Note:
This is a translation of the ESK discussion paper entitled
"Standortvergleich"
In case of discrepancies between the English translation and the German original, the original shall prevail.

E S K

Site comparison

DISCUSSION PAPER

Contents

1 Background

The ESK regards the site comparison as one of the key processes in the site selection procedure. For the determination of the site "with the best possible safety for a repository pursuant to § 9a(3) sentence 1 of the Atomic Energy Act in the Federal Republic of Germany ..." [StandAG] it is essential that the chosen comparison procedure meets the highest quality standards and that it is transparent and comprehensible.

The regulatory framework is defined by the Site Selection Act (StandAG) as well as by the Disposal Facility Safety Requirements Ordinance [EndlSiAnfV] and the Disposal Facility Safety Analyses Ordinance [EndlSiUntV]. Individual aspects, such as the procedure for safety-oriented weighing, the prioritisation and weighting of criteria, a possible aggregation of criteria or the comparison of repository systems with different safety concepts (with or without containment-providing rock zone (CRZ)) must be addressed as soon as possible in order to be able to carry out a transparent and comprehensible site comparison.

In this discussion paper, the ESK addresses – without claiming to be exhaustive – those challenges that may arise from the safety aspects of a site comparison in the context of the site selection procedure.

2 Regulatory requirements

2.1 Site Selection Act

The Site Selection Act (StandAG) regulates the site selection procedure. In a participatory, science-based, transparent, self-questioning and learning process, a site is to be identified that offers the best possible safety for the disposal of high-level radioactive waste. Best possible safety relates to the long-term protection of man and the environment against ionising radiation and other harmful effects of such waste for a period of one million years. With the aim of final closure, the high-level radioactive waste is to be disposed of in deep geological formations in a repository mine constructed for this purpose. Therefore, rock salt, claystone and crystalline rock can be considered as possible host rocks. The decision on the site is sought by 2031.

The site selection procedure includes three comparative assessments between siting regions or sites, which are carried out by the project implementer BGE *[Note: in the translation of the Site Selection Act referred to as project delivery organisation]* (see Annex 1):

- preparation of a proposal for the siting regions to be explored from the surface (§ 14(2)),
- preparation of a proposal for the sites to be explored from the subsurface (§ 16(3)), and
- preparation of a proposal for the site on the basis of a comparative assessment of the sites explored from the subsurface (§ 18(3)).

2.2 Ordinances on safety requirements and preliminary safety analyses for the disposal of high-level radioactive waste

§ 26(3) and § 27(6) StandAG contain authorisations to issue ordinances on safety requirements for the disposal of high-level radioactive waste and requirements for the performance of preliminary safety analyses in the site selection procedure for a repository for high-level radioactive waste. The Disposal Facility Safety Requirements Ordinance (EndlSiAnfV) and the Disposal Facility Safety Analyses Ordinance (EndlSiUntV) establish the sub-legislative framework for a licensing procedure concerning the repository site selected in accordance with the StandAG and for the respective performance of the preliminary safety analyses.

Article 1: Ordinance on Safety Requirements for the Disposal of High-Level Radioactive Waste (Disposal Facility Safety Requirements Ordinance – EndlSiAnfV)

According to § 26 StandAG, the Disposal Facility Safety Requirements Ordinance already constitutes an essential basis in the site selection procedure for the assessment to be carried out within the framework of the preliminary safety analyses pursuant to § 27 StandAG as to whether safe containment of the radioactive waste can be expected at a site in combination with the planned disposal concept. In this respect, the Disposal Facility Safety Requirements Ordinance is also relevant for site comparison and selection. This applies in particular to those sections that concern the safety concept and the preparation of a corresponding safety case, namely

- Section 2: long-term safety (assessment period and developments of the repository system, safe confinement of radioactive waste, integrity and robustness of the containment-providing rock zone, integrity and robustness of the engineered and geotechnical barriers, dose levels during the assessment period, exclusion of self-sustaining chain reactions),
- Section 3: safety concept, design of the disposal facility, optimisation of the repository system,
- Section 4: retrievability and facilitation of recovery,
- Section 5: safety of the repository during construction, operation and decommissioning of the repository.

Article 2: Ordinance on Requirements for the Performance of Preliminary Safety Analyses in the Site Selection Procedure for the Disposal of High-Level Radioactive Waste (Disposal Facility Safety Analyses Ordinance – EndlSiUntV)

The Disposal Facility Safety Analyses Ordinance does not contain any requirements for the comparison of repository systems, but it contains requirements for the safety analyses, the results of which form an essential basis for site comparison and selection. This applies in particular to the provisions on the content of safety analyses, comprising the following individual topics:

- geosynthesis (§ 5),
- preliminary safety concept and repository design (§ 6),
- system analysis (§ 7),
- operational safety analysis (§ 8),
- long-term safety analysis (§ 9),
- comprehensive assessment of the repository system (§ 10),
- assessment of uncertainties (§ 11).

3 General aspects

3.1 Geoscientific weighing criteria

The weighing of safety-related and other advantages and disadvantages of subareas, siting regions or sites[1] is a central element of the process of site selection on the way to the “site with the best possible safety for a disposal facility pursuant to § 9a(3) sentence 1 of the Atomic Energy Act in the Federal Republic of Germany” [StandAG]. The following exclusively deals with the challenges in connection with safety-oriented weighing which lies in the area of expertise of the ESK. Moreover, the Site Selection Act implicitly postulates a primacy of safety-oriented weighing through the purpose of the Act formulated in § 1. While § 25 StandAG stipulates the subordinate status of planning-scientific weighing criteria as compared to safety-oriented weighing criteria, no detailed statements are provided on the role and weight of other considerations, e.g. based on socio-economic potential analyses (§ 16(1)) and the “consideration of all private and public interests” (§ 19), in relation to safety-oriented weighing and assessments.

The legal basis for safety-oriented weighing are, first of all, the geoscientific weighing criteria explicitly formulated in the Site Selection Act under § 24, which, like the exclusion criteria under § 22 and the minimum requirements under § 23, must be applied in every step of the site selection procedure. The Site Selection Act requires the application of these criteria in the identification of subareas under § 13(2) and then again, on the basis of the preliminary safety analyses to be further developed step by step, in the identification of siting regions for surface exploration pursuant to § 14(1) and of sites for subsurface exploration pursuant to § 16(2). The site proposal pursuant to § 18(3) is also to be based on the application of the assessment criteria to be established for underground exploration pursuant to § 17.

The Site Selection Act does not give any indication of possible weighting or prioritisation with regard to the geoscientific weighing criteria among each other, but it introduces an integrated performance assessment of the repository system as a basis for decision-making with the above-mentioned preliminary safety analyses pursuant to § 27. This integrated assessment requires the definition of a (possibly preliminary) safety and disposal concept. § 7(4) of the Disposal Facility Safety Analyses Ordinance assigns an important function to the preliminary safety analyses in connection with issues related to weighing, according to which the relevance of the individual weighing criteria according to appendices 1 to 11 of the Site Selection Act for the assessment of the respective repository system shall be presented for the investigation area. The RESUS R&D project investigated how safety analyses can be used for the proper application of the weighing criteria [GRS 2020].

[1] In accordance with the EndlSiAnfV, the generic term “investigation area” is used hereinafter when referring to subareas as well as siting regions and sites.

