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# Development of Site Selection Criteria for Radioactive Waste Disposal in View of Favourable Geological Settings in Germany

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## 1. INTRODUCTION

In Germany, it is intended to dispose of all types of radioactive waste in deep geological formations. In the past, the Gorleben salt dome in the North East of Lower Saxony has been investigated for its suitability to host a deep repository for all types of radioactive waste, mainly for heat-generating radioactive waste (high-level waste) originating from reprocessing and spent fuel elements, while waste with negligible heat generation was intended to be disposed of separately.

After the federal elections in September 1998, the new Federal Government made a pronounced change in energy policy, the most important feature of which is the abandoning or phasing out of nuclear energy. The new policy also comprises important alterations and changes in radioactive waste management.

Since the government has doubts regarding the suitability of the Gorleben site, the investigation of the Gorleben salt dome shall be interrupted for at least 3 years, however for 10 years at maximum, until conceptual and safety-related questions have been clarified. Further sites in different host rock formations shall be investigated. This investigation process has to be carried out with respect to technical suitability and safety as well as to public acceptance. For this reason, in February 1999 the BMU has established the 'Committee on a Site Selection Procedure for Disposal Sites' (AkEnd) (in the following referred to as "the Committee").

The mandate of the Committee is to develop a comprehensible procedure for the selection of sites for radioactive waste disposal in Germany. The procedure should be based on well-founded criteria and also include participation of the public /[www.akend.de/](http://www.akend.de/).

For the development of a site selection procedure, the Committee has predefined the following basic requirements:

- A transparent and clear structured procedure shall be developed which makes a fair and objective selection of sites possible. The selection procedure shall be designed traceably in its process and its decisions.
- The selection procedure must exhibit a proper and convincing method structure and sound criteria on a scientific basis. The bases of the procedure must be determined before starting site selection to prevent inappropriate or arbitrary modifications during the procedure.

## **2. BOUNDARY CONDITIONS AND EVALUATION BASIS**

Under consideration of the valid legal norms, the protection goals and safety principles, the Committee recommended several decisions for the development of the procedure for one site:

- All kinds of radioactive waste should be considered.
- The disposal concept shall be based on the 'Concentrate and Contain' principle.
- Disposal shall take place only in deep geological formations at least several hundred meters below ground.
- The repository shall be built as a mine in accordance with the state of the art.
- The isolation time period should be in the order of magnitude of one million years.
- A robust multi-barrier system in a favourable integral geological setting is pursued.

## **3. STRUCTURE OF THE PROCEDURE**

The Committee developed a stepwise and iterative procedure which provides, besides the increase of transparency, the necessary flexibility in dealing with assessment results.

The method is governed by geo-scientific and social-scientific criteria. Decisions made during the transition from one step to the next have to be justified to make them traceable. This procedure permits reconsideration of decisions already taken before, which might be required due to new findings. The iterative procedure allows returning to previous steps (Fig. 1). The procedure identifies - after exclusion of areas with obviously unfavourable conditions - areas, regions and finally sites with favourable conditions.

The report /AkE 01/ presents, among other things, the status of the development of the geo-scientific criteria.

## **4. DEVELOPMENT OF GEO-SCIENTIFIC CRITERIA**

### **4.1. Procedure independent on host rock**

A central question for any site selection procedure is at which step in the procedure a decision on the host rocks is to be made. In a number of countries, a pre-specification takes place on one or more host rocks before performing the selection procedure.

The Committee is of the opinion that suitable repository sites do not depend on host rocks alone but rather on the integral geological settings that provide the required isolation potential. Therefore, the Committee pursues the development of a selection procedure which at first does not consider a pre-specification regarding the host rock. The selection procedure shall rather enable the identification of integral geological settings with favourable conditions for the final disposal of radioactive waste.

## 4.2. Criteria for obviously unfavourable geological conditions

The Committee agreed that prior to selection of areas with favourable conditions for the disposal, at first areas with obviously unfavourable conditions shall be excluded by criteria. These are areas which obviously are not able to satisfy the boundary conditions and evaluation basis of Chapter 2.

