AkEnd
Arbeitskreis Auswahlverfahren Endlagerstandorte

Site Selection Procedure for Repository Sites

Recommendations of the AkEnd - Committee on a Site Selection Procedure for Repository Sites

Imprint

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Printed by W & S Druck GmbH, Niehler Str. 254, 50735 Köln.

December 2002

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With the establishment of the "Arbeitskreis Auswahlverfahren Endlagerstandorte" (AkEnd) - *the Committee on a Site Selection Procedure for Repository Sites, in the following referred to as the "Committee"* - the Federal Minister for the Environment set up a discussion forum on radioactive waste disposal, which has been called for by the public for quite some time. With the support of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU), the Committee discussed the topic of waste disposal, irrespective of the different positions of the individual members concerning nuclear energy, in a constructive atmosphere contributing to find new scientific and societal approaches to solve the waste disposal problem.

A central intention of the Committee is to transfer its open attitude and the awareness to assume responsibility for the safe disposal of radioactive waste to the broad public. To this end, the Committee recommends to conduct a societal discourse, before searching a repository site, in which the relevant stakeholders and the general public develop a consensus on the procedure for selecting a repository site. The Committee expects that the result of this discussion will be validated politically and statutorily in order to achieve maximum possible legitimacy for the siting procedure.

The fears and concerns of the public have to be taken seriously. Giving priority to safety, the participation of the public in all steps of the siting process, the integration of the repository in a regional development concept and the transparency of the selection procedure as such have therefore been guiding principles in the development of both the siting criteria and the siting procedure. In accordance with the strategy of the BMU, to identify a site for the disposal of all types of radioactive waste in Germany, the Committee has formulated the following basic requirements:

- The underground repository shall be constructed and operated at a site which provides long-term safety and which is to be identified in a criteria-based selection procedure as relatively best site.

- The repository shall meet the highest safety requirements, i. e. it will be designed as not to impose undue burdens on future generations. A waste retrieval concept will not be considered in site selection, since technical provisions on this line could degrade the favourable characteristics of rocks and geotechnical barriers aiming at the long-term safety.

- A maximum possible willingness of the regional population to participate in the process is striven for from the outset. The investigation of a site depends on public assent. If the population does not declare its willingness at least at two sites, the Federal Government and the *Bundestag* (German Federal Parliament) have to take a decision on the further procedure.

- From the outset, the site selection procedure shall be closely related to the perspectives of regional development. The analysis of the given possibilities of regional development and the envisaged concepts for a future "repository region", to be established with the participation of the public, are essential elements in the identification and selection of a repository site.

Highest priority is given to the aspect of long-term safety of the repository, since the population of today as well as future generations have to be protected sustainably against hazards from radioactive material.

The public has to be extensively involved in the selection of the repository site. Continuous and independent information by the different actors on issues related to waste disposal and the selection procedure is to be given by an information platform. With regard to traceability and transparency, the selection procedure is divided into different successive steps with participation possibilities. As preparation for the decision to be taken by the public on the participation in field and underground exploration, citizens' forums are to be established in the areas concerned. Support is to be given by centres of competence with experts of their choice. A control committee consisting of independent experts and renowned public figures will monitor the progress of the procedure and respond to critical questions from the public.

With regard to the technical implementation of the selection procedure, the Committee is of the opinion that the favourable overall geological setting of a site is decisive for the safe enclosure of the radioactive waste and its isolation from the biosphere in the long term. The rock formation at the site has to ensure the isolation of the waste for a period of about one million years. The geotechnical barriers required for the repository serve the safe sealing of disposal cavities and shafts.

Regarding site selection and site assessment, the Committee differentiates between exclusion and weighing criteria. From a geological point of view, those regions have to be excluded that are characterised by high seismic activity and tectonic instability, increased uplift rates, recent volcanism and young groundwaters. If the remaining areas fulfil the minimum requirements of the Committee regarding the geological isolation of the radioactive waste, the specific site characteristics are assessed by means of weighing criteria. In this respect, geological safety reserves and the aspect of reliability of proof play an important role. It is necessary to perform safety analyses to evaluate the results from field and underground exploration and to confirm site selection.

The same applies to the regional planning criteria. Areas, such as national parks, protected areas and groundwater catchment areas, are protected to such a degree that they are generally not available for the siting of a waste repository. However, these areas can be checked case by case in which the public interest in a repository and the status quo to be protected are weighed up.

The Committee attaches special importance to the socio-economic criteria related to the region and the site. With the help of so-called potential analyses, the development possibilities of a potential “repository region” are to be determined. Important indicators are developments in the labour market, the housing market and future investment volume. Regional development models are to be drawn up together with the citizens and in agreement with the regional planning offices.

The willingness of a region to participate is an essential element of the selection procedure. Despite the doubts expressed by different sides that regions can be found in which the majority of the population argue for a repository, the Committee is of the opinion that a willingness to participate can be achieved in case of sufficient preparation and after intensive discussion. It is important that the consent to field exploration and the following underground exploration will be determined in separate steps. With regard to the enormous technical efforts and the considerable financial resources required, it has to be made clear to the public that, in case of a favourable result, the site will in all probability be chosen for disposal. In any case, the Committee additionally proposes a final vote which may serve the *Bundestag* as orientation guide prior its decision on the nomination of a waste disposal site.

A credible site decision requires that underground exploration and safety assessments are performed at least at two sites. It requires further that the development potential is assessed taking into account the regional planning measures of the regions. Finally, it requires that the population of each region approve the construction of a repository. These conditions have to be met before the *Bundestag* with the participation of the *Länder* takes the decision on the repository site.

The proposals of the Committee will only be successful if the political will of the Federal Government on the construction of a repository is made clear to the public by appropriate actions and communications. The impulse gained by the activities of the Committee should be used now to achieve visible progress in site selection in the near future.

On its own account, the Committee underlines that it consensually developed the proposals in this recommendation with regard to scientific-technical criteria and public participation on the basis of experiences in Germany and abroad and against the background of the needs of a modern democratic society.

1 The Committee on a Site Selection Procedure for Repository Sites

World-wide, there is to this day no repository for spent fuel elements from nuclear power plants and high-level radioactive waste from reprocessing. In Germany, the Gorleben salt dome has been explored with regard to its suitability as repository for all types of radioactive waste since 1979. However, the Federal Government has doubts concerning the suitability of Gorleben. Therefore, it suspended exploration on 1st October 2000 for a period of between three and a maximum of ten years in agreement with the electric power utilities in order to clarify conceptional and safety-related issues (Moratorium) [BMU 2000].