3.2 Safety-oriented weighing: possible approaches

In addition to the formal application of the geoscientific weighing criteria according to § 24 StandAG, the term "weighing" is generally understood hereinafter to mean any safety-oriented scientific and technical weighing in the site selection procedure. The need for weighing arises, for example, in the following conceivable situations, which are described generically here:

- Investigation area A has more favourable properties than investigation area B with regard to factor X but less favourable ones with regard to factor Y. How is this to be assessed, how are the two situations to be weighed against each other? This is to be answered differently, depending on whether the same, similar or fundamentally different safety concepts are intended to be used for A and B.

- Investigation area A has potentially more favourable properties than investigation area B with regard to a given factor, but these are more difficult to explore or verify (thus with less certainty) for investigation area A (e.g. due to greater heterogeneity) than for investigation area B, see also sections 3.4 and 3.5.

- For two investigation areas, fundamentally different safety concepts are provided (e.g. a CRZ for one investigation area, and containment essentially based on engineered and geotechnical barriers for the other), so that a comparison of individual factors is not always expedient.

For such problems, three approaches (or combinations thereof) are basically conceivable with the aim of aggregating the individual factors:

- verbal-argumentative (i.e. qualitative) weighing,

- a formal-numerical assessment of quantified assessment parameters using mathematical methods, e.g. multi criteria decision analysis (MCDA) [2], and

- a qualitative and quantitative view of the repository system as a whole, in particular on the basis of the preliminary safety analyses (see Chapter 3.3 for details).

In any case, a consistent approach with regard to safety is required for all investigation areas considered. The methods that could be used to develop such an approach are discussed below.

In the opinion of the ESK, the selection of a site with the best possible safety can only be achieved on the basis of an acceptable and legitimised process if safety-oriented weighing meets high standards regarding the internal logic of the methodology used as well as transparency and comprehensibility also for stakeholders who are less familiar with the technical background (interested laypersons). This also includes that weighing decisions based on expert opinions must be identified as such. Otherwise, there is a risk of pretending objectivity or objectifiability where this does not exist.

[2] For an overview, see Department for Communities and Local Government London (2009) [DCLGL 2009].

The ESK is of the opinion that an exclusively verbal argumentative (qualitative) assessment cannot fully meet these requirements, as this does not exhaust the potential for quantification and objectification. However, verbal argumentation is seen as an indispensable part of the overall process of weighing, e.g. in connection with the description of potential evolutions of the repository system, the use of subjective expert judgements or with the classification of factors given. The use of verbal-argumentative methods is particularly suitable for the assessment of non-quantifiable or hardly quantifiable criteria (e.g. the robustness of a repository system). Since no quantitative aggregation of numerical individual values takes place, no accuracy is conveyed by exact numerical values, which could not be justified in case of insufficient data and a lack of knowledge about interdependencies [MABeSt 2020]. Examples of the application of verbal-argumentative methods in the field of repository system comparison are the projects VerSi I [GRS 2010] and VerSi II [GRS 2017].

A formal-numerical assessment using mathematical methods allows a quantitative or at least semi-quantitative assessment and, in particular, an aggregation of given factors that can be measured or otherwise (semi-)quantitatively represented or at least classified. Such a representation or classification is possible on various scales:

Using an ordinal scale (ranking scale), the factors themselves can probably only be described qualitatively, but it is possible to establish a reasonable order. An example would be a safety-relevant potential geological evolution that may occur for a specific investigation area but not for another. In the Site Selection Act, appendices 1 to 11, the various criteria or indicators are assigned to the assessment groups favourable / conditionally favourable / less favourable / unfavourable for the weighing criteria according to § 24. This is done both for verbally described facts (claystone – solid clay – semi-solid clay) and for indicators that are quantifiable in the strict sense (e.g. rock permeability) but also for combinations (e.g. Appendix 7 on gas formation). In the Swiss site selection procedure (Sectoral Plan for Deep Geological Repositories), Nagra also used such ordinal scales for its proposal of siting areas to be investigated further in stage 3 by assigning the predicates very favourable, favourable, conditionally favourable, unfavourable or insufficient to certain facts [NTB 14-01].

Stronger or more precise differentiations of facts is possible if numerical values are arranged on metric scales. These include interval scales (differences in terms of content, e.g. for temperatures measured in °C), ratio scales (proportional scales, formation of quotients are appropriate e.g. for temperatures measured in K or energies) and absolute scales (quantification inevitably results from the facts, e.g. activity). However, it should be noted that although such metric scales allow more precise descriptions of the individual facts, they are disadvantageous when aggregating facts of different types (e.g. hydraulic permeabilities and uplift rates) into a uniform assessment system since different facts, units and orders of magnitude are used.

Ultimately, the transfer to ordinal scales appears to be appropriate for two reasons: On the one hand, as indicated above, a projection of differently scalable facts (from verbally described to well quantifiable ones) into a uniform system is possible, which then allows aggregation. On the other hand, the transfer to the ordinal scale requires a safety-oriented valuation of the facts, which is the ultimate aim of the weighing. However, this is at the same time a challenge since the respective classification is to be justified in terms of safety. With its appendices 1 to 11, the Site Selection Act anticipates such a justification for the weighing criteria and creates legal and procedural certainty in this respect but provides the actually required justifications at most implicitly in the brief accompanying texts or the explanatory memorandum to the Act. These are based on experiences from earlier safety analyses and on experience-based assumptions. The above-mentioned classifications made by Nagra in the Swiss site selection procedure (Sectoral Plan for Deep Geological Repositories) are also based on comparable sources. In contrast to the German site selection procedure, however, it can be assumed for the Swiss procedure that, irrespective of the site ultimately selected, a safety concept will be applied that is already known in its essential features and that is the same or at least very similar for all potential sites, and that there is therefore clarity to a great extent about the safety significance of geological issues [NTB 08-05]. For the German site selection procedure, however, a diversity of concepts is to be assumed due to the requirements of the Site Selection Act, e.g. with regard to the host rocks to be considered, and thus also with regard to the safety significance of facts (e.g. hydraulic permeability of the host rock formation for concepts with or without containment-providing rock zone). This diversity is considered in the Site Selection Act only selectively by the “special regulation for the host rock crystalline" (explanatory notes to §§ 23, 24).

Ordinal scales can be quantified and thus made usable for numerical treatment and aggregation. Nagra, for example, converted the classifications (very favourable, favourable, conditionally favourable, unfavourable, unsuitable) into numerical values (so-called usage values from 5 to 1 [NTB14-01]), which were then handled in a quantitatively aggregated manner. The explanatory memorandum of the Site Selection Act to § 24(1) states with regard to such an aggregation: “A mathematical overall assessment of the fulfilment of the weighing criteria is deliberately not provided for. In the weighing for the assessment of the overall geological situation, the significance of the respective weighing criteria for a specific site and the repository system envisaged there must be recognised.”