Four geo-scientific scenarios have been identified and corresponding exclusion criteria have been derived:

- Scenario: Extensive vertical movements  
Criterion: No uplift/subsidence of several millimetres per year during the required isolation time
- Scenario: Active disturbance zones  
Criterion: No active disturbance zones in the repository area
- Scenario: Seismic activity  
Criterion: No seismic activity greater than in earthquake zone 1 according to DIN 4149
- Scenario: Volcanic activity  
Criterion: No quaternary or expected volcanic activity in the repository region

## 4.3. Identification of a favourable integral geological setting

A favourable integral geological setting is given if the geo-scientifically investigated site characteristics can fulfil the required boundary conditions and evaluation basis of repositories with a high probability.

On the basis of international experience and evaluation of existing safety assessments, the Committee recommends the following requirements characterising a favourable integral geological setting:

- None or only slow ground water movement at repository level
- Favourable hydro-chemical conditions
- High retention potential of the rocks regarding pollutants
- Good compatibility of the rocks with gas generation
- Low tendency to build new pathways
- Favourable configuration (e.g. spatial extension) of the rock formations
- Situation which allows a good spatial characterisation of the rock formation
- Situation which allow a reliable prognosis of the long-term stability of the favourable conditions of the rock formation
- Good compatibility of the rocks with temperature changes

Features are assigned to the general requirements on a favourable integral geological setting, i.e. characteristic features concerning site ground water and rock formation. For these features, criteria are developed. If a feature cannot be measured directly or as long as a feature has not been measured, indicators are used for the assessment. The approach will be demonstrated for the requirement 'none or low ground water movement at the repository level'. The features 'migration velocity, hydraulic gradient, rock permeability', which are not directly measurable, are assigned to the requirement. Therefore, for their assessment, indicators such as rock type, temperature distribution in deep underground, ground water age and linear density increase with depth are used for which criteria are derived.

#### **4.4. Development of criteria for a favourable integral geological setting**

The following conditions apply to the derivation of criteria:

- The features to be checked must be essential for the site suitability.
- The information required for the application of a criterion must be available before or during the application of the procedure and must be interpretable with reliability.

On the basis of these conditions for the mentioned features and indicators, quantitative criteria are derived. For the derivation of the criteria, the Committee has compiled the technical and scientific state of the art. Based on the current knowledge, criteria could be derived for a number of indicators. At present, further criteria are under development. For others, the state of knowledge is not sufficient for the derivation of a criterion. Examples are listed in Table 1 /Ake 01/.

### **5. PERSPECTIVE**

During the development of the criteria, minimum requirements must be established for the features to be judged. A ranking of the requirements and features will also be carried out.

Exclusion criteria with social background will be applied to the areas with favourable integral geological settings (Fig. 1). Areas which do not satisfy these criteria are also excluded from the procedure. The remaining areas show favourable integral geological settings and are not excluded from planning for legal or socio-economic reasons.

In the next step, regions within the remaining areas are identified. Regions which offer relatively more favourable conditions for a repository than other regions must be identified within the areas. In order to do so, again a comprehensive set of geo-scientific and social-scientific criteria has to be developed. The criteria at this level have the function of weighing criteria. The significance of the geo-scientific and social scientific criteria must be evaluated so that a ranking of the regions and sites can be performed.

In this step, safety assessments have to be used to a larger extent, e.g., to be able to judge data uncertainties with regard to the isolation capability

of the geological setting. This requires increasingly concrete ideas about the repository concept. Furthermore, weighing of the criteria is required so that a ranking of the sites can be performed to identify the relatively most suitable site.

## REFERENCES

/AkE 01/ 2. Zwischenbericht des Arbeitskreises Auswahlverfahren  
Endlagerstandorte (AkEnd)  
August 2001