For the safe long-term disposal of radioactive waste, the Federal Government sees no alternative to disposal in deep geological formations. This is why the Government intends to investigate further sites in different rock formations and to explore them with regard to their suitability to host a repository.

This raises the question of how suitable sites for repositories can be identified and at the same time find public acceptance.

1.1 Installation

Against this background, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) established the Committee on a Site Selection Procedure for Repository Sites (in the following referred to as the "Committee"). The recommendations of the Committee serve to support the Federal Government in the performance of its task, according to Para. 9 a Section 3 of the Atomic Energy Act (AtG) [ATG 2002].

The Committee is a technical-scientific body working independently and free of directives within the framework of the established objectives. As to the appointment of the Committee members, the BMU has sought a balance with regard to persons and institutions to ensure that the wide spectrum of opinions held among experts on the topic of disposal is represented on the Committee.

The members of the Committee are experts in the fields of geosciences, social sciences, chemistry, physics, mathematics, mining, waste management technology, engineering and public relations. Annex 1 includes the profiles of the members. Fig. 1.1 shows the members of the Committee and the persons involved from BMU/BfS, the Federal Ministry of Economics and Labour (BMWA) and CCM, who took part in a Committee meeting in Braunschweig on 29th August 2002.

Fig. 1.1: The members of the Committee at the Old City Market in Braunschweig (from left: M. Sailer, D. Ipsen, B. Thomauske, D. Appel, R. Wernicke (BMU), B. Baltes, W. Brewitz, J. Kreusch, A. Nies (BMU), G. Jentzsch, V. Bräuer, G. Arens (BfS), K. Kühn, H. Alder (BMU), G. Bäuerle (BMWA), H.-J. Haury, A. Wiederhold (CCM), R. Gömmel, K.-H. Lux, K. Duphorn)

The Committee wants to express its thanks for the support received in its work from numerous sources. Special thanks, however, go to Alexander Nies and Dr. Rolf

Wernicke from BMU as well as Georg Arens and Ms. Heinke Hagge from BfS. Without their dedicated and continuous commitment to all issues dealt with by the Committee, especially during the numerous meetings and events of the Committee, its discussions and debates would not have been as target-oriented as they can now be documented in this final report.

Ms. Anette Wiederhold of CCM Cologne was responsible for all organisational matters. She also deserves special thanks for her effective work.

An editing team, consisting of Ms. Eva Hartmann (Öko-Institut e. V.), Thomas Beuth and Dr. Jörg Mönig (GRS), significantly contributed to the preparation of this final report. They also deserve the thanks of the Committee for their efforts.

1.2 Task and political general requirements

The Committee had been commissioned to develop a traceable procedure for the identification and selection of a site for the disposal of all types of radioactive waste in Germany. The procedure was to provide for public participation in an appropriate form and to include substantiated criteria. The development was to take place on a scientific basis in an objective and unprejudiced manner without exclusion of relevant aspects. In this respect, the procedures and experiences in other countries were to be taken into account. The Committee was to discuss its considerations both with the corresponding experts on a national and international level and the general public during the development of the procedure.

As general requirements for the development of the procedure, the BMU specified the following objectives:

- All radioactive waste shall be disposed of in deep geological formations in Germany.
- For the disposal of all types and quantities of radioactive waste, one repository is sufficient, to be operational from 2030 onwards.

It was not the task of the Committee to implement the procedure, to apply the procedure or the criteria to the selection of or for a judgement on the suitability of Gorleben or Konrad, or to choose or assess other sites.

1.3 Way of working and organisation

At completion the Committee consisted of 14 members. During its working period of nearly four years, there were only four changes within the Committee. Here, attention was always paid to retaining the balance of Committee members. During the work of the Committee, this balance, in particular, turned out to be a motor for discussions and helpful for the quality of the work. The Committee strived to reach decisions in consensus. This aim was achieved in all issues, whilst paying attention to not impairing the quality of the Committee’s recommendations with regard to their contents. Divergent scientific opinions would not be overruled, but documented.

In accordance with the focal points of its work, the Committee had set up two working groups, the Working Group Criteria and the Working Group Public Relations. These consisted of five and seven members, respectively, designated by the Committee from among its members. The other members of the Committee were free to participate.

From the outset, the Committee had been seeking intensive interaction with interested members of the public to both consider all relevant aspects and to ensure the transparency of its activities. Moreover, the Committee also informed itself on activities in other countries on site. In this respect, the Committee placed special importance on receiving direct information from different stakeholders. The rounds of talks and information visits are documented in detail in Annex A.2.

In addition, the Committee was supported by research and advisory services. The allocation of contracts and the technical support for these tasks were managed by the Federal Office for Radiation Protection (BfS) and the BMU. The work resulting from these contracts is listed in Chapter 8.2.

Organisational support was provided by the CCM Cologne Corporate Communication Management GmbH.

The BMU assisted the Committee in its organisational and scientific work and ensured the availability of adequate financial means.

1.4 Communication with the public

The Committee regards the selection of repository sites as a task that lies within the responsibility of society as a whole. For this reason, the Committee informed the public about its work and offered the possibility of obtaining direct information and to give suggestions and feedback to the Committee. With its public relations work, the Committee also wanted to improve the prerequisites for the later participation of the public in the agreement on and implementation of the selection procedure. In order to achieve these objectives, the Committee

- hosted three public workshops,
- was in dialogue with, e. g., the members of the *Bundestag* and the *Länder* Parliaments, associations, churches, trade unions, citizens' initiatives and other stakeholders,
- informed about its work progress via the Internet (www.akend.de) where it was also possible to send suggestions per E-mail, and
- informed about current topics in two progress reports and at two forums, thus providing a platform for the guests to present their personal views.

In addition, members of the Committee

- held lectures and
- had personal talks with interested persons.

The Committee attached importance to getting to know the opinion of the general public about disposal and the wish of the population to participate in the selection procedure for repository sites. For this purpose, representative polls were conducted by the Institute for Technology Assessment and Systems Analysis (ITAS) in the years 2001 and 2002. The results are discussed in Chapter 2.3.

The results of the polls support the recommendation of the Committee to involve the population and the stakeholders in the agreement on the selection procedure before the actual selection procedure is started.

The Committee would like to thank all those involved in the discussion and who contributed to the development of a safe solution and a socially acceptable approach for the selection of a site for the disposal of radioactive waste.

