necessary, applying suitable upscaling methods.

The SDM is compiled and based on discipline specific models and where the integration/synthesis is performed the final SDM can be defined. The earlier the integration of the models is performed, the smoother integration process is. The geological site model provides the geometrical framework and the geoscientific descriptions necessary for developing e.g. rock mechanics, hydrogeological, and (hydro)geochemical models. These static models are required for simulating repository behaviour over both the short and long term, i.e. supporting repository design, construction and the demonstration of both operational and post-closure safety.

1.3 Strategies

The essential topics and the scope of the discipline-specific models that are parts of the integrated SDM are based on international criteria and general guidelines (e.g., IAEA, 2011, IAEA, 2015, IAEA, 2024) and national laws and regulations. The aim of these strategies is to achieve an adequate site characterisation to support modelling needs. The essential discipline-specific topics to consider are:

1) Geology
2) Hydrogeology
3) Hydrogeochemistry
4) Geomechanics
5) Biosphere (surface system and environment)
6) Radionuclide transport (defining and parametrising/simulating possible routes for radionuclide transport, including surface environment/biosphere)
7) Thermal, diffusion and sorption properties of the bedrock

Throughout the modelling process, there are several discipline-specific models, with specific criteria and properties, that through interaction and iteration are building blocks for these sub-models. The specific criteria and properties depend on the geological context, and the concept of the engineered barrier system, thus these are site specific. The SDM includes relevant characteristics of a DGR site, such as, the following:

- Rock type distribution, stratigraphic formations, alteration, thermal properties
- Hydrogeological properties (e.g. aquifers, groundwater and pore-water)
- Flow and solute transport properties (most important site-specific characteristics of flow and gas transport; this may include radionuclide-specific diffusion and sorption properties, particularly in diffusion-dominated sedimentary systems)
- Groundwater chemical composition, redox, bacterial processes, water residence times, ages, isotopes and water-rock interaction
- Deformation zones (brittle and ductile), the geological and tectonic properties of these zones, such as, alteration, orientation, kinematics, extent of cores and influence (damage) zones
- Extent and orientations of distinct/discrete fractures and faults coupled to Discrete Fracture Network (DFN) models, including, e.g., hydraulic and transport properties
- Types of ecosystems, internal, mutual and external connections, material resources and material cycles, climate, weather
- Topography and thickness of soil cover, surficial deposits
- Stress field, strength and deformation properties of rocks

1.4 Activities

A SDM is generally a description of the target or a site, based on existing investigation and site-specific data. The simplest form of such a model would be a direct description of the data itself. However, usually it takes the form of a deterministic or stochastic description of certain properties, structures or processes within the site. It is essential that the model is based on the best and most recent data of the site. Therefore, it should be updated and developed as new data becomes available. In addition to main model versions, several minor model revisions can also be produced especially during the main Site Investigation phase, if needed. To ensure transparency, a data freeze period should be established at the start of each new modelling round. During this period, the dataset used for modelling remains unchanged, allowing for consistent and traceable model development. The SDM can further evolve from more static models (e.g. geological, hydrogeological, DFN) to more dynamic (e.g. hydrogeochemical, flow and solute transport) to models that include simulations on different topics and future scenarios for the DGR site. Listed below is a short introduction to various discipline specific models used to describe the SDM for the whole site, these are often independently modelled but input is needed from the other models.

1) **Geological modelling**

The geological model is the fundamental model for the SDM and contains rock type distribution (lithology) that will be described and modelled based on geological observations from outcrops, trenches and boreholes, as well as results from geophysical surveys or relevant underground research laboratories (URL). Each crystalline rock type unit or sedimentary unit (stratigraphic sequence) can be constructed as a 3D solid. Based on the solids, a lithological block/voxel model can be prepared. Locations and orientations of deformation zones, faults and fractures will be determined based on orientations of structural features, through geophysical investigations or geological mapping. Also, if the bedrock has a long (multi-phase) deformation history, the most intense ductile deformation, typically controlling brittle deformation, will be modelled as form lines or solids. In addition, the altered section of the bedrock is modelled, this alteration can be related to deformation zones or whole-rock alteration.

2) **Discrete Fracture Network (DFN) modelling**

The complexity of the geometry and physical diversity of fractures, as well as the flow and transport of solutes in a fracture dominated system, there is no possibility to incorporate all the flowing fractures that might exist at a site into deterministic geological and hydrogeological models. The crystalline rock mass is typically interpreted as an effectively impermeable background matrix with a superimposed stochastic fracture network that at a minimum takes into account frequency distributions illustrating a range of fracture length, orientation, spacing and aperture. Consequently, a DFN model is constructed that incorporates a stochastic representation of fracturing, utilising the initial fracture data from outcrops, trenches and boreholes. The model is a representation of the rock mass through means of stochastic DFN model, for areas that have not been deterministically defined earlier. Deterministic and stochastic approaches for modelling are both needed to form a representative realisation of the fractures in 3D. The stochastic DFN model, together with the deterministic model, will serve especially subsequent flow and solute transport modelling.