Such a significance can be higher or lower depending on the safety or disposal concept. Assignment of significance already takes place in the projection of facts on uniform ordinal scales. For example, weighing can already take place through the choice of threshold values on a graded scale. Furthermore, facts (e.g. values of indicators) can be interdependent (e.g. correlated). In such a case, there is a risk that, when regarded isolated, these are assessed too high, i.e. that a multiple valuation is made, e.g. of hydrogeological facts (see Table 1 in Annex 2), which are in fact linked to each other. Furthermore, it is conceivable that facts interact, i.e. that in combination they have a greater impact on safety than individually. In this case, an isolated consideration would lead to an assessment that is too low.

In its aggregation for Stage 2 of the Swiss site selection procedure [NTB 14 01], Nagra took such interrelationships into account by performing a multi-stage aggregation at three levels (criteria group – criterion – indicator), using different cases of aggregation (mean or minimum of the values to be aggregated) [NTB 14-01]. As mentioned above, the starting point was the assumption of identical or very similar safety concepts for all potential sites, since only clays or clay-rich rocks were available for selection. Given the differences expected for Germany, such an aggregation would have to be done differentiated according to the respective concept. The multi-level aggregation in the RESUS R&D project at the levels indicators – assessment-relevant properties – criteria – overall assessment follows such a logic. It should be noted in this context that the aggregation in the RESUS project was supported by safety analyses for various concepts.

Aggregation also requires the consideration of possible uncertainties. There are essentially two conceivable approaches: the consideration of possible bandwidths, e.g. through consideration of variants, or through the use of special complex methods of the multi-criteria analysis, e.g. on a probabilistic or fuzzy logic basis. These, however, are not undisputed with regard to their practicability [DCLGL 2009], [Röhlig 2015]. Another approach would be to transfer the fact of uncertainty itself into assessment parameters. In the Swiss site selection procedure, for example, a criteria group “Reliability of the geological statements” is specified, which includes the uncertainties regarding rock characterisation, spatial conditions and long-term prognosis.

Decisive for the results of an aggregated assessment is the question of whether and, if so, how individual parameters are weighed. Multi-criteria analyses are often used in connection with valuations and normative facts, where views on weighing can be strongly varying. Accordingly, it is pointed out in literature that there are limits to objectification and that the decision-making process plays an essential role for weighing: *“The purpose [of multicriteria decision analysis] is to serve as an aid to thinking and decision making, but not to take the decision.”* [DCLGL 2009]. One such example of application in the field of nuclear waste management is the multicriteria analysis within the framework of the comparison of options for the management of all types of radioactive waste in Great Britain by the Committee on Radioactive Waste Management [CoRWM 2006].

3.3 Weighing on the basis of safety analyses

In the specific case of weighing in the site selection procedure, a tool for the integral assessment of the repository system is available according to the Site Selection Act in the form of preliminary safety analyses, which can provide information on the safety relevance and on the dependencies and interactions of facts depending on the respective concept. Conceivable approaches are those that use the results of these examinations either verbally-argumentatively or in aggregations (see Chapter 3.2 on the approach in the RESUS project). However, these results could also be included in the weighing within the framework of multi-criteria analyses.

According to § 27(1) StandAG, the central subject of the preliminary safety analyses is “the assessment of the extent to which safe containment of the radioactive waste can be expected by exploiting the geological conditions at the site”. This raises two fundamental questions – that of the containment capacity per se, i.e. in particular the physicochemical properties of barriers that prevent or hinder the inflow and outflow of any contaminated fluids, and that of the preservation of such properties during the assessment period, i.e. the question of integrity. In the context of the weighing criteria of the Site Selection Act, this is referred to as “achievable quality of containment” for the target parameter containment capacity. The weighing criteria in § 24(3) refer to this target parameter as well as to the “robustness of verification”. For the target parameter integrity, the term “preservation of the isolation capacity” is used in § 24(4).

The second question is addressed against the background of the consideration of the probability of occurrence and possible consequences of potential evolutions of the repository system (scenarios), which are to be systematically derived and classified. In particular with regard to the possibility that the actual future evolution of the repository system will significantly deviate from the scenarios derived in the safety analysis (e.g. due to unforeseen events or effects, so-called “unknown unknowns”), the robustness (§ 2 EndlSiAnfV) of the system is also to be assessed. Finally, it is to be ensured that the repository as designed can be constructed safely.

The results of the safety analyses include calculated indicators which can be used for comparative quantitative assessment and weighing. The Disposal Facility Safety Requirements Ordinance specifies such indicators: § 4 requires an assessment on the basis of a containment capacity indicator, and § 7 requires an assessment on the basis of the additional annual effective dose which, according to the ordinance, may occur during the assessment period as a result of releases of radionuclides from the emplaced radioactive waste. The first indicator refers directly to the “main barriers” and is therefore relevant for weighing. It is inherent to this indicator that it can also be determined for different safety concepts. The annual effective dose is an integral safety indicator which is to be determined on the basis of calculation specifications and conventions that are still to be specified. For these calculation specifications, the central question is to what extent the calculation should rather be site-specific or rather generic. The calculated additional effective dose does not represent a prognosis of a real radiation exposure but an indicator of whether the system as a whole can fulfil safety requirements. The specifications for the dose values in § 7 have been chosen so low that a comparison and weighing based on different values below the values specified in § 7 are not permissible in the opinion of the ESK.

A compilation by the OECD/NEA [OECD 2012] provides information and suggestions on the potential of different indicators. There, among other things, a categorisation is proposed according to

- ‘content and concentration’ related indicators,
- ‘flux’ related indicators,
- ‘status of barriers’ related indicators.

The first two categories aim at the containment capacity per se (the indicator according to § 4 EndlSiAnfV is a ‘flux’ related indicator). In contrast, ‘status of barriers’ related indicators (e.g. container lifetime or dilatancy strengths) are primarily aimed at integrity. § 5 EndlSiAnfV contains references to such indicators. The ESK recommends compiling indicators for different safety concepts with regard to their informational value in terms of containment capacity, integrity and robustness as well as their universal applicability in view of different safety concepts. With such a compilation, a methodological basis for safety-oriented and practicable weighing could be provided.

According to the Disposal Facility Safety Analyses Ordinance, the purpose of the preliminary safety analyses is, among other things, to demonstrate the relevance of the individual weighing criteria under appendices 1 to 11 of the Site Selection Act for the assessment of the respective repository system (§ 4(4)). In this context, the ordinance mentions, among other things, the relevance of the criterion for the safety functions of the envisaged repository system and its components. In this context, the ESK points out

- that facts considered in the exclusion criteria and minimum requirements are also significant in this respect, and

- that there are interdependencies between the facts considered in the criteria.

The ESK therefore suggests that the facts considered in the exclusion criteria and minimum requirements should also be considered in the weighing: Even if an investigation area is accepted after application of the exclusion criteria and minimum requirements, there are differences with regard to the related safety margins and thus with regard to robustness.