2 Fundamentals

In this chapter, the Committee explains the essential fundamentals for the development of the selection procedure for repository sites. These are the general requirements which were to be fulfilled by the Committee, which include the protection goals and safety principles, type and quantity of the waste to be disposed of, as well as the basic requirements of the BMU for the development of the procedure. This is supplemented by specifications which the Committee itself laid down as general requirements for its work after weighing of the different alternatives. These include the specification that the geological barrier shall bear the main load with regard to long-term safety and the non-consideration of retrievability. The reasons for the agreement on a certain alternative are presented respectively. Moreover, international approaches and experiences are a valuable source used by the Committee in its work. These will be presented, as well as the general importance of public participation from the Committee’s point of view.

2.1 Technical general requirements

2.1.1 Protection goals and safety principles

For the disposal of radioactive waste material two essential protection goals are pursued:

- Long-term protection of man and the environment against potentially hazardous effects of the release of harmful substances from the waste packages.

- Avoidance of imposing undue burdens and commitments on future generations (no post-closure maintenance)

The protection goals have to be further specified to be suitable for consideration in the development of the site selection procedure. In this respect, the safety principles are referred to, as formulated by the International Atomic Energy Agency (IAEA) in 1995 [IAEA 1995], as stipulated in the "Joint Convention on the Safety of Spent Fuel

Management and on the Safety of Radioactive Waste Management" (IAEA 1997), and as adopted by the European Community [ÜBEREINKOMMEN 1997], which has been enacted in Germany since 2001:

- Disposal has to ensure that man and the environment are adequately protected against radiological and other hazards.

- The potential consequences for man and the environment resulting from disposal shall not exceed the degree of consequences accepted today. Undue burdens shall not be imposed on future generations.

- The potential transboundary consequences for man and the environment from disposal must not exceed those permissible within Germany.

The standards established in the German legislation meet the requirements regarding the above-mentioned protection goals and safety principles. The risk awareness is implied in the Atomic Energy Act (AtG). Further safety principles to be applied in the operating phase of a repository are based, in particular, on the Radiological Protection Ordinance [STRLSCHV 2001], according to which

- each unnecessary radiation exposure or contamination of man and the environment has to be avoided, and

- each radiation exposure or contamination of man and the environment including those below the limit values has to be kept as low as possible in accordance with the state of the art in science and technology and in consideration of all circumstances of the individual case,

as well as on the Safety Criteria [BMI 1983] and the Convention of 1997, according to which

- radionuclides which might be released from a sealed repository into the biosphere due to migration processes, which cannot be ruled out completely must not lead to individual doses exceeding the effective dose of 0.3 mSv per year. This value corresponds to the mean range of natural radiation exposure in Germany.

The above-mentioned safety criteria are currently being revised.

In order to be able to comply with the protection objectives, the International Commission on Radiological Protection (ICRP) recommends the optimisation of radiation protection in all phases of dealing with disposal to limit potential releases in the post-operational phase, particularly also with regard to the site selection [ICRP 1998]. This implies the application of a qualified site selection procedure on the basis of a defence-in-depth concept (multi-barrier system) and the selection of a robust site.

Regarding disposal in geological formations, the following basic requirement according to the Federal Water Act (WHG) [WHG 2002] has to be observed:

- Material must only be stored or disposed of in such a way that there is no need for concern about harmful pollution of the groundwater or any other negative change to its properties.

On this item, the Committee notes that in case of a strict interpretation only the complete confinement of the waste in the repository meets this basic requirement. Under this aspect, a repository in rock salt clearly has advantages compared to other barrier rocks.

If the long-term safety of the repository is demonstrated regarding the adherence to "significance thresholds" or "immission neutrality", the water authority may grant a permit in accordance with the water law. Even if the conditions for granting a permit are fulfilled, the grant is at the discretion of the authority. It considers the aspects of weighing and appropriateness, which means that the competent water authority plays a decisive role. Thus, the feasibility of a repository in groundwater-bearing rocks involves a licensing risk.

For the later licensing of a repository it is of great importance that the selection procedure for repository sites aims at the selection of geological overall settings which ensure the best possible "confinement of the waste". This includes that the confinement in groundwater-bearing formations should preferably be in a small isolating rock zone and that the amount of contaminated water should be small (limitation to the emplacement area). This has to be achieved in a reliable and long term manner by a combination of geological and technical barriers in order to meet the requirements of the water law protection goal.

The Committee sees no need for general changes regarding the development of the selection procedure due to the requirements of the Federal Water Act (WHG). Against the background of the WHG, great importance is attached to the isolating rock zone which in normal repository development and together with the technical and geotechnical barriers has to ensure the confinement of the waste for the isolation period. This has to be considered when weighting the criteria for a favourable overall geological setting. The Committee recommends the development of a regulation which clarifies the application of the WHG for disposal in deep geological formations.

2.1.2 Radioactive waste

The majority of the radioactive waste is produced by the use of nuclear energy for electricity generation. This concerns, above all, waste from reprocessing spent fuel elements, the spent fuel elements (FE) themselves, and waste from the operation and decommissioning of nuclear power plants or other installations of the nuclear fuel cycle. With the 9th amendment of the Atomic Energy Act of 27 April 2002, which limits the amount of electricity generated by nuclear power in Germany, the overall volume of radioactive waste is now restricted.

To a lesser extent, radioactive waste also arises from research, medical and industrial applications. For these types of waste it is necessary that long-term disposal options be provided even beyond the point of termination of the use of nuclear power for electricity generation.

In addition to the classification as high active waste (HAW), medium active waste (MAW) and low active waste (LAW), in Germany, distinction is made between heat-generating waste and waste with negligible heat generation with regard to waste disposal. The total amounts of these waste categories accumulated in Germany up to 2040 are shown in Table 2.1.

Table 2.1: Accumulation of radioactive waste up to 2040 [m^3]

	Volume	Prognosis	Prognosis	Prognosis	Prognosis	Total
	End of 2000	**2001 – 2010**	**2011 - 2020**	**2021 - 2030**	**2031 - 2040**	
Waste with negligible heat generation	76,000	58,000	54,000	76,000	33,000	297,000
Heat-generating waste	8,400	9,200	5,700	700	about 27	24,000

The heat-generating waste contains about 99% of the radioactivity of all wastes. They mainly consist of long-lived radionuclides and account for about 10% of the total waste volume. In particular, the highly heat-generating waste, i. e. vitrified HAW from reprocessing or spent fuel elements, is placed in interim surface storage for some decades to enable a reduction of the heat output for safety-related and economic reasons before disposal. This period can be reduced by optimisation of the geometric design of the repository.