**Table 1: Requirements, indicators and criteria /AKE o1/**

<b>Requirement</b>	<b>Indicator</b>	<b>Criterion</b>	<b>Remark</b>
<p><b>None or low groundwater movement at repository level</b></p>	<p><b>Rock type as Indicator for the rock permeability</b></p>	<p>The rock body of the effectively enclosing geological domain shall show a low rock permeability impeding the ground water movement.</p>	<p>The results on hand must still be analysed for the derivation of a reliably applicable criterion "rock type as an indicator for the rock permeability".</p>
	<p><b>Temperature distribution in the deep underground</b></p>	<p>The temperature distribution in deep underground may not be influenced by ground water flows. The temperature signal in deeper underground caused by the last ice age may not be overwritten by advective transport of heat with the ground water.</p>	<p>With this method, unfavourable areas for the disposal of radioactive waste can therefore be identified reliably with regard to the ground water flow. Favourable areas are not recognisable reliably by an analysis of the temperature distribution.</p>
	<p><b>Groundwater age</b></p>	<p>The ground water in the host rock and the effectively enclosing geological domain must not contain tritium and/or C 14. Only if the influencing factors are known, conclusions concerning the ground water age can be drawn from the relationship between deuterium and oxygen 18.</p>	<p>The fulfilment of this criterion alone is not a sign of evidence for a sufficiently high ground water age. However, unfavourable conditions can be identified reliably with it.</p>
	<p><b>Linear increase of groundwater density with depth</b></p>	<p>In general, the indicator "mineralisation with depth/salt content with depth", is not considered appropriate for the fulfilment of the requirement "no or slow ground water movement at the repository level".</p>	<p>The indicator is derivable with an adequate data density</p>

Requirement	Indicator	Criterion	Remark
<b>Favourable hydro-Chemical conditions</b>	<b>Chemical equilibrium</b>	The deep ground water in host rock and inclusion effective geological setting shall be in the chemical equilibrium with the rocks. The evidence is to be derived from site-specific geochemical modelling.	Quantitative criteria are only derivable with knowledge of the site conditions and the repository concept.
	<b>pH-value</b>	A favourable pH range depends on the content of carbonate species in deep ground water. In general, a pH value of 7-8 of deep ground water is classified as favourable.	
	<b>Redoxic conditions</b>	Favourable redox conditions offer anoxic, reducing environments in deep ground water. The presence of iron(II) minerals in the host rock indicates favourable redox conditions.	
	<b>Colloid formation and colloid stability</b>	The content of colloids in the deep ground water shall be as low as possible. High ion strengths in deep water generally destabilise colloids and therefore have to be classified as favourable indicator.	
	<b>Complex formation with ground water solutes</b>	Content of complex builder in the deep ground water should be as low as possible. The carbonate concentration in the deep ground water should be low. The derivation of a general quantitative criterion is not possible.	
	<b>Sorption and precipitation</b>	Rocks with mineral phases which show a high reactive surface (e.g. clay minerals, Fe and Mn-hydroxide and oxyhydrate) are desirable. The sorption capacity is strongly influenced by the geochemical environment.	

Requirement	Indicator	Criterion	Remark
Good gas compatibility	Gas pressure in the repository	<p>The geological situation must be of such a quality that a pressure increase in the repository due to gas generation of the waste remains so limited that the barrier integrity and the barrier effectiveness of the isolation system is not endangered. Differences arising for dry and saturated host rocks as well as between gas developing waste and waste without internal gas production are to be regarded.</p> <p><u>Repositories in dry host rocks</u>  For the LAW/IIW waste which show an internal gas generation, countermeasures against pressure increase are appropriate waste conditioning or conceptional measures of the repository, e.g. by provision of gas collecting rooms (pore volumes).  The HAW/spent fuel waste stream does not demand any essential requirements on the effectively enclosing geological domain with regard to the gas generation.</p> <p><u>Repository in a water-saturated host rock</u>  The gas formation rate, the cavity of the repository and the hydraulic conductivity of the effectively enclosing geological domain must be matched to each other to limit the pressure build up.  An effectively enclosing geological domain is favourable with regard to the limitation of the ground water supply and to the limitation of gas generation in the case of the HAW/Spent fuel waste if the hydraulic conductivity is less or equal <math>10^{-12}</math> m/s.  For non-heat-producing waste, for which a reference gas formation rate must be assumed for the internal and external gas generation, the hydraulic conductivity of the effectively enclosing geological domain should be greater than <math>10^{-10}</math> m/s. Lower hydraulic conductivities require a reduction of the gas generation rates for these waste streams, e.g. by conditioning.</p>	<p>Check of the criteria on the basis of information on the site and repository concept  Is necessary.</p> <p>Working hypothesis:  For the preservation of the integrity and the effectiveness of the enclosing geological domain in water saturated formations, the pressure increase to be expected due to the gas generation shall not exceed 20% of the hydrostatic pressure in the repository.</p>

**Fig 1: Site selection procedure**