The ESK further suggests using the safety analyses to clarify interdependencies between the facts and related indicators considered in the criteria as well as to clarify the influence of the facts on target parameters such as "achievable quality of containment" (containment capacity), "robustness of the safety case to be expected" and "preservation of the isolation capacity" (integrity).[3]

The matrices in Annex 2 show examples of how the described factors could be systematically presented and made clearer within the framework of the conception and implementation of preliminary safety analyses and thus weighing could be supported. Matrix 1 shows possible interdependencies between the exclusion criteria (light blue), minimum requirements (green) and weighing criteria (yellow). Matrices 2 and 3 show exemplary interdependencies between the indicators according to Appendix 1 StandAG for assessing the transport of radioactive substances by groundwater movement in the containment-providing rock zone and according to Appendix 9 StandAG for assessing the retention capacity in the containment-providing rock zone and Appendix 10 StandAG for assessing the hydrochemical conditions. Both matrices are to be read clockwise, the arrows indicate influences. The representation is inspired by approaches developed in [SKB 1994, Nirex 1998, DBE Technology 2008]. In addition to the representation of influence directions via arrows used here, the matrix representation also opens up the possibility of a further differentiated representation considering influence degree and explanations. Furthermore, Matrix 4 shows the significance of criteria for the "achievable quality of containment" (§ 24(3) StandAG) for different host rock types and safety concepts. Reference was also made to criteria that are assigned differently in the Site Selection Act (see Note below Matrix 4).

3.4 Challenges in comparing repository systems with different safety concepts

In general, one of the main challenges in the site selection procedure is the comparative assessment of repository systems in different host rocks. Repository systems in different host rocks differ considerably with regard to their safety concepts and the respective relevance of the safety functions of their barriers. Internationally, there are no examples of safety-oriented comparisons of or weighing between repository systems in different host rocks that could be used for a selection process in Germany.

According to § 24(2) StandAG, in areas where no CRZ can be identified, the weighing criterion for assessing the configuration of the rock bodies (Appendix 2 (ad § 24(3)) StandAG) is replaced by the mathematical derivation of the containment capacity that can probably be expected from the engineered and geotechnical barriers. How these calculated results can be weighed using the weighing criterion for assessing the configuration of the rock bodies in areas where a CRZ can be identified remains to be clarified. In particular, criteria allowing the classification of the repository system according to the respective categories based on a mathematical derivation of the containment capacity of engineered and geotechnical barriers still need to be developed.

According to § 24(2) StandAG, the other weighing criteria (appendices 1, 3 to 11 StandAG) are to be referred to the emplacement zone instead of the CRZ for areas where no CRZ can be identified. By definition, the emplacement zone is the spatial zone of the rock formation in which the radioactive waste is to be emplaced. If the containment capacity of the repository system is mainly based on engineered and geotechnical barriers,

[3] If several factors have a joint influence on a target parameter and their effects for example reinforce each other, this is referred to as "interaction".

this also includes the zone of the rock formation which ensures the functioning and the preservation of these barriers, i.e. a seam of crystalline rock surrounding the emplaced waste and the engineered and geotechnical barriers.

The problem here is that all weighing criteria refer to safety-related properties of host rocks for which a CRZ can be identified. However, for concepts in which the containment capacity of the repository system is mainly based on engineered and geotechnical barriers, other requirements for an emplacement zone would be required for . These requirements would have to be aimed in particular at protecting the engineered and geotechnical barriers. For example, the hydrochemical conditions in the emplacement zone are of great importance with regard to the long-term corrosion protection of the containers. This shows that the geoscientific weighing criteria are only suitable to a limited extent for comparing different repository systems in different host rocks, which makes a direct comparison more difficult. For this purpose, criteria for comparison would have to be developed within the framework of the preliminary safety analyses that are oriented towards specific safety functions of such concepts (§ 7(4) EndlSiUntV).

3.5 Dealing with different levels of knowledge

In compliance with the final report of the Commission on Storage of High-Level Radioactive Waste [KLHRA 2016], the site selection procedure started with a “white map” of Germany. Particular challenges arise in Phase 1 of the site selection procedure, which includes the identification of subareas (§ 13 StandAG) and their narrowing down to siting regions (§ 14 StandAG), which are subsequently to be explored from the surface in Phase 2 (see Annex 1). Phase 1 is based exclusively on already existing data and information. Specific subarea or siting region explorations are not planned in this phase. It is to be assumed that the data situation for the individual investigation areas is regionally heterogeneous with regard to scope and informative value. In this respect, it can be noted that

- for some investigation areas, the data situation is so incomplete that not all exclusion criteria and/or minimum requirements can be examined (for example with regard to the exclusion criterion “groundwater age” (§ 22 StandAG), it is unlikely that comprehensive information on the subsurface of all areas in the Federal Republic of Germany is available),

- for a large number of geoscientific weighing criteria, the data situation is not sufficient to allow a reliable classification of an investigation area into the corresponding assessment groups (“safety-oriented weighing of the results for all weighing criteria” (§ 24 StandAG) is thus only possible to a limited extent),

- the scope and quality of the data and thus the reliability of results when applying the geoscientific criteria differ between the investigation areas (see Chapter 3.2),

- the application of the criteria according to § 24 StandAG can only be carried out on the basis of generic (i.e. preliminary) concepts for subareas and, in the second part of Phase 1 (see Annex 1), for siting regions, and will therefore not be conclusive (for example, the space required will have to be estimated using preliminary assumptions for a host-rock-specific disposal concept).

The application of generic (i.e. preliminary) disposal concepts involves the risk that

- such concepts developed in an early phase of site selection lead to the exclusion of investigation areas that would have led to a safe solution in case of further optimisation of the concepts in a later procedural step,
- in one and the same selection phase, repository systems with disposal concepts at different stages of optimisation are compared, resulting in an imbalance in the assessment.

As the procedure progresses (Phase 2, surface exploration, and Phase 3, subsurface exploration), these different levels of knowledge are to be balanced by site-specific exploration programmes to the extent necessary for a safety-oriented comparison. Geological conditions with different degrees of complexity and different safety concepts at the sites impose different requirements on the level of detail needed to collect the geological knowledge required in later phases. The exploration programmes are defined in § 2 StandAG such that the purpose of the exploration is to determine the site-specific geoscientific data required for conducting the preliminary safety analyses. Consequently, different levels of knowledge are admissible in principle, provided that the corresponding safety analyses are possible in such a way that they allow a safety-oriented comparison and decisions based on it.

According to § 13 and § 14 StandAG, the project implementer must also list areas in Phase 1 that cannot be conclusively assessed due to insufficient geological data and make a recommendation on how to proceed with these areas. In the subareas interim report pursuant to § 13 StandAG [ZwiTeil 2020], the project implementer worked with reference data sets: where insufficient data was available for the proper application of a weighing criterion for areas of a specific host rock type, all areas of this host rock were assessed uniformly with regard to this criterion. The reference data used for this purpose were selected in such a way that they were as favourable as possible within the conceivable bandwidths for the respective host rock type in order to avoid premature exclusion of areas. Such a uniform assessment per host rock type with reference data sets was carried out for 8 (rock salt in steep stratification), 9 (crystalline host rock) and 7 (claystone and stratiform rock salt) of the 11 weighing criteria. Consequently, the project implementer did not address areas with insufficient data separately.