The waste with negligible heat generation accounts for about 90% of the total waste volume, but contains only about 1% of the radioactivity. As soon as a repository is available, it can be disposed of after appropriate conditioning without storage at an interim storage facility. Almost all of the heat-generating waste is produced by the electric power utilities, whereas about one third of the waste with negligible heat generation comes from public facilities.

The expected temporal accumulation of heat-generating waste and waste with negligible heat generation is presented in the two following Tables 2.2 and 2.3, taking into account the nuclear phase-out stipulated in the agreement of 14th June 2000 and in the 9th amendment of the Atomic Energy Act [ATG 2002].

*Table 2.2: Accumulation of heat-generating waste up to 2040 [m³] **

	Volume end of 2000	Prognosis 2001 – 2010	Prognosis 2011 – 2020	Prognosis 2021 – 2030	Prognosis 2031 – 2040	Total	Total volume
	Number						[m³]
HAW canisters	84	4,582	112	0	0	4,778	908
MAW (Q) packages	0	840	7,576	2,400	0	10,816	2,814
Spherical AVR + THTR fuel elements	908,705	0	0	0	0	908,705	1,920
	Mass [Mg]**						
LWR fuel elements	3,142	3,962	1,819	24	0	8,947	18,258
VKTA fuel elements	2.3	0	0	0	0	2.3	49
FRM-II fuel elements	0	0.35	0.35	0.35	0.35	1.4	108
						Total	24,000

* Boundary conditions:		Explanations:
HAW:	4,778 canisters x 0.19 m^3	vitrified waste from reprocessing
MAW (Q):	8,764 canisters x 0.19 m^3	conditioned medium active reprocessing waste
	2,052 drums x 0.56 m^3	
AVR+THTR:	457 Castor THTR x 4.2 m^3	fuel elements from high-temperature reactors AVR and THTR
LWR:	1,790 POLLUX x 10.2 m^3	fuel elements from light-water reactors
VKTA:	18 Castor MTR2 x 2.7 m^3	fuel elements from the Rossendorf Research Reactor
FRM-II:	40 Castor MTR2 x 2.7 m^3	fuel elements from the Forschungsreaktor München II

** 1 Mg = 1 ton.

Table 2.3: Accumulation of waste with negligible heat generation up to 2040 [m³]

	Volume end of 2000	Prognosis 2001 – 2010	Prognosis 2011 – 2020	Prognosis 2021 – 2030	Prognosis 2031 – 2040	Total
Electric power utilities	23,000	31,000	46,000	73,000	22,000	195,000
Public sector	53,000	27,000	8,000	3,000	11,000	102,000
Total	76,000	58,000	54,000	76,000	33,000	297,000

The volumes of the heat-generating waste to be disposed of also depend on the host rock formation of the repository and the disposal technique to be applied. The conversion of the amounts of high-active waste into volumes is based on the repository conception pursued until now for a repository in the Gorleben salt dome. Thus, the following explanations have to be made on the volumes of heat-generating waste of about 24,000 m^3 in Table 2.2:

1. HAW canisters: When constructing a repository in salt, these canisters shall be emplaced in deep boreholes stacked on top of each other without additional containers. The gross volume of a canister is 0.19 m^3 with a diameter of 430 mm and a length of 1,345 mm.

2. Conditioned medium-active waste from reprocessing in France is packed in canisters of the same dimensions and the same volume so that the same disposal technique can be applied for their disposal in a repository in salt.

   Conditioned medium-active waste from reprocessing in Great Britain is packed in stainless steel drums with a volume of 0.56 m^3 each. These can either be stored in boreholes or in drifts.

3. About 910,000 spherical fuel elements, the size of a tennis ball, originating from the operation of the decommissioned AVR- and THTR-reactors are currently packed in 457 containers of the CASTOR-THTR type with a gross volume of 4.2 m^3 each. 305 of these containers are stored at the Ahaus interim storage facility and a further 152 at the Research Centre Jülich. Whether these containers can also be directly disposed of in a repository is subject to an examination still to be performed.

4. Irradiated LWR fuel elements: Two packing techniques have been tested or developed, respectively, for the disposal of these fuel elements in a repository. The first technique includes the packing of pulled fuel rods into POLLUX containers especially designed for disposal. The loading of POLLUX containers with a gross volume of 10.2 m^3 (length 5,517 mm, diameter 1,560 mm) and a gross weight of 65 Mg requires the operation of a corresponding conditioning plant. A POLLUX container can be loaded with 5.5 Mg of heavy metal which is equivalent to the fuel rods of ten PWR-FE or thirty BWR-FE. For disposal of

POLLUX containers in a repository in salt, the emplacement technique in drifts has been developed and tested.

As an alternative to this large container the so-called fuel rod canister BSK 3 (also referred to as ELB 3) has been designed. The number of fuel rods that can be packed in two of them is equivalent to three PWR-FE or nine BWR-FE. The loading of the BSK 3 also requires the operation of a corresponding conditioning plant. The BSK3 diameter of 430 mm is identical to that of a HAW glass canister so that the same technique as used for HAW canisters can be applied for their disposal in deep boreholes in salt.

5. The 951 irradiated fuel elements with 2.3 Mg of heavy metal from the decommissioned Rossendorf Research Reactor have been packed by the Nuclear Engineering and Analytics Rossendorf Inc. (VKTA) into 18 containers of the CASTOR-MTR 2 type with a gross volume of 2.7 m^3 each and are currently stored at the Rossendorf site.

   It is intended to pack the fuel elements of the Forschungsreaktor München II (FRM-II) into containers of the same type.

   The resulting number of 58 CASTOR-MTR 2 containers (18 from Rossendorf, 40 from Munich) account for a total disposal volume of 157 m^3.

The sum of the described package volumes and their number leads to a total volume of about 24,000 m^3 of heat-generating waste.

Due to its radiation and heat output, heat-generating waste demands increased requirements on the host rock envisaged for disposal. Potential negative radiation effects can be compensated by shielding. Crucial for the design of a repository is, above all, the heat production of the spent fuel elements from light-water reactors which are disposed of directly, followed by that of the HAW canisters. All other heat-generating waste plays a minor role with regard to the heat input into the repository and also with regard to the radioactivity of the mainly long-lived radionuclides.

Waste with negligible heat generation is generally conditioned in a less qualified manner and is more heterogeneous in its composition compared to heat-generating waste. In principle, it can be assumed that it releases gases into the repository due to internal processes. Although the volume of waste with negligible heat generation is much larger compared to that of heat-generating waste, the rock volume required for its disposal is considerably smaller.