3) **Hydrogeological modelling**

Hydrogeological modelling considers corresponding transport properties, the geometry and the nature of flow within and between the different hydrogeological units. These hydrogeological units can be described as the contribution from matrix, stratigraphic units, deformation zones and/or fractures and other hydrogeological relevant features within the bedrock. The model describes the hydraulic and transport properties associated with the hydrogeological units (e.g. transmissivity, hydraulic conductivity, porosity, flowing fracture frequency, dispersion lengths), thus flow and solute migration within and between the different domains in the model. It is essential that the gathered data is sufficient to delimit and define baseline properties and boundary conditions for groundwater flow models and to achieve an appropriate hydrogeological understanding for the site. This information will be further used in repository design, construction and operation and further for the environmental impact assessment.

4) **Hydrogeochemical modelling**

Understanding the current undisturbed hydrochemical conditions at the proposed repository site is important when predicting future changes in groundwater chemistry that may be of relevance to the long-term integrity of a repository system. In hydrogeochemical modelling, the hydrogeochemical data will be combined into a simplified 3D model that outlines the layer structure of the groundwater and its main parameters, including the preliminary merging with hydrological data. The model considers also main features of the interfaces, such as significant redox changes or rapid microbial growth. Furthermore, the model will consider water residence times, rock water interaction as well as ages and isotopic compositions of the various water types. These data are used to study the possible mixing dynamics between water types, porewater and groundwater interactions and rock-water interactions. The data will be compared and integrated with the observations from the hydrological studies to determine flow rates and directions. Conclusions of the hydrochemical and hydraulic investigations will be used for flow and transport modelling and for further considerations (e.g. interactions between technical and geological barriers).

5) Geomechanical modelling

Geomechanical modelling utilises empirical and theoretical modelling approaches to estimate the mechanical properties of the rock mass that can either be crystalline, sedimentary or clay depending on the site chosen for DGR. In rock mechanical studies in crystalline and sedimentary rocks, the rock mass will be divided into volumes based on fracturing, intact rock strength, and the presence of brittle fault zones. In addition for sedimentary layers, the contacts between layers are also important. For these volumes, all relevant rock parameters will be calculated including median values and confidence limits. Fracture set parameters include orientations, deformability (fracture type and filling), and shear strength parameters. For intact rock and brittle faults, key parameters are deformability (fault type and filling) and long-term in-situ strength. In-situ stress measurement data will be interpreted as depth gradients for each principal stress component, including magnitude and orientation, with mean gradients and confidence limits provided. Depending on brittle fault zone geometry stress modelling could be required to describe stress field variation, particularly in crystalline environments. For clay formations the geomechanical modelling is considering the differences between competent and incompetent units.

6) Flow and solute transport modelling

The modelling of flow and transport of solutes is acquired to understand and characterise the site, but more importantly for the safe operation and long-term safety aspects of the DGR. Flow and transport modelling is often divided into surface hydrological modelling and deep bedrock hydrogeological modelling, due to complexity of combining these models. Surface hydrogeological models provide components of water balance and surface boundary conditions for the deep bedrock models. Numerical flow and solute transport modelling are based on either porous medium approaches or stochastic DFN models and methods. The choice of modelling approaches will be decided based on the local geological environment, data and specific needs assigned to the modelling. For example, in crystalline rocks, the importance of discrete fractures is highlighted as the permeability contrast between matrix and fractures is much more pronounced compared to other rock types, such as clay formations and rock salt. For fracture-dominated transport, as typical for crystalline host rocks, porous medium models may not adequately represent transport, making DFN-modelling a more suitable approach, while in clay rock the solute transport is diffusion-dominated.

7) Biosphere modelling

The biosphere modelling is an integral part of the SDM since this part is in direct connection with the subsurface and thus affects especially modelling for long-term safety assessments. Site modelling for the surface environment involves developing a Digital Elevation Model (DEM) that includes layers of overburden and unconsolidated sediments, along with topography. The DEM serves as a starting point for characterising the future surface environment evolution (due to, e.g., land uplift, subsidence and related erosion and sedimentation) of the site and its accuracy can be improved iteratively along with the site investigations. Other factors of importance for the biosphere are properties and processes of soil and surface waters, as well as climate-related issues, including plant and animal species, and human activities. For the site characterisation and evolution aspects, benefits are gained from compilation of essential Features, Events and Processes (FEP). The surface environment is a very complex biogeochemical system. For post-closure safety assessments, the challenge is to develop simple, robust and readily scrutinised models that address the FEPs that are important for post-closure safety. Complex models can provide more detailed simulations of contaminant transport and accumulation in the biosphere, but these simulations can be subject to substantial uncertainty and might not contribute to the making of robust arguments for safety (IAEA, 2025). The uncertainty may well be enveloped by considering a broad range of alternative biosphere reflecting different geomorphological and climatic evolutions.

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The different specific sub-models listed above are naturally modelled independently but utilise data and information from other models. The static geo-hydrological property model can be deterministic and/or stochastic in nature, and it serves as the basis for flow and transport simulations by providing initial information. Numerical flow and transport simulation methods include both porous media modelling and fracture network models. In addition, the integrated static model incorporates hydrogeochemical, rock mechanical, and biosphere properties. It is important to ensure that these static sub-models are integrated in a meaningful and coherent manner to support reliable numerical modelling and simulations for future scenarios and long-term safety assessments. An important aspect is feedback loops from simulations and related sensitivity analyses on the SDM, that guides targeted data acquisition and update of static models, aiming at reducing the most relevant uncertainties and knowledge gaps.