The ESK is of the opinion that in the further course of action, the following approaches could also be pursued:

- The project implementer can argue that a corresponding geoscientific weighing criterion is not decisive in the upcoming site comparison or that the expected range of values is almost identical and that therefore the obtainment of additional data (e.g. seismic measurements, boreholes) by means of further exploration steps may not be necessary. This approach is cost- and time-efficient but requires that for a site comparison sufficient data are available at the other sites to be compared so that the safety-relevance of the respective criterion can be conclusively assessed.
- The project implementer can dispense with (further) data collection if they can comprehensively show that the expected data lie within a bandwidth that (a) clearly does not fulfil an exclusion criterion (§ 22 StandAG) or fulfil a minimum requirement (§ 23 StandAG) or (b) on the basis of the expected data, there is a clear safety-related advantage or disadvantage compared to other sites with regard to one or more

criteria (§ 24 StandAG). With this approach, time-consuming data collection can be reduced until the bandwidths of safety-relevant parameters can be reliably estimated. However, such an approach only works if (a) the estimated bandwidths can be clearly separated from the specified limit values of the exclusion criteria and minimum requirements, considering the uncertainties, or (b) the weighing criteria in the site comparison have corresponding bandwidths so that there is no overlap between the sites within the bandwidths.

- Alternatively, the project implementer can include the corresponding data acquisitions in its exploration programme and thus strive for the knowledge balance necessary for the comparison. Depending on the complexity of the geological conditions, this approach is more time-consuming and costlier. The results of an exploration do not necessarily guarantee proof of a clear undercutting/exceeding of exclusion criteria and minimum requirements or an effective difference between siting areas with regard to the weighing criteria.

The approach chosen should be carefully justified. The following three questions or procedural steps could be used as a starting point for a strategy to deal with incomplete knowledge:

1 Is the incomplete data basis relevant for safety? If not, there is no need to compensate for the data gap; if so: → Question 2

2 Is it possible to replace the incomplete knowledge with literature data (use of “proxies”, e.g. data from similar rocks, similar geological conditions)? If so, the choice of proxies is to be based on a substantiated justification. This approach was taken in the subareas interim report [ZwiTeil 2020] with the use of so-called “reference data sets”.
If not: → Question 3

3 Can the knowledge gaps recognised as safety-relevant be reliably closed using scientific exploration methods? If so, the corresponding data should be collected. If not, an appropriate approach is to be defined.

The fulfilment of all exclusion criteria and minimum requirements is to be checked in all phases due to progressive developments in scientific methods and new data generated outside the procedure (see Annex 1). For this purpose, corresponding data should be collected if there is a possibility that a siting region could thereby fulfil an exclusion criterion or not fulfil a minimum requirement. It is conceivable that further data collection will not necessarily lead to more clarity in all aspects with regard to safety-related advantages or disadvantages. For the data collection, it is to be checked in advance what the effect of additionally collected data could be with regard to exclusion or site comparison. These constraints influence the need to balance different levels of knowledge.

In summary, it can be stated that the procedure started with significant differences in the level of knowledge but that a lack of knowledge must not automatically lead to the exclusion of areas. Knowledge gaps are to be filled by justified assumptions or completed by data collection to such an extent that clear safety-related judgements can be made with regard to the exclusion criteria, minimum requirements and weighing criteria.

Thus, different levels of knowledge can remain between individual sites if this does not adversely affect the site comparison. The potential for further data collection is to be clarified on a case-by-case basis.

3.6 Dealing with uncertainties

Scientific data typically involve uncertainties. The more data are available, the better their uncertainties can be characterised and possibly narrowed down. How to deal with uncertainties should be determined at an early stage in the process. For example, when considering exclusion criteria or minimum requirements or when comparing two sites with regard to weighing criteria, the uncertainties should always be considered as a measure of the reliability of a statement on the site characteristics in addition to the absolute values.

Geological data and processes are subject to uncertainties of various origins:

- Aleatoric uncertainties are based on a natural fluctuation of geological parameters and processes. This is not due to a lack of knowledge but to intrinsic heterogeneity. These uncertainties cannot be reduced by further data collection, or only to a certain degree.

- Epistemic uncertainties are due to a limited knowledge base. These uncertainties may be further minimised by further data collection and include methodological uncertainties due to inaccuracies of the measurement method. Such uncertainties can only be reduced by a more accurate measurement method, if available.

Methodological uncertainties should be reduced to what is technically achievable by using state-of-the-art methods. The most appropriate method for data collection should be continuously ascertained. The identification of natural heterogeneities requires that methodological uncertainties are smaller than aleatoric uncertainties. In the opinion of the ESK, epistemic uncertainties should be reduced for the final assessment of exclusion criteria and minimum requirements, as far as methodologically possible and useful for exclusion and comparison (see Chapter 3.4).

It is to be clarified in the procedure how to deal with a situation where, for example, a site has a favourable overall geological situation in the reference scenario but has a high bandwidth when considering scenarios: How should good performance in the reference scenario be assessed together with limited robustness? For example, a site may have a good host rock, but possible developments that deviate from the reference scenario may show the formation of hydraulic pathways. In a site comparison, it would have to be regulated how such cases are to be weighed against other advantages and disadvantages. In addition, it is to be clarified whether so-called comparison parameters should be defined that allow a direct comparison between different sites.

From the ESK's point of view, uncertainties should be systematically identified and their influence on the fulfilment of the criteria/requirements should be shown. Type and extent of uncertainties are important information with regard to the question of how these can be reduced within the procedure through further investigations and data collection (see Chapter 3.5). It is to be regulated for the procedure how the uncertainties documented for the individual sites are to be considered in the site comparison.

3.7 Optimisation and reasonableness

According to § 8 of the Radiation Protection Act, any exposure or contamination of man and the environment shall be kept as low as possible, even below the respective limits (principle of optimisation). According to § 26 StandAG and § 12 EndlSiAnfV, optimisation shall be complete if further improvement in safety can no longer be achieved with reasonable efforts. These requirements raise questions about the procedure, especially if decisions have been made in the procedure that subsequently prove to be inadmissible. Here, the question arises whether the site selection procedure must return to the point at which this inadmissible decision was made.

Optimisation is always to be understood in a manner oriented to the respective objectives ("with regard to which objective is optimised?"). § 26(3) StandAG stipulates that the requirements for the safety concept of the operational and post-closure phases of a repository are to be optimised step by step. This optimisation is to be linked to clear objectives. The Disposal Facility Safety Requirements Ordinance specifies the following objectives: 1. the long-term safety of the repository, in particular the quality of the safe containment of radioactive waste and the robustness of the repository system, and 2. the operational safety of the repository. The ICRP requires "optimisation below constraint" [ICRP 2006], whereby the constraints do not represent targets but rather boundary limits that should be undercut as far as possible.

During optimisation, conflicts of objectives may arise. These should be identified at an early stage as each phase of the site selection procedure, as well as the subsequent realisation of the repository, has its own specific objectives. Thus, optimisation in the construction phase can cause conflicts in the operational phase, and optimisation in the operational phase can in turn have unfavourable effects on long-term safety. Priorities need to be clarified here.

The objectives are to be prioritised also in the case of conflicting design objectives. For example, a greater depth of the facility can protect it better from long-term glacial and near-surface processes. However, depending on the host rock, a greater depth can also lead to increased difficulties regarding the excavation of the underground cavities. If necessary, these conflicting objectives should be identified for specific host rocks and/or sites, and solutions should be sought that result in optimised safety in the case of competing weighing criteria in a site comparison.