If humidity enters the repository and the waste packages, gas generation due to corrosion of the containers is to be expected both in the cases of heat-generating waste and waste with negligible heat generation.

2.1.3 Establishment of a repository in Germany until 2030

As general requirements for the development of the procedure, the BMU specified the following objectives:

- All radioactive waste shall be disposed of in deep geological formations in Germany.
- For the disposal of all types and quantities of radioactive waste, one repository is sufficient, to be operational from 2030 onwards.

The Committee confirms the specification of the BMU that in Germany the main emphasis shall be placed on disposal. Therefore, the Committee based its development of a procedure on conditions, knowledge and data in Germany and developed a selection procedure for repository sites in Germany.

The Committee thinks that the Federal Government's aim to have a repository ready for operation by the year 2030 is very ambitious in view of the tasks to be coped with within this period. Nevertheless, the Committee is of the opinion that the selection procedure is laid down so as to enable the selection of sites for underground exploration by 2010. This, however, requires the rapid legitimisation and implementation of the selection procedure.

The requirements on waste disposal in deep geological formations and the disposal of all types of radioactive waste in a repository, as well as the alternatives of disposal are discussed in the following chapters in detail.

2.1.4 Disposal in deep geological formations

As an essential general condition for the work of the Committee, the BMU decided that all radioactive waste shall be disposed of in deep geological formations in Germany. Disposal at a carefully selected and explored site in deep geological formations guarantees that the waste is isolated from the biosphere for very long periods of time. The disposal of the waste should be maintenance-free and with few controls. Owing to the depth and the corresponding great distance of the waste emplaced to the biosphere, neither social changes, changes in the surface-near utilisation of the site, nor climatic changes can put the isolation of the waste at risk. Therefore, undue burdens will not be imposed on future generations after the establishment and sealing of the repository.

In several countries, which also pursue the disposal of high-level waste in particular, corresponding political preliminary decisions have been made. Extensive research and development procedures are being conducted. Some countries have already initiated a preselection of sites. With the aim of establishing the scientific and technical prerequisites for the concrete planning of such repositories, work is taking place at various underground laboratories world-wide. Moreover, repositories in geological formations already exist in Sweden and Finland for low- and medium-active waste and in the USA for long-lived transuranic waste. On the basis of international expertise, the IAEA and the OECD/NEA have developed principles for planning and safety regarding this approach to waste disposal.

The question of whether there are any alternatives to disposal has often been dealt with in the Committee's discussions with the general public. Ethically founded principles, such as the demand to keep various options for action open for future generations, but also the question of resources protection, play an important role in this respect. Against this background, the Committee has evaluated the internationally most widely discussed alternatives:

- Long-term interim storage or retrievable disposal of radioactive waste
- Partitioning and conversion (transmutation) of long-lived and highly toxic radionuclides into less toxic radionuclides that are as short-lived as possible

As concerns long-term interim storage and retrievable disposal, (long-term) safety would have to be guaranteed by long-term social control. This presupposes the continuity of the present economic and scientific capabilities and the ability and willingness of all members of society to carry out the controls and necessary measures. Examples from the past have shown that this cannot be assumed. Moreover, predictions of longer-term social development bear considerably larger uncertainties than predictions of the functional efficiency of geological barriers acting as passive safety systems of a backfilled and sealed repository.

Besides, the demand to keep various options for action open for future generations also presupposes the continuity of the present economic and scientific abilities and skills as well as the willingness of society. Should social upheavals occur, such as wars or the like, that involve negative consequences for the economic and scientific capabilities, then the fact that certain options have been kept open will have exactly the opposite effect: future generations will no longer be able to attend to the waste, with the consequence that safety will be jeopardised and the freedom to act restricted. What needs to be recognised as well is that by shifting the final decision to future generations, the polluter-pays principle is also violated.

For the second alternative – the partitioning and transmutation of radionuclides – it is necessary to operate chemical and nuclear facilities of which the risks involved (including those of the proliferation of fissile radioactive material) are by all means higher than the risk posed in the long run by a repository. The only economically sensible way to pursue such a waste management path would be to establish a branch of nuclear industry that would be solely dedicated to the partitioning and transmutation of radionuclides. This, however, is contrary to the phase-out spirit of the Atomic Energy Act. Besides, a complete transmutation of all radionuclides is not possible. In any case, the remaining amount would have to be disposed of as long-lived radioactive waste. Transmutation does therefore not present a real alternative.

For these reasons, the Committee sees no alternative to the long-term safe disposal of radioactive waste other than the disposal in deep geological formations. From the point of view of the Committee, their general advantage is that certain rock formations only show low permeabilities for fluid phases or that they are even water tight in the technical sense due to their physical and chemical properties and the rock formation. Partly, their properties have remained unchanged over geological periods of time so that they are able to isolate hazardous substances from the biosphere for periods in the order of magnitude of one million years. A prerequisite, however, is the identification of suitable rock zones, e. g. by means of a criteria-based site selection procedure.

In addition to the concept of isolation in deep geological formations, there are several other disposal alternatives which have been discussed in the past and which were and are partly being practised, as for example

- transport into space,
- disposal in the Antarctic ice,
- dumping of radioactive waste at sea,
- sub-seabed disposal,
- near-surface disposal, and
- interim storage at near-surface facilities.

Transport into space is a proposal which had mainly been discussed in the USA in the early phases of concept drafting for the disposal of long-lived radioactive waste. This idea has the advantage that the radioactive waste will be permanently removed from the human habitat. Due to the costs involved, this concept alternative is only applicable to very small quantities of waste. In addition, there is a considerable risk with incalculable consequences. If a world-wide acceptance of this way of disposal could be achieved at all, so it would remain limited to only a few countries due to its sophisticated technology.

A concept for waste isolation is presented by the **disposal in the Antarctic ice**. In large areas the Antarctic ice is 15 million years old and up to 4 km thick. There are no doubts that this situation will not change basically in the foreseeable future. However, there are essential questions to be solved regarding the geophysical and geochemical properties of the ice masses and their impact on the global climate. Likewise, changes in the internationally applicable legal provisions and political agreements would be required. There is no country world-wide currently pursuing such a concept.