1.5 Host rock

Many geological settings can be suitable for a deep geological disposal facility. In all national programmes the term 'host rock' refers to the formation (or rock unit) in which the disposal rooms of a repository are constructed. The geological environment surrounding the host rock is also part of the natural barrier system. Sedimentary rocks are studied either as potential host rocks for waste disposal or as part of the surrounding geological environment, such as in the basement-under-sedimentary-cover concept. However, it's important to properly characterise these cover rocks, as they can significantly help the containment of radionuclides through processes like retention, retardation, (adsorption, sorption, ion exchange and chemical reaction), dispersion, and dilution. Host rocks are often categorised and discussed in three main rock groups: ***Evaporites (such as rock salt), Crystalline rocks, and Argillaceous (clay) rocks*** (IAEA, 2024), although also other classifications are in use (see EURAD Domain Theme Overview 4 Geoscience). However, the overall geological environment (e.g., the underlying and overlying rock formations, structural geology, the topography, the regional tectonics, the regional groundwater systems) and the effects of the local long-term geological evolution (e.g. geodynamics, climate, erosion) are also important in identifying an appropriate site. Additionally, it is important to make sure that the construction of the repository, and the used materials, do not adversely affect the host rock or the geological environment at the DGR site. The diverse host rock types also need a different approach in modelling to understand their flow and transport properties.

1) Evaporites (Salt formations)

These rock formations are more or less dry and show no mobile water and thus effectively no transport of radionuclides within the host rock. In such setting, the main transport barrier is provided by the geological environment itself (the surrounding host rock) and the host rock also primarily offers mechanical stability for waste emplacement (IAEA, 2024). However, the constructability and the chemical compatibility against corrosion can be challenging in this host rock type setting. This type of formation can be observed at the Gorleben site in northern Germany, which was developed as a potential site for a geological repository for high-level radioactive waste and is situated within a large, homogeneous salt dome. Salt is considered an ideal host rock due to its low permeability, high thermal conductivity, and ability to self-seal through creep, which enhances long-term containment. The repository design prioritises natural geological barriers to ensure isolation for up to one million years (Berlepsch and Haverkamp, 2016).

2) Crystalline bedrock (hard, fractured rock type)

This rock type shows variable groundwater flow and can show relatively rapid transport by advection. The host rock, which possesses favourable containment properties is often part of a larger geological unit that shares similar characteristics but has less effective containment capabilities. Lithological characteristics, deformation zones (brittle and ductile), together with faults and fracturing (DFN) are essential to define crystalline bedrock models. Therefore, a robust geological understanding is important for predictability of the site during the different stages of siting. This is typical of crystalline bedrock found in areas hosting the DGRs in Canada, Sweden and Finland (IAEA, 2024). The geological modelling of crystalline sites can be complex and time-consuming, but the constructability and stability of the DGR site is usually straightforward with modern techniques.

3) Argillaceous rocks (various different clays)

This rock type is saturated, but it experiences little or no groundwater flow, meaning that transport occurs mainly by diffusion. It serves as the primary barrier to radionuclide transport while the surrounding geological units typically play a secondary role in containment. Examples of this rock type include the Boom Clay in Belgium and the Callovo-Oxfordian claystones in France. However, in certain clays, while the host rock provides a major containment function, the adjacent geological formations also contribute significantly to limiting radionuclide release. Examples include the Opalinus Clay in Switzerland, associated with nearby clay-rich confining units and the Cobourg Formation in Canada, surrounded by Ordovician shales and argillaceous limestones (IAEA, 2024). Often, clay-rocks show a high lateral continuity so that lab results or 1D borehole test can be inter- and extrapolated with high confidence over large areas. This allows to demonstrate the barrier function of a host rock block with high confidence based on a limited number of boreholes. For high clay-content and low to intermediate burial, existing fractures do not represent preferential flow-paths. Deformation is often accommodated in a more distributed and discontinuous manner with soft-linked fault segmentation. This and efficient self-sealing processes favour diffusion-dominated transport. The construction feasibility and stability of clay rocks might pose some challenges and requires sufficient planning for the construction of the DGR facility.

1.6 Geographical area and timeline of studies

The SDM is evolving during the timeline and different phases of the planning, construction and operation of the DGR. During the initial site characterisation phases the SDM is more generic and covering a larger regional area surrounding the site. In case of large areas with a similar (e.g. crystalline) host rock and limited (quaternary) sediment cover, the process can be initiated through a lineament study, which identifies linear features on the Earth's surface to delineate rigid host rock blocks (DesRoches et al., 2018; Engström et al., 2025), and to assess the regional geological framework of the area. For sedimentary sites, this can be achieved by compiling existing reflections seismic data. Site characterisation includes investigations aiming at producing sufficient amount of site-specific data from the underground (e.g. trenching, boreholes, geophysical data) and surface environment (e.g. Digital Terrain Models, geological mapping) to produce the required models and understanding that will be used to demonstrate the site suitability for a DGR (e.g. Andersson et al., 2013).