In analogy to radiation protection, in optimisation, weighing up has to be performed as comprehensively as possible ("taking into account all circumstances of the individual case"). In this respect, it is to be clarified

- what degree of optimisation (safety gain) is effectively achieved in the procedure,
- whether, in addition to optimisation in a specific area, disadvantages are caused in other areas,
- to what extent optimisation affects an area far below legal requirement,
- whether optimisation involves comparing personal doses of the operating personnel (e.g. due to conditioning and/or emplacement) with hypothetical doses of the population in the distant future (due to possible release from the repository), and

- what additional risks and costs are associated with it.

Ensuring safety involves costs and the financial resources for disposal are finite. Optimisation measures are therefore always to be reflected against the background of the financial resources available. It is to be ensured that optimisation of safety is carried out at the right place and at the right time. Optimisation should be considered as a whole and the optimisation effort should be checked for its reasonableness. If, for example, it turns out that a repository can be optimised in one investigation area with far less effort than in another, both investigation areas would still have to be treated as equivalent in terms of safety. Without considering reasonableness, there is a risk that investigation areas that only fulfil the requirements with unreasonable optimisation efforts cannot be excluded. Accordingly, the Disposal Facility Safety Requirements Ordinance also stipulates in §12(2) that optimisation shall be complete if further safety improvement can only be achieved with unreasonable effort.

3.8 Return to previous steps

In the Site Selection Act, the question of how exactly a "site with the best possible safety" is to be determined is solved by a procedural approach: The site is defined by the fact it emerges from the procedure. This means that in certain steps of the procedure decisions are made for investigation areas that are based on science and guided by criteria due to the legal and sub-legal requirements. This formal approach contributes to procedural certainty, but at the same time it must satisfy the requirement of a "self-questioning and learning" procedure and the requirement of reversibility (§ 1(5) StandAG). This creates a field of tension: on the one hand, procedural certainty and trust in a process are sought which strives for reliability on the basis of criteria defined at the outset and then also fixed for the procedure. On the other hand, the requirement that the procedure should be "learning" and "self-questioning" also implies possibilities for changes to just these criteria.

Reversibility implies the possibility of returning to previous steps [KLHRA 2016], for example in response to significant increase in knowledge or significant methodological developments. Possible examples of new findings that result in returning to previous steps could concern the investigation area or safety-relevant processes (or only dissent between experts regarding their assessment). In the case of methodological developments suggesting a fundamental revision of safety concepts, the revised concepts might be more favourable for investigation areas that have already been discarded or deferred on the basis of the previous concepts.

This raises the question of the criteria for setbacks as another challenge. According to the Site Selection Act, a repository should be constructed as soon as possible. This objective is clearly safety-driven since a perpetuation of storage is to be avoided. Accordingly, setbacks should not lead to endless loops but should only be undertaken if safety in accordance with the safety requirements is seriously questioned .

Possible criteria for returning to a previous step could be the following:

- The justified expectation that, contrary to earlier assumptions, the safety requirements cannot be met in investigation areas, for example in the case of a massive deterioration in robustness assessments for the investigation areas. Depending on the respective phase of the procedure (see Annex 1), such return to previous steps may have to take place if only (too) few investigation areas have remained in the procedure.

- Significant changes in the assessments of robustness which may make approaches that have already been discarded appear more attractive again.

From the ESK's point of view, criteria for setbacks should therefore be defined and communicated as soon as possible.

4 Summary of the main aspects in the site comparison

With regard to the necessary site comparison in the started selection of a “site with the best possible safety for a disposal facility pursuant to § 9a(3) sentence 1 of the Atomic Energy Act in the Federal Republic of Germany" (StandAG), the ESK sees a number of challenges and aspects that need to be clarified, which are summarised below.

- With regard to the **approach of safety-oriented weighing**, the ESK is of the opinion that every safety-oriented weighing on a scientific-technical basis in the site selection procedure must take an integral qualitative and quantitative view of the repository system. In this context, the safety-oriented weighing must meet high standards in terms of the internal logic of the methodology used as well as in terms of transparency and comprehensibility for all stakeholders, and subjective (i.e. based on expert opinions) weighing decisions must be identified as such.

- For **weighing on the basis of safety analyses**, the ESK recommends compiling indicators for different safety concepts with regard to their informational value in terms of containment capacity, integrity and robustness as well as their universal applicability in view of different safety concepts.
  The ESK suggests using the safety analyses to clarify interdependencies between the factors considered in the criteria and related indicators as well as to clarify the influence of the factors on target parameters such as “achievable quality of containment” (containment capacity), “robustness of evidence to be expected” and “preservation of the isolation capacity” (integrity).
  The ESK further suggests that the factors considered in the exclusion criteria and minimum requirements should also be considered in the weighing: Even if an investigation area is accepted after application of the exclusion criteria and minimum requirements, there are differences with regard to the related safety margins and thus at least with regard to robustness.

- The ESK sees a major challenge in the **comparison of repository systems with different safety concepts**. For areas where no CRZ can be identified, the containment capacity that can be expected from the engineered and geotechnical barriers is derived by calculation. How these calculated results can be weighed against the weighing criterion for assessing the configuration of the rock bodies in areas where a CRZ can be identified remains to be clarified.

- In **dealing with different levels of knowledge**, the ESK notes that the procedure started with significant differences in the level of knowledge but that, in accordance with the requirements of the Site Selection

Act, a lack of knowledge must not lead to the exclusion of investigation areas. Information deficits are to be countered by assumptions to be justified or by data collection to such an extent that clear safety assessments can be made with regard to the exclusion criteria, minimum requirements and weighing criteria. Thus, different levels of knowledge can remain between individual sites if this does not adversely affect the site comparison. The potential for further data collection is to be clarified on a case-by-case basis. From the ESK's point of view, uncertainties should be systematically identified and their influence on the fulfilment of the criteria/requirements should be shown. Type and extent of uncertainties are important information with regard to the question of how these can be addressed within the procedure through further investigations and data collection. It is to be regulated for the procedure how the uncertainties documented for the individual sites are to be taken into account in the site comparison.

- The ESK is of the opinion that **optimisation** should base on a holistic view and **reasonableness** should be adapted to the optimisation effort. This is stipulated in § 12(2) of the Disposal Facility Safety Requirements Ordinance according to which optimisation shall be complete if further improvement of safety can only be achieved with unreasonable effort.

- With regard to possible setbacks in the site selection process, another challenge is the question of the relevant criteria. According to the StandAG, a repository should be constructed as soon as possible. This objective is clearly safety-oriented, as the perpetuation of interim storage should be avoided. Accordingly, setbacks should not lead to endless loops, but should only be undertaken if the safety requirements are seriously questioned. The ESK therefore recommends defining and communicating criteria for a reversion as soon as possible.

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Annex 1

Phases of site selection

From: Methoden für sicherheitsgerichtete Abwägungen und vergleichende Bewertungen im Standortauswahlverfahren (MABeSt) – Vorhaben 4718F13001
[MABeSt 2020]

Phase 1
In Phase 1, the subareas are identified as a first step and as the identification proceeds, the subareas are narrowed down to siting regions.

§ 13 StandAG Phase 1A Identification of subareas

Procedural steps	Description
13-1 (2) sentence 1	Application of the geoscientific exclusion criteria according to § 22
13-2 (2) sentence 1	Application of the minimum requirements according to § 23
13-3 (2) sentence 2	Application and weighing of the geoscientific weighing criteria according to § 24
13-4 (2) sentence 4	Preparation of an interim report
13-5 (2) sentence 3	Submission of the interim report to the BASE
13-6 § 9(1) sentence 1	Convening of the Subareas Conference by the BASE

For the application of the geoscientific weighing criteria, there are three possible classifications for each area.