The **dumping of low- and medium-active waste at sea**, as it was permitted in accordance with clearly specified conditions of the IAEA, has not been practised since 1983 in accordance with a voluntary moratorium, and was banned in 1993 by the contracting parties to the London Convention. The concept was aimed at the disposal of short-lived waste at sea depths where an exchange between water layers – with the corresponding consequences for potential radionuclide diffusion - only takes place restrictedly due to reduced flow and high water density. Dumping high-active waste at sea with long-term application of the dilution principle has not been taken into consideration seriously by any country until now.

Another option for disposal, analysed by some member states of the OECD/NEA at the beginning of the eighties, is the **disposal of high-active waste in the sea bed**. The deep-sea beds of oceans have favourable properties in large areas and their thick sediment layers have a high retention potential. The probability of an accident is relatively low. However, there are no tried and tested technologies available for the opening up of such a repository and the corresponding emplacement of waste. Such an option would require an amendment of the mentioned international Convention. This option is not being pursued actively world-wide.

The **near-surface disposal** of low- and medium-active waste represents the state of the art in science and technology today. Many countries, also in Europe, operate such repositories. Here, the isolation of the waste material for the required, relatively short periods of time (in general less than 1,000 years) is ensured by the selection of a suitable subsurface with a geological barrier and by the construction of technical and geotechnical barriers. In addition, the facilities are being monitored. After clearance measurements, such repositories shall be transferred to the status of a normal storage site. Such a concept is a priori not applicable to high-active waste due to the long decay times.

The **near-surface interim storage** of radioactive waste is practised in several countries with the declared intent to finally remove this waste and store it in a repository after a decision on a concept and a site. Partly, there are concrete legal provisions according to which interim storage is only permitted for a specified time frame (some decades) and the availability of a repository is required. In this case, interim storage presents a technical and administrative preliminary stage to disposal, which is subject to a strict institutional control. This also applies to the interim storage facilities in Germany.

In some countries, where there is no final concept for the disposal of waste, the long-term interim storage of the spent fuel elements represents an alternative to final disposal, at least for the foreseeable future. In this respect, questions arise concerning the life time of the technical components and the nature of future social systems. Since the access to interim storage facilities is generally possible any time and with relatively simple means, permanent monitoring is required to prevent the use of nuclear fuels for military or terrorist purposes. This implies a very far-reaching requirement regarding sustained stability of today's social system with its ethical values and standards for a long period of time. Experience shows that a substantiated prediction on this issue cannot be made.

In summary, it can be stated that the disposal in deep geological formations after appropriate site selection, i. e. in the case of a favourable overall geological setting at the envisaged site (simple geological-tectonic structure, non-existence of deep aquifers with meteoric water, no recent tectonic activities, rocks with low permeability and good retention potential for radionuclides, favourable rock-mechanic properties of the repository formation) has decisive advantages in comparison with other disposal options on the earth. These are, above all

- a large distance between waste and biosphere,
- a good long-term isolation capacity for radionuclides,
- extrapolability of the development of a repository over long periods of time due to verifiably slow changes of the geology in the past,
- repair and long-term monitoring of the repository are principally not required after sealing and backfilling of a repository, and
- anthropogenic impacts have little impact on safety.

Thus, radiation exposure of man and the environment resulting form the waste disposed of can be excluded for very long periods of time. Human intrusion into a sealed repository in deep geological formations in case of war or by terrorism is highly improbable. The long-term behaviour of deep geological formations can be better predicted than the development of human society.

The disadvantage of disposal in deep geological formations is – compared with the longevity of the waste – a monitoring of the processes taking place in a repository, such as geochemical processes, can only be performed over a relatively short period, and then only in a limited way. Any misjudgements might possibly be recognisable only after much longer periods. In this case, a wrong siting could not be corrected and repair measures in the repository itself could no longer be taken.

All this results in great demands on the site selection procedure, on the verification of the suitability of a repository and, in particular, on the procedure for the proof of long-term safety. In this respect, it has to be considered that essential basic principles for the assessment of long-term safety and the achievable prediction reliability have to be provided during the siting procedure. Therefore, the procedural methods applied have to be appropriate and conclusive, the procedures have to comply with the legal and social boundary conditions in an adequate and binding manner and have to be understandable to persons not technically involved. This also involves the explanation of the basic scientific-technical principles and the international state of the art in science and technology.

2.1.5 Consequences of the single-repository concept

As a second political general condition for the development of the procedure, apart from giving preference to disposal in deep geological formations in Germany, the BMU decided that one single repository shall suffice for all types and amounts of radioactive waste. The Committee has checked whether this may result in any special aspects for the development and implementation of the search and selection procedure for a repository site. In this context, the Committee has concentrated on assessing scientific and technical issues.

The Committee has arrived at the conclusion that the proposed selection procedure for the search for a repository site for all kinds of radioactive waste is in principle suitable in the same way as it is for the search for a repository site for just certain types of radioactive waste.

However, the stipulated repository concept may have an influence on the relevance and weighting of individual criteria that have to be applied in the search for a site and the eventual site selection. Furthermore, special requirements may ensue, e. g. with regard to the size of the repository area. It is therefore conceivable that different sites will be identified with the help of the search and selection procedure, depending on which repository concept is applied. From the point of view of the Committee it is thus necessary that it should be specified prior to the application of the procedure at which types of waste the search for a repository is directed. What applies in general is that if all types of waste are disposed of at one single site, all requirements resulting from these different types of waste have to be equally fulfilled. It therefore has to be expected that the number of sites that are potentially suitable to take all kinds of waste is lower than the number of sites suitable for just certain types of waste.

In the analysis of the consequences of the single-repository concept for the selection procedure carried out by the Committee [AKEND 2002], the technical-scientific assessment fields concentrated on aspects related to disposal concepts, long-term safety of the repository and the methods to furnish proof on long-term safety. Under the aspect of long-term safety, the Committee primarily dealt with the safety-related consequences of heat input, gas generation and the chemical interactions between the different types of waste.

Against this background, the Committee arrived at the following conclusions:

- The spatial separation of different waste types, in particular of HAW/BE und LAW/MAW, is indispensable under the aspects of safety and its proof.
- This spatial separation of different waste types in case of a single-repository concept involves greater efforts compared to the distribution of the different waste types to, e. g., two repositories.
- For a single-repository concept, the long-term safety assessment might be more difficult to perform than in the case of a distribution of the waste to, e. g., two repositories.
- In the case of a single-repository concept, the identification of favourable overall geological settings/sites fulfilling all requirements optimally will probably be more difficult and the number of corresponding regions/sites limited.

Regarding gas generation, considered to be of particular safety significance, the required long-term isolation of the waste against groundwater-transport on the one hand and the prevention of critical gas pressures in the repository on the other hand, are requirements on the geological site conditions that, in part, are difficult to reconcile. This problem cannot be solved by spatial separation alone and may require technical measures.