The SDM is an iterative process that requires multiple revisions throughout the entire characterisation program as new data becomes available. The overall duration of characterisation and modelling, from preliminary investigations to site selection, is project specific and depends on the investigation strategy, the number of potential sites and the available resources. In principle, the process follows a stepwise approach: beginning with general and discipline-specific data collection, followed by analysis and interpretation, and culminating in both discipline-specific and inter-disciplinary integrated static modelling and numerical simulations. This cycle is repeated at each stage of the investigation, and simulation based on preliminary site-specific models can help to identify data needs to plan targeted field investigation campaigns to improve the next version of the SDM, to reduce relevant uncertainties. There are typically dependencies not only between successive steps but also between different disciplines. For this reason, all investigations and modelling must be planned in detail. Effective data management, that includes QA/QC processes of data collection, analysis, modelling and traceability of data. This is important for the transparency that gain public and authorities trust, which in turn is leading to obtain required permits. The planning and timing of the investigations and related modelling require close collaboration between disciplines, making it essential to develop, maintain and regularly update a detailed investigation concept and schedule throughout the investigation program.

2. Contribution to generic safety functions and implementation goals

This section describes how SDM and its associated information, data, and knowledge contributes to high level disposal system requirements using EURAD Roadmap Generic Safety and Implementation Goals (see, Domain 7.1.1 Safety Requirements). It is recognised that the various national disposal programmes adopt different approaches to how disposal system requirements are specified and organised. Each programme must develop its own requirements, to suit national boundary conditions (national regulations, different spent fuel types, different packaging concept options, different host rock environment, etc.). The generic safety functions and implementation goals developed by EURAD and used below are therefore a guide to programmes on the broad types of requirements that are considered, and are not specific or derived from one programme, or for one specific disposal concept.

2.1 Features, characteristics, or properties of Site Descriptive Model that contribute to safety assessment

Depending on the local conditions and the repository design, as an example rock stability, groundwater ingress, other hydrogeological implications and thermal properties of the rock mass may need to be characterised to assure overall operational safety and impacts of the operational phase on long-term safety. All of these can be derived from the SDM. For the safety case (including long-term and post-closure safety), the SDM serves a basis (initial state) for various types of safety case simulations. The initial data and modelling gathered before the construction of a DGR, define a baseline for the site, which can be used for comparisons on latter effects from and during the underground construction. Numerical flow and transport models as part of the SDM, are used to establish the input for further geochemical calculations and transport properties in the safety assessment. The first version of the SDM produces an integrated model of the area and the modelling provides essential data for repository layout planning and further modelling for the safety case (Laine et al. 2014; IAEA, 2024).

The SDM can for example be used to assess the long-term safety, where the key input is the Kd values, i.e. partition coefficients which are used to indicate the relative mobility of radionuclides, for various rock and groundwater types (IAEA, 2024). When combined with hydrogeological data, it will contribute to information on the barrier efficiency of the host rock and the surrounding geological environment. Furthermore, also the characterisation of the groundwater and/or porewater compositions are essential for scenario development. Water compositions relevant for the safety case, particularly those at repository depth, are derived from field investigations and hydrogeological flow/reactive transport modelling. This modelling incorporates paleo-hydrological development to support predictions of future groundwater development. Thus, modelling recharge and discharge related processes, diffusive transport in aquitard sequences (particularly in sedimentary environments) and related geochemical changes are essential to understand the evolution of the site conditions over time (also needed also for the Engineered Barrier System (EBS) performance models) as well as potential releases from the repository.

The host rock type strongly influences the nature of the SDM and the relevance of different properties for the demonstration of post-closure safety. For example, transport in Opalinus Clay can be demonstrated to be due to diffusion-dominated processes Nagra (2024). This is because the deformation behaviour and the self-sealing capacity of the clay-mineral-rich unit. Fractures, which are of sub-seismic scale (and can thus not be detected on 3D-seismics and avoided when placing the repository) do not represent relevant preferential flow paths. The role of fracture networks for radionuclide transport in clay-rich host rocks is thus fundamentally different compared to, e.g. crystalline rocks.

In addition, SDM provides basis for scenario development related to geological, hydrogeological and geomechanical long-term processes. These processes include e.g. potential for seismic activity, loading and unloading due to glaciation, changes in stress regime etc. The interpretative modelling for the safety case (including, e.g., exposure models) should be planned early, in alignment with the level of detail in the processed data and the scope of site investigations. Overall, the developed models should undergo a quality assessment similar to that applied to site investigation data, and they should be verified and validated as far as possible.

2.2 Features, characteristics, or properties of Site descriptive model that contribute to achieving long-term interim storage stability and feasible implementation of geological disposal

To ensure the DGR project feasibility and optimise the construction, planning the SDM is an integrative part from the early stages of site scheduling. The SDM helps to identify and evaluate key technical construction and environmental factors that influence whether a project can be successfully implemented. SDM simplifies the transition from planning to execution of the DGR site. The SDM can also improve the constructability of the DGR avoiding and mitigating risk with unfavourable bedrock or groundwater occurrences, this reduces uncertainties and supports better scheduling and risk management. As a result, construction processes for a DGR become more predictable and manageable.