1 **a "favourable"** overall geological situation
2 **no "favourable"** overall geological situation
3 there is **insufficient data** available or no comparison is possible due to data heterogeneity between individual areas

For the application of the geoscientific weighing criteria and the assessment of the overall geological situation based on these, different questions and challenges arise.

Challenges:

1 Availability of sufficient data

- The availability and quality of data varies widely between subareas or siting regions, respectively.

2 Weighting of the geoscientific weighing criteria among each other

- Different safety concepts require, depending on the host rock type, different weighting of the weighing criteria for a favourable overall geological situation, especially if the host rock is one of the main barriers.
- The weight of the weighing criteria will be different for repository systems without identifiable CRZ compared to those with identifiable CRZ. For areas without identifiable CRZ, the weighing criteria are to be applied to the emplacement zone.
- The application of geoscientific weighing criteria requires knowledge/development of host rock-specific safety and disposal concepts.
- Since it is not possible to develop site-specific concepts in Phase 1 of the Site Selection Act, the application of the criteria according to § 24 StandAG can only be based on generic (preliminary) concepts for subareas and thus cannot be conclusive.

3 Applicability of all geoscientific weighing criteria in Phase 1

- A single weighing criterion is not sufficient to prove a favourable overall geological situation or to be able to assess it conclusively. Due to the heterogeneous and partly incomplete data situation, the consideration of "all" weighing criteria and the reliable classification of individual criteria into an assessment group is difficult.
- Since detailed site-specific knowledge is not available for all areas and can usually only be obtained through special exploration work in the further course of the procedure, many of the weighing criteria cannot be determined.
- No preliminary safety analyses are provided for in the procedural step according to § 13 StandAG. The majority of the geoscientific weighing criteria relate to the CRZ or the emplacement zone. At this early stage, only the possibility of the existence of a CRZ in the rock body can be identified.

§ 14 StandAG Phase 1B Identification of siting regions for surface exploration

The subareas identified in accordance with § 13 StandAG shall be narrowed down in Phase 1B (§ 14 StandAG) to siting regions with favourable geological conditions in terms of number and area. These will then be explored from the surface subsequently in Phase 2.

Procedural steps	Description
14-1 (1) sentence 2	Carrying out representative preliminary safety analyses according to § 27
14-2 (1) sentence 3	Repeated application of the geoscientific weighing criteria according to § 24 and identification of favourable siting regions
14-3 (1) sentence 4	Application of planning-scientific weighing criteria according to § 25
14-4 (2)	Preparation of a proposal for the siting regions to be explored from the surface
14-5 (1) sentence 5	Development of site-specific exploration programmes for surface exploration
14-6 (3)	Submission of the proposal and the site-specific exploration programmes to the BASE

Challenges:

1 Carrying out representative preliminary safety analyses

- The varying availability of data for the subareas makes it difficult to evaluate the results of representative preliminary safety analyses.
- Due to the limited knowledge about the site-specific geological conditions, the results of the representative preliminary safety analyses obtained in Phase 1 can only be understood as guideline figures and thus do not allow for a sufficiently robust safety statement.
- If different disposal concepts are possible for a host rock or an investigation area, it is necessary to consider different variants for the selection of siting regions (e.g. emplacement in drifts or boreholes).

§ 15 StandAG Phase 1C Decision on surface exploration and exploration programmes

The site-specific surface exploration programmes proposed by the BGE for the siting regions selected by federal law shall be examined and determined by the BASE.

Procedural steps	Description
15-1 § 7(2)1	Publication of the BGE proposal by the BASE (initiation of public participation)
15-2 (1) sentence 1	Examination of the BGE proposal by the BASE
15-3 (2) sentence 1	Preparation of a reasoned recommendation on the BGE proposal
15-4 (2) sentence 1	Submission of the proposal by the BASE to the BMU including all necessary documents
15-5 (3)	Determination on how to proceed by federal law for areas with insufficient information for the application of the criteria according to §§ 22 to 24
15-6 (4)	Examination of the site-specific exploration programmes for surface exploration for the siting regions selected by federal law and determination as well as publication in the Federal Gazette by the BASE

Challenges:

The challenges largely correspond to §13 Phase 1A and §14 Phase 1B. However, in Phase 1C they concern the BASE.

Phase 2

In Phase 2, the surface exploration programmes are carried out and the siting regions (area and number) are narrowed down to sites for subsurface exploration.

From Phase 2 onwards, it is possible to derive certain safety indicators and their consequences from safety analyses.

§ 16 StandAG Phase 2A Surface exploration and proposal for subsurface exploration

The BGE shall be responsible for the implementation and evaluation of the surface exploration programmes and the preparation of the subsurface explorations.

Procedural steps	Description
16-1 (1) sentence 1	Surface exploration of the siting regions
16-2 (1) sentence 2	Carrying out further developed preliminary safety analyses
16-3 (1) sentence 3	Carrying out socio-economic potential analyses for the siting regions
16-4 (2) sentence 1	Repeated application of the requirements and criteria (§§ 22 and 23)
16-5 (2) sentence 1	Repeated application of the weighing criteria according to § 24 to identify favourable sites
16-6 (2) sentence 2	Application of the planning-scientific weighing criteria in accordance with the provisions in § 25
16-7 (3)	The BGE shall draw up a proposal for sites to be explored underground
16-8 (2) sentence 3	Development of exploration programmes and assessment criteria for underground exploration of the sites identified in procedural step 16–7
16-9 (3), (4)	The BGE shall submit its proposal for the sites to be explored underground and the corresponding exploration programmes and assessment criteria to the BASE

Challenges:

1 Weighing and/or comparative assessments of the described procedural steps

- It is assumed that all the information required for the application of the requirements and criteria can be obtained through surface exploration. §16 StandAG does not refer to the potential problems that may arise due to insufficient data for the application of the requirements and criteria.

- The Site Selection Act does not specify a point in time at which the results of the socio-economic potential analyses are to be considered in the procedure according to § 16 StandAG.

- Whether and, if so, how the results of potential environmental and other impacts of a disposal project presented by the BGE should be considered in the selection of disposal sites for underground exploration is not specified.

2 Application of the geoscientific weighing criteria

- The robustness of the safety statement and the safety of the repository system must be emphasised in the weighing, as must the uncertainties that still exist in the application of the geoscientific weighing criteria and in the performance of the safety analyses.

3 Assessing the fulfilment of safety requirements

- The scope and depth of the reviews of the further developed preliminary safety analyses will be considerably more extensive in Phase 2. The geological conditions in the siting regions must be considered in the further developed disposal concepts.

4 Application of the planning-scientific weighing criteria

- The planning-scientific weighing criteria are applied again. Due to the relatively long periods in the procedure between the phases and during them, new or modified planning-scientific specifications could result. Areas that are considered as sites with the best possible safety for disposal must be protected from changes that could impair their suitability as site for a repository.

- If there are no candidate sites with comparable suitability in terms of safety, it must be clearly defined methodically, in addition to the planning-scientific weighing criteria, whether, or with what weight, the results of the socio-economic potential analyses can be taken into account in an overall weighing under the primacy of safety.