2.1.6 Isolation period

The aim of disposal is to isolate the waste safely from the environment. The quality of the isolation decisively depends on the period during which the radioactive material is retained in the isolating rock zone of the repository. The site shall be selected in a manner that a longest possible isolation period is achieved. In this respect, both the time periods of radiotoxicity and the half-lives of the radionuclides in the respective waste spectrum as well as the geological time periods have to be considered, for which practically reasonable predictions can be made according to the state of scientific knowledge.

The objective of the selection procedure is to find sites which have favourable overall geological settings for the implementation of a repository for all types of radioactive waste. The radioactive waste also contains radionuclides with half-lives which are longer, by far, than the periods for which practically reasonable predictions on geological developments can be made. This applies, in particular, to the uranium contained in the spent fuel elements. Nature shows that a number of uranium ore deposits can be enclosed by rocks over geological periods of time without negative effects on the biosphere.

With regard to the requirement of isolation of radioactive waste from the biosphere it can be stated that certain rock formations only show low permeabilities for fluid phases or that they are even water tight in the technical sense due to their physical and chemical properties and to the type of rock formation. Any well-founded predictions of the future evolution of such rock formations and their properties can only be made if the geological setting and its geological history are taken into account. Here, the prediction period is closely related to knowledge of geological evolution in the past. If the evolution of such a geological system can be traced back over many millions of years and can be scientifically interpreted and if furthermore no major changes of the safety-relevant features of this geological system are registered, justified predictions about its future evolution can be made that lie within an order of magnitude of one million years. This is the case for large areas in Germany.

The Committee is of the opinion that, according to scientific knowledge, practical and reasonable predictions of the geological evolution of sites in favourable areas, as they exist in Germany, can be made for a period in the order of magnitude of one million years. These are the prerequisites for furnishing proof on the long-term safety of a repository in a licensing procedure at a later stage.

For the development of quantitative criteria for the identification of repository sites with favourable overall geological settings, the Committee defined that the isolation period shall lie within an order of magnitude of one million years.

2.1.7 Retrievability

Retrievability means the possibility to retrieve waste from a repository in case of demand according to a plan and without major technical efforts. Retrievability of radioactive waste is an issue discussed internationally and concentrates on the retrieval of spent fuel elements. The arguments for retrievability are mainly safety-related, ethical and economical. These arguments, especially the safety-related ones, are disputed.

For all internationally discussed plans on retrievability, final disposal is still the ultimate objective. Before disposal can be realised, several phases have to be carried out with step-by-step backfilling of disposal sections, access drifts and shafts. The access to the waste becomes increasingly difficult with each phase and the technical effort required for the retrieval also increases. After sealing the repository, retrieval will only be possible using mining techniques. There are no uniform concepts on the precise proceedings and durations of the different phases. As for the period for which relatively simple technical retrievability is possible , several decades up to several centuries are being internationally discussed.

The technical realisation of retrievability concepts depends, among other things, on the host rock. The different mechanical properties of the rocks require respective technical solutions and different effort to maintain the accessibility of the waste. Therefore, the intention of retrievability may influence the decision in favour of or against certain host rocks as well as the site selection. However, up to now, retrievability has never been considered in any selection procedure for repository sites.

Against this background, the Committee had to clarify whether retrievability has to be considered for the site selection, and if so, in which manner. Such a consideration presupposes that retrievability is consistent with the following safety-related principles of the procedure development:

- Regarding the development of the selection procedure, the geological barrier is the most important criterion (see Chapter 2.1.9).
- The selection procedure shall serve to identify areas, regions and sites with particularly favourable overall geological settings with regard to long-term safety.

This ensures that the long-term safety of the repository is based on a carefully selected passive and thus maintenance-free safety system. Without the phase of retrievability with facilitated access to the waste, the passive safe repository condition is reached as quickly as possible.

If facilitated retrievability of the waste is considered to be possible, the passive safe condition will be reached considerably later. Until then, active safety measures in form of monitoring and control are required, the performance of which can hardly be guaranteed with the necessary reliability. Moreover, active safety measures require stable social and economic conditions, which likewise cannot be guaranteed for the long periods of retrievability.

Further, it has to be taken into account that favourable conditions with regard to long-term safety and retrievability are not identical. So, for example, rock types that support accessibility to disposal cavities due to their deformation behaviour are to be considered as less favourable regarding the intended complete and impervious confinement of the waste. Therefore, the early consideration of retrievability with respect to the site selection can also lead to a concentration on areas, regions or sites with less favourable overall geological settings. This is not desired for safety reasons.

Therefore, the Committee sees no reason to consider retrievability of waste from the repository in the development of the site selection procedure and rather pursues a consequent safety-related approach by concentrating on a repository system which exclusively features passive safety with emphasis on long-term safety regarding the site selection.

The ethical principles cited for retrievability, in particular the freedom to act for future generations, are not convincing. From the Committee's point of view it is not acceptable to strive for the fulfilment of an ethical principle if this inevitably leads to a loss of safety. The protection of current and future generations in itself represents a fundamental ethical requirement. This protection is of the highest priority, because without safety all other aspects will become, to a large degree, insignificant.

However, the omission of any consideration of retrievability in the procedure development and application for the site selection does not rule out at all that the aspect of retrievability will be taken into account for the final decision on the site. This is due to the fact that at the end of the selection procedure, one site could be selected from the remaining group of several sites being under consideration that displays the same favourable conditions for passive safety but also offers favourable conditions for retrievability.

2.1.8 Possible repository concepts in geological formations

In Europe and in the USA, in Canada, Korea, Japan, Argentina and China, geological formations, partly of very different types, are being investigated for their suitability as repositories for radioactive, and, in particular, high active waste. In this respect, the geological situation in the respective country is the decisive factor. In Germany and in the USA, experience has already been gained with the disposal of low- and medium-active waste in saliferous rock. In France, Switzerland and Belgium, clay and claystone have priority, whereas in Sweden and Finland it is planned to use crystalline rocks as a host rock.

Decisive for the long-term safety of a repository is the isolation potential of the overall system, consisting of the respective repository formation and the appropriate technical and geotechnical barriers, which are important, among other things, for the effective long-term sealing of disposal cavities and shafts.