3. International examples of compiled SDMs and general description of their national programmes on site selection

In 1983, Finland established nuclear waste management principles that guided site selection and investigations for a DGR. The program aimed to identify suitable host rocks and environments, considering the characteristics of the waste being planned for disposal and the conditions at a suitable site. Preliminary investigations were conducted at five sites, and four sites Romuvaara, Kivetty, Olkiluoto, and Hästholmen, were selected for detailed characterisation. The detailed site investigation program (1993–1996) included baseline studies of bedrock conditions, additional data collection, and verification of earlier findings to strengthen confidence in site understanding. From 1997–2000, the focus shifted to groundwater sampling, fracture mineralogy studies for palaeohydrogeological analysis and hydraulic testing to assess bedrock structure and properties. According to McEwen and Äikäs (2000), only minor geological differences were found between the four different Finnish DGR candidate sites, making a detailed ranking based solely on long-term safety impractical and inconclusive. Instead, socio-economic and logistical factors favoured Eurajoki (Olkiluoto site) and Loviisa (Hästholmen site) sites, which already hosted nuclear facilities and had higher public acceptance. Olkiluoto (the site chosen) benefited from proximity to existing infrastructure. Investigation during site confirmation included surface investigations, underground facility construction, and test facility development to assess rock suitability and support geoscientific studies. The SDM of the Olkiluoto site is based on extensive surface-based investigations, including drilling, geological mapping, hydrogeological studies, environmental research, and multidisciplinary monitoring. During underground facility construction at the Olkiluoto site, further investigations were carried out to support design, modeling, and safety analysis. These included tunnel mapping, probe and pilot hole drilling, geophysical and hydrological surveys, and niche experiments. While some rock volumes were found to be unsuitable for disposal, sufficiently favorable areas were identified for the placement of final disposal tunnels (Aaltonen et al., 2016; Nordbäck and Engström, 2016; Posiva, 2021).

Sweden's siting process for a spent nuclear repository began in 1977 but intensified in 1992 when all municipalities were invited to consider hosting the facility. Feasibility studies were conducted in eight municipalities, leading to site investigations in Oskarshamn (Laxemar site) and Östhammar (Forsmark site) starting in 2002 (IAEA, 2024). Permanent local organisations were established to manage the investigations, which were well-planned but required complex coordination across disciplines. In Sweden, SDM was determined as a collective term encompassing all evaluation and interpretation of data gathered during investigations. Initially, modelling was conducted within individual disciplines, geology, hydrogeology, hydrogeochemistry, geomechanical, thermal properties and radionuclide transport, each involving several types of investigations. Interdisciplinary evaluation was carried out in collaboration with on-site activity leaders before integrated modelling across disciplines began. The results of measurements were analysed and evaluated to produce a description of the site that was further used for design and safety assessment. The process of SDM, site investigation, repository design, and safety assessment were conducted in parallel, with multiple feedback loops between them. During the siting process the Äspö HRL was established and site modelling was developed for visualisation and understanding of the site that would support repository design, long term safety assessment and environmental impact assessment. The lessons learned during the Äspö HRL site project are being applied by the Swedish Nuclear Waste Organisation (SKB) in the development of the final disposal facility in Forsmark (IAEA, 2024).

To find suitable sites for a DGR in Canada the Canadian Nuclear Waste Management Organisation (NWMO) has compiled a SDM in both crystalline and sedimentary bedrock environments (NWMO, 2023a, 2023b). At the Revell site, six deep boreholes confirmed a homogenous biotite bearing granodiorite-tonalite rock type to 1000 m depth (NWMO, 2023a). The investigations on the six deep boreholes supported the initial studies that the site is suitable for a DGR. The South Bruce site, located in the Michigan Basin, features sedimentary rock formations deposited between 540–300 million years ago (NWMO, 2023b). The key geological unit is the Cobourg Formation, a strong, low-permeability argillaceous limestone, bounded by similarly low-permeability shale and limestone layers. These formations form a natural barrier suitable for a DGR, as demonstrated by an intensive site investigation program at the south Bruce site including 2 deep boreholes at the site and considering earlier site characterisations at the nearby Bruce site (NWMO, 2011) in a very similar geological setting. NWMO selected the Wabigoon Lake Ojibway Nation-Ignace area (Revell site) for Canada’s DGR for used nuclear fuel. This decision followed, beside extensive technical studies, community engagement and that people in the area confirmed their willingness to host the project.

Since 1991, Andra has led the research on managing high-level and long-lived intermediate-level radioactive waste in France through the Cigéo project, in the Callovo-Oxfordian claystones, Meuse/Haute-Marne districts (Leverd, 2023; IAEA, 2024). Development has been supported by extensive Research and Development (R&D), including surface investigations and over 50 deep boreholes. The Bure Underground Research Laboratory (URL), licensed in 1999, enabled studies in real repository-like conditions. Between 2004 and 2019, 1700 m of drifts were excavated using four techniques. In 2007, Andra established the Environmental Observatory (OPE) to monitor the site's baseline and changes over time, although it’s not part of the URL’s regulatory monitoring (IAEA, 2024). The accumulated knowledge has guided Cigéo’s progressive development and culminated in the 2023 licence application. The SDM was constructed in several steps, using all acquired data including 3D-seismic, boreholes and URL. Andra has established local consultation forums to engage civil society on environmental and regional topics like water, energy, transport, and quality of life. These inputs inform the environmental impact assessment that together with SDM is an ongoing iterative process updated throughout the project (IAEA, 2024).