§ 17 StandAG Phase 2B Decision on sites for subsurface exploration

The BGE proposal shall be published immediately after submission to the BASE. The BASE shall initiate the public participation procedure. Subsequently, the BASE shall examine the BGE proposal for the sites to be explored from the subsurface. The work to identify the favourable sites must have been performed in a comprehensible manner.

Procedural steps	Description
17-1 § 7(2)2	The BASE shall publish the BGE proposal (according to § 16(3)).
17-2 (1) sentence 1	Examination of the proposal (according to § 16(3))
17-3 (2) sentence 1	Evaluation of the results of the participation procedure, including the results of the NBG's deliberations and drawing up a reasoned recommendation on the BGE's proposal
17-4 (3)	The BASE shall determine by administrative act whether so far, the site selection procedure has been carried out in accordance with the provisions of the Site Selection Act and whether the selection proposal complies with them.
17-5 (2) sentence 1	Submission of the BGE proposal (according to § 16(3)) and additional documents to the BMU
17-6 (2) sentence 3 and sentence 4	Informing the German *Bundestag* and the *Bundesrat* about sites to be explored underground; determination of the sites to be explored from the subsurface by federal law
17-7 (4)	The BASE shall review the site-specific exploration programmes and assessment criteria for underground exploration for the sites selected by federal law, determine these and publish them as well as amendments in the Federal Gazette.

Challenges:

- In order to be able to check the plausibility, robustness and comprehensibility of the result, the BASE must have the possibility to make its own considerations and/or comparisons within the framework of their examination and review tasks.

- It is still unclear whether and to what extent the results of the public participation and the results of the NBG’s deliberations will be incorporated into the BASE's reasoned recommendation on the BGE proposal.

- Objections may come from the public participation procedure, which may lead to weighing and/or comparative assessments of different investigation areas by the BASE.

Phase 3

In Phase 3, the subsurface exploration programmes are carried out and the site proposal is prepared by the BGE. Finally, the site proposal is evaluated by the BASE and the decision on the site is made by the *Bundestag/Bundesrat*.

§ 18 StandAG Phase 3A Subsurface exploration and site proposals

The procedural steps from the subsurface exploration to the proposal of a site by the BGE and the subsequent environmental impact assessment by the BASE shall be defined.

Procedural steps	Description
18-1 (1) sentence 1	Subsurface exploration of the sites selected by federal law
18-2 (1) sentence 2	Carrying out comprehensive preliminary safety analyses according to § 27
18-3 (1) sentence 2	Preparation of an EIA report according to § 16 of the Environmental Impact Assessment Act
18-4 (2) sentence 1	Application of the assessment criteria and applying again the requirements and criteria (§§ 22 and 23)
18-5 (2) sentence 1	Applying again the weighing criteria according to § 24
18-6 (2) sentence 2	Application of the planning-scientific weighing criteria according to § 25
18-7 (3) sentence 2	Preparation of a site proposal in accordance with § 18(3) based on a comparative assessment of the sites to be considered
18-8 (3) sentence 1 and 2	Submission of the site proposal for a repository to the BASE including its justification
18-9 (3) sentence 3	The BASE shall conduct an environmental impact assessment

Challenges:

In Phase 3, the methodological aspects of a comparative assessment are regarded as major challenge. Although the methodological challenges have been reduced due to data uncertainties, there are still uncertainties due to the future (host rock-specific) evolution of the repository systems (scenario development). These must be considered in a comparative assessment.

The BASE will arrange environmental impact assessments for the selected sites.

The Site Selection Act does not specify how the results of the assessments are to be considered for the selection of disposal sites.

1 Application of the geoscientific weighing criteria

- The data situation for the full applicability of all requirements and criteria must be given by this time at the latest. Due to bandwidths, however, there are still uncertainties that need to be identified for some parameters (e.g. porosity).

- For sites where no CRZ can be identified, a mathematical proof of the containment capacity of the technical and geotechnical barriers must be provided instead of the fulfilment of the minimum requirements and weighing criteria for sites. The appropriate methodology is still to be defined.

- Although selection criteria (geoscientific weighing criteria) can indicate possible sites, they are not individually suitable for conclusively determining the safety of a repository. This safety-oriented comparison must be made on the basis of safety indicators.

2 Assessing the fulfilment of safety requirements

- In subsequent safety analyses, further developments in the state of the art in science and technology must be considered due to the long duration of the site selection procedure.

3 Comparative assessment of the sites to be considered

- Should sites in different host rocks remain in Phase 3, the greatest challenge of the comparative assessment will be the comparability of the repository systems in different host rocks.

§ 19 StandAG Phase 3B Conclusive comparison of sites and site proposal

After publication of the BGE's site proposal by the BASE, the site proposal shall be examined, including the underlying site comparison of at least two sites. Based on the results of this assessment and considering all private and public interests as well as the results of the public participation, the BASE shall assess which site offers the best possible safety.

The BASE shall determine by administrative act whether so far the site selection procedure has been carried out in accordance with the provisions of the Site Selection Act and whether the site proposal complies with them.

After the site proposal has been drawn up by the BASE, the proposal shall be submitted to the BMU including all required documents.

Procedural steps	**Description**
19-1 § 7(2)3	The BASE shall publish the site proposal (according to § 18(3)).
19-2 (1) sentence 1, sentence 2	The BASE shall examine the BGE proposal in accordance with § 18(3) and assess which of the sites is the one with the best possible safety.
19-3 (2) sentence 3	The BASE shall determine by administrative act whether so far the site selection procedure has been carried out in accordance with the provisions of this Act and whether the site proposal complies with them.
19-4 (1) sentence 3 and 4	Preparation of a site proposal
19-5 (2) sentence 1	The BASE shall submit the site proposal to the BMU including all necessary documents.

Challenges:

- The challenges with regard to the weighing and/or comparative assessments largely correspond to § 18 Phase 3A.

- The results of the participation procedure for a safety-oriented assessment and weighing of the sites against each other as well as the weighing/significance of public and private interests still need to be clarified.

§ 20 StandAG Phase 3C Decision on the site by the *Bundestag* and the *Bundesrat*

The procedure will be determined by federal law until the final decision on the site.

The BASE site proposal shall be submitted by the Federal Government to the German *Bundestag* and the *Bundesrat* in the form of a draft act.

In addition, the documents to be submitted comprise a summary report on the results of the site selection procedure and the results of the participation procedure, including the results of the National Citizens' Oversight Committee deliberations.

A decision on the acceptance of the site proposal is made by federal law.

The licensing procedure for the construction, operation and closure of the repository will then be binding.

Procedural steps	Description
20-1 (1) sentence 1	The Federal Government shall submit the site proposal to the German *Bundestag* and the *Bundesrat* in the form of a draft act.
20-2 (2)	The acceptance of the site proposal shall be decided on by federal law.
20-3 (3)	On the basis of this decision, the suitability of the project shall be fully assessed during the licensing procedure.

Challenge:

- In the subsequent licensing procedure, it is required to fully assess the suitability of the project.

- It might become necessary to determine according to which procedure returning to a previous step will take place if, contrary to expectations, the selected site should turn out to be unsuitable in the licensing procedure.