Nagra, Switzerland’s agency for radioactive waste disposal, is responsible for implementing a DGR as mandated by the Nuclear Energy Act. The site selection process, outlined in the Sectoral Plan approved in 2008, is led by the Swiss Federal Office of Energy, with Nagra as the implementer and oversight by the Federal Nuclear Safety Inspectorate. The process began with a blank-map approach and was narrowed down in three stages, with Stage 1 approved in 2011 and Stage 2 in 2018 (Müller et al., 2024). The 3 candidate sites feature further investigated in Stage 3 feature Opalinus Clay, a 175-million-year-old shale demonstrated to be suitable due to low permeability, high self-sealing capacity and favourable sorption properties. Between 2015 and 2017, Nagra conducted 3D seismic surveys across three siting regions in Northern Switzerland: Jura Ost, Zürich Nordost and Nördlich Lägern (Müller et al., 2024). The surveys achieved high-resolution mapping, seamlessly identifying faults with vertical offsets as small as 10 meters. In 2018-2020, Nagra investigated Quaternary sediments in Northern Switzerland to assess past erosion and tectonic activity. Using geophysical methods (2D seismic and passive seismic) and direct investigations (trenches and 12 boreholes totalling ~1845 m), they reached underlying bedrock formations up to 325 m deep (Müller et al., 2024). Core samples were analysed and dated to support geological understanding. The investigations continued in 2019-2022, when Nagra drilled nine deep boreholes to investigate Mesozoic sedimentary layers, including Opalinus Clay. The campaign resulted in approximately 11 km of drilling of which 60% was wireline cored. Special drilling fluids were used to stabilise clay-rich sections. All cores were scanned in high resolution, and 4 600 samples were analysed in specialised labs for various geological properties (Müller et al., 2024). With the described site investigation program, Nagra collected an extensive, high-quality data set. In September 2022, Nagra proposed Nördlich Lägern as the most suitable site for a DGR for both low-/intermediate- and high-level radioactive waste. All three candidate regions meet safety requirements, but Nördlich Lägern offers the best overall conditions, especially in terms of host rock depth (~900 m), distance from aquifers, ancient porewater containment, and layout flexibility. The proposal is based on 13 safety and engineering criteria, summarised under quality, stability, and flexibility (Müller et al., 2024). The general license application for a combined HLW and L/ILW repository and the underlying documentation was submitted by Nagra in 2024 and is publicly accessible (see www.drbg.ch). The geological synthesis serving as an important basis for the site selection and the post-closure safety case for the Nördlich Lägern site is documented in Nagra (2024).

4. Critical background information

The section highlights specific key information, components and processes related to the compiling of a SDM and the whole process related to site selection and site confirmation. The guidelines developed by Posiva in Finland define foundational information for the site characterisation and site descriptive models. These guidelines are tailored to the Finnish disposal concept (see, e.g., McEwen and Äikäs, 2000). General guidelines is also defined in the IAEA (2024) report and general conclusions and critical insights can be drawn from both reports. These factors define how a SDM can be utilised for several aspects during the whole life cycle (from planning to construction and finally post-closure safety) of a DGR:

1. Long-term safety
    - Geological framework of the site including the distribution of geological units and structural features that might act as barriers to radionuclide migration or as fast pathways.
    - Hydrogeological framework including the nature of groundwater flow in terms of flow mechanisms and solute transport retardation and retention processes, potential radionuclide migration pathways, flow velocities and hydraulic gradients
    - The geochemical composition and nature of groundwater bodies, their evolution over time and their potential to affect barrier safety functions. These processes should occur slowly enough to support long-term safety, and their impacts on the repository can be reasonably well understood.
    - Nature of the driving forces that influence the potential migration of fluids through the geosphere (groundwater, gas) such as topography and groundwater density.
    - An understanding of the regional stress and thermal regimes.
    - Understanding of the effects of repository construction and design on the nature of the zone surrounding a repository (i.e. the volume of rock that is damaged or disturbed during excavation and drilling (termed an excavation damaged zone or an excavation disturbed zone (sometimes referred to as an EDZ)).
    - In a favourable geochemical and mechanical environment, the EBS is expected to maintain its isolation functions for as long as possible. According to regulatory assessments, this time span may extend to hundreds of thousands of years. In the Finnish case, such an environment is characterised by reducing conditions (i.e., absence of oxidisers), nearly neutral pH, low sulphide concentrations, and moderate groundwater salinity level (dissolved salt content corresponding to TDS <100 g/l).
2. Feasibility of construction
    - Repository volume and layout. The repository footprint (plan area at the surface reflecting the disposition of the underground components of the repository).
    - Requirements and assessment of construction feasibility included the possibility to be constructed using normal construction methods in the required depth without application of special techniques. *"The conditions for this kind of environment require sufficient suitable rock at a suitable depth, so that the disposal tunnels can be constructed without excessive requirements for support"*.

- Necessary construction methods (incl. use of various materials in underground openings) are connected to site disturbance and uncertainties in the assessment of long-term safety, and it was noted that in the worst-case scenario, problems with bedrock stability during the construction and operation phases could prevent disposal taking place.
- Requirements for site suitability included the need for sufficient flexibility in the location of the repository ("a robust site"), and possibilities of locating underground openings in the most suitable parts of the rock mass.
- Identification of geotechnical and environmental hazards (such as gases, water, in situ stresses and creep, etc.) and other risks.
- Identification of surface hazards (e.g. landslides, alluvial flood risk and tsunami, pyroclastic and lava flow, etc. with the potential to affect construction, existing buildings and operations).
- Risk management strategy for minimizing risk and dealing with identified hazards. Strategy for dealing with excavation and construction wastes.

3. Repository operation
    - The facility shall be planned and built in such a manner that it can be operated at the chosen site with all the safety requirements stipulated in the regulations. The discussed risks were related to such factors as the stability of the disposal tunnels and safe transport of the spent fuel to the disposal facility.
    - The possibility for future extension of the repository can be considered in the assessment. Therefore, it might be necessary to consider the suitability of a site in larger extent, and to preliminarily assess the plans for additional site characterisation activities required to investigate the possibility of such an extension.
4. Social impact
    - Monitoring and understanding social acceptance were critical aspects of the repository program. This is achieved through active collaboration with the local municipality and its residents, particularly during the latter stages of siting.
    - Engagement also during planning of the construction, operation and closure phases of the facility, ensuring continued dialogue and trust throughout the project lifecycle.
    - Enhance positive social aspects of the development of a repository and communicate to the public.
    - Inform decision making and establish conditions for approval.
5. Land usage and environmental burden
    - A disposal facility site requires a designated land area and an approved land use plan that permits its construction and operation. The traffic and transportation of spent fuel to the site will increase the environmental impacts both to the area immediately adjacent to the site and also along the transport route, which must be considered and mitigated.
    - Avoid serious and irreversible damage to the environment through the identification of potential impacts and the application of measures for avoiding or mitigating them.
    - Ensure efficient resource use at the site.
6. The infrastructure
    - The assessment included considerations of required transport network for the repository, both on and to the site, and services provided by the local authority and industry.
7. The cost
    - The cost of construction and operation of the facility is varying depending on the site selection, for example, due to the transport distance for spent fuel. The main uncertainty in the cost estimations is related to the possible variations associated with the development of the underground facilities.

4.1 Integrated information, data or knowledge (from other domains) that impacts understanding of Site descriptive model

The SDM insight is naturally connected to several other topics even though the main topic is the Geoscience topic and Domain that it is located under:

EURAD Domain Theme Overview 4 Geoscience

The SDM insight is naturally connected to several other topics and most importantly to the different phases of siting. The SDM development should already commence early on during the siting and evolve during the concurrent steps of site procedures. Links and connection to all these Insights can be inferred:

EURAD Domain Theme Overview 6 Siting and Licensing

EURAD Domain Insight 6.1.1 - Conceptual planning

EURAD Domain Insight 6.1.2 - Area survey and site screening

EURAD Domain Insight 6.2.1 - Site Investigation

EURAD Domain Insight 6.2.2 - Site characterisation and site confirmation

5. Maturity of knowledge and technology

This section provides an indication of the state-of-the-art and the relative maturity of information, data and knowledge from the most advanced SDM projects. It includes the latest developments, with the most promising advances and innovations for ongoing RD&D within SDM projects and relevant reports for further information.

5.1 Advancement of safety case

The SDM is the basis for the safety assessment and thus is a crucial and integral part for the safety case in each DGR project. The information gathered through the SDM is therefore always, either directly or indirectly, implemented in the development of the safety case for disposal of nuclear waste. The current development of SDM aims to increase coupling of discipline specific models towards fully integrated models and/or digital twins that could serve as platforms for continuous performance and safety assessments of the system during repository operation and optimisation.

5.2 Past and ongoing (RD&D) projects

Past and ongoing (RD&D) Projects:

These projects are usually nation and site specific so more can be read and found from the websites of respective countries Nuclear Waste Management Organizations. However, listed below are few relevant reports and papers:

- **Finland, Posiva:** Aaltonen, I., Engström, J., Front, K., Gehör, S., Kosunen, P., Kärki, A., Mattila, J., Paananen, M., Paulamäki, S., 2016. Geology of Olkiluoto. Posiva Report No. 2016–16. Posiva Oy, Eurajoki. https://www.posiva.fi/en/index/media/reports.html
- **Sweden, SKB:** Andersson, J., Skagius, K., Winberg, A., Lindborg, T., Ström, A., 2013. Site-descriptive modelling for a final repository for spent nuclear fuel in Sweden. Environmental Earth Sciences 69, 1045–1060. https://doi.org/10.1007/s12665-013-2226-1
- **Switzerland, Nagra:** Müller, H.R., Blechschmidt, I., Vomvoris, S., Vietor, T., Alig, M., Braun, M., 2024. Status of the Site Investigation and Site Selection Process for a Deep Geological Repository in Switzerland. Nuclear Technology 210, 1740–1747. https://doi.org/10.1080/00295450.2023.2262298
  Nagra (2024): Geosynthesis of Northern Switzerland. Nagra Technical Report NTB 24-17. https://www.drbg.ch/rbg-gtl/zentrale-referenzberichte/geosynthesis-of-northern-switzerland-ntb-24-17
- **France, Andra:** Leverd, P.C., 2023. The French Underground Research Laboratory in Bure: An Essential Tool for the Development and Preparation of the French Deep Geological

Disposal Facility Cigéo. Journal of Nuclear Fuel Cycle and Waste Technology 21. https://doi.org/doi.org/10.7733/jnfcwt.2023.035

- **Canada, NWMO:** NWMO, 2023a. Confidence in Safety - Revell Site - 2023 Update. Technical Report No. TR-2023-07. Nuclear Waste Management Organization. https://www.nwmo.ca/Reports/NWMO-TR-2023-07

  NWMO, 2023b. Confidence in Safety - South Bruce Site - 2023 Update. Technical Report No. TR-2023-08. Nuclear Waste Management Organization.

  https://www.nwmo.ca/Reports/NWMO-TR-2023-08
- **Japan, NUMO:** NEA., 2023. The Nuclear Waste Management Organization of Japan's Pre-siting Safety Case Based on the Site Descriptive Model: An International Peer Review of the NUMO Safety Case. OECD Publishing, Paris. https://www.oecd-nea.org/japan-pre-siting-site-descriptive-model

5.3 Lessons learnt

Geoscientific investigations encompass a wide range of studies, including petrology, sedimentology and structural geological work, hydrogeological mapping and measurements, geophysical investigations, rock mechanic surveys, thermal property measurements, systematic drilling program with associated borehole surveys, and the development of an investigation database to support characterisation and evaluation needs. Due to the diversity of investigation topics and methods, high-quality data acquisition and robust data management are critical. It has been observed that data requirements evolve throughout the process, making iterative development essential in the siting strategy. When significant changes occur, such as in data processing, modelling and conceptual understanding, the original data may require reassessments. This underscores the need for a comprehensive and well-maintained dataset, supported by structured data management procedures. Furthermore, transparent and traceable documentation in all the phases of data processing is imperative.

The various needs of end users for the SDM, such as those for long-term safety assessment, facility design and construction, and licensing, set specific requirements for site understanding, the site description, and site modelling, that is crucial to understand when compiling a SDM. Thus, all these factors need to be considered during the site investigations, leading to a need for multidisciplinary modelling efforts and well-organised teamwork to produce an integrated site description. One important tool for improving the site description during the process is the use of existing models for predictive purposes, followed by comparison with new observations and outcomes (so called prediction-outcome modelling) from ongoing investigations and experiments (see, e.g., Nordbäck and Engström, 2016).

6. Uncertainties

The resolution and accuracy of a SDM depend heavily on the resolution of the input data and the assumptions made during interpolation and extrapolation of the modelled features. The uncertainties within the basic static models (geological, hydrogeological etc.) need to be quantified and addressed. The relevance of these uncertainties, regarding construction, operation and the safety case, can be assessed by numerical simulations (sensitivity analyses). The results of the sensitivity analyses can be used to identify uncertainties in the static models that are particularly relevant and should be reduced, e.g. by targeted field work such as drilling campaigns. The results are used for updating the sub-models, mitigating uncertainties and finally enhancing confidence in the SDM.

The SDM is constructed from separate datasets and discipline-specific interpretations across various scales (e.g. regional mapping to borehole scale). The geological model utilises primary borehole data, typically dense in vertical dimensions, but sparse in lateral dimensions, since the boreholes are often located at some distance from each other (>100 m). Geological observations from the ground surface (outcrops, investigation trenches) are also unevenly distributed. As a result, the geological model is most reliable in areas with direct observations, such as outcrops, investigation trenches, drilling locations and in the vicinity of a DGR facility. In contrast, large surface areas covered by soil and lacking direct observations rely heavily on interpolation, extrapolation, or indirect data (e.g. geophysics), leading to lower confidence and reduced accuracy in the model geometry. The confidence in the interpolation depends on the nature the host rock and the related heterogeneity of key properties including the potential for preferential pathways (e.g. along sedimentary layers or fault zones). The confidence in the interpolation between boreholes can significantly be increased by high quality geophysical data (e.g. 3D-seismic data).

The main uncertainties of the site model should be identified at both the conceptual (referring to uncertainties associated with the conceptual thinking applied in the modelling) and technical levels (referring to the technical uncertainties of the modelling, caused by modelling methodologies and available data). The magnitude of uncertainty in a SDM reflects an empirical estimate of how significantly a specific uncertainty affects confidence in the model, thereby reducing its predictive capability. A low magnitude of uncertainty means that its impact on model confidence is minimal and has little effect on predictive reliability. In contrast, a high magnitude indicates that the uncertainty substantially lowers confidence in the model, thereby reducing its predictive capability. A medium magnitude suggests that the uncertainty has a noticeable impact on confidence and should be considered, although its effect is not deemed critical (Aaltonen et al., 2016). To address and mitigate uncertainties a description, a risk assessment should be defined, with aims and procedures for further exploring the impact of these uncertainties on the repository layout and for the long-term safety (SKB, 2008). All these uncertainties involve the methodologies and data quality that when identified and evaluated accordingly, enhance the robustness, transparency and confidence in the SDM.

7. Guidance, Training, Communities of Practice and Capabilities

This section provides links to resources, organisations and networks that can help connect people with people, focussed on the domain of SDM (Site Descriptive Model). At the moment not directly specific training material for this DI but some relevant information can be found in EURAD training materials.

Guidance
https://www.oecd-nea.org/ https://www.iaea.org/
Training
https://euradschool.eu/eurad-training-materials/
Active communities of practice and networks
https://www.ejp-eurad.eu/ https://igdtp.eu/
Capabilities (Competences and infrastructure)
https://www.oecd-nea.org/radioactive-waste-management https://euradschool.eu/

8. Further reading, External links and References

8.1 Further Reading

The comprehensive IAEA report on Management of Site Investigations for Radioactive Waste Disposal Facilities is an extensive report describing key factors and relevant information for SDM. It can be downloaded from the IAEA website:

Management of Site Investigations for Radioactive Waste Disposal Facilities

8.2 External Links

https://www.posiva.fi/en/index/media/reports.html

https://www.skb.com/publications/

https://www.andra.fr/documents-et-ressources

https://nagra.ch/downloads/

https://drbg.ch

https://www.nwmo.ca/Site-selection

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