The repository concepts are determined by radiation protection aspects and the technical requirements derived from the radiotoxicity and the longevity of the wastes to be disposed of and, to some extent, from their thermal rating. In addition, the experience gained from mining, tunnelling and underground storage of hydrocarbons is essential to repository planning. This applies, in particular, to saliferous formations where intensive rock salt and potash mining has been taking place since the 19th century. Moreover, several underground repositories for chemical-toxic wastes are being operated in saliferous rock in Germany. The situation is different with regard to claystone which are only the objective of mining activities in exceptional cases. Here, it is of special importance to make use of the experience from tunnelling and, above all, the experience with the clay-based seals being developed for mines and underground storage facilities.

For conditioned solid waste, only the disposal in deep boreholes, salt cavities or mines can be considered as concrete options (see Fig. 2.1). The disadvantage of deep boreholes and cavities is that they are not accessible and can only be filled with waste material from above ground. This makes the disposal under controlled conditions considerably more difficult, if not impossible.

At present, the mining concept is favoured by all countries active in this field. The advantage is the customised mine planning with the possibility of a precise investigation of all essential geological parameters and the use of additional geotechnical barriers. For the case that a longer-lasting monitoring and control of the waste is intended or even that the retrieval of the waste cannot be precluded for the future, only the mining concept is suitable under safety-related aspects. Its realisation requires appropriate disposal and handling techniques, a comprehensive system-understanding for the repository including the determination of the resulting consequences for man and the environment, as well as the proof of long-term safety.

For the disposal of high active waste, further R&D activities are to be performed to complement the technical and scientific knowledge already obtained. In Germany, corresponding activities on the disposal in saliferous rock are already in an advanced stage. At an international level, the development of repository techniques for granite, claystone and tuff rock (in the USA) is continuously being promoted.

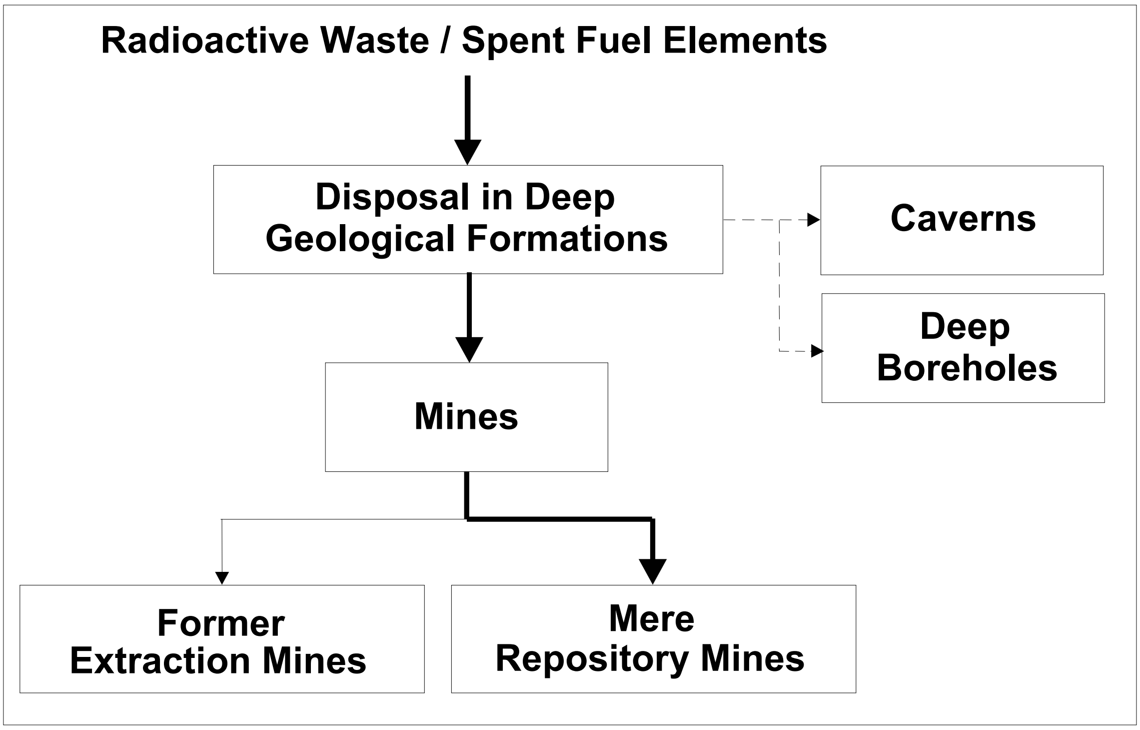

Fig. 2.1: Mining possibilities and concepts for disposal in deep rock formations

2.1.9 Relative significance of geological and technical barriers

The multi-barrier principle is applied world-wide to ensure the long-term safety of disposal of radioactive waste. The aim of using several barriers is to effectively prevent the release of contaminants during the required isolation period, where the capacity of the barriers is based on their efficiency as an entire system. In this respect, the individual components of the system have to be balanced and shall complement each other in their time-dependent efficiency.

This particularly applies to the two main groups of the geological and technical barriers. The time-dependent efficiency of technical barriers mainly depends on the geological conditions, and vice versa, a repository concept with technical barriers enhances a favourable overall geological setting. An example of this is the disposal of spent fuel elements in fractured solid rock (e. g. crystalline). Here, the very costly technical barriers, e. g. copper containers and bentonite backfill, compensate for the disadvantage of partly water-percolated rock areas. On the other hand, the functional performance and efficiency of these technical barriers require a geological environment with stable hydrochemical conditions. In contact with saline solutions, however, a copper container would not be an effective long-term barrier.

For the development of a site selection procedure it is necessary to specify whether the repository conception should be oriented towards technical barriers with a suitable geological environment or vice versa, primarily towards a favourable overall geological setting, the barrier effectiveness of which is supplemented by suitable technical barriers. For the decision between these alternatives and the assessment of the significance of the barriers, the Committee has attached special importance to the aspect of long-term safety. Therefore, the Committee is of the opinion that within the selection procedure a favourable overall geological setting shall be identified first. The advantages and disadvantages of the alternatives taken into consideration are presented in the following.

In case of a repository concept based on a favourable overall geological setting, the geological environment forms the main barrier. Here, the technical barriers have a supplementary function.

From the point of view of long-term isolation, it is an advantage that these geological structures have mainly been formed and maintained over very long periods of time. Under favourable conditions, the transport of substances by groundwater, particularly deep underground, is strongly limited and generally takes place only very slowly. It has to be assumed that changes in the geological barrier system are also characterised by an extreme slowness which is necessary for long-term safety of a repository. These processes cover time scales of millions of years and can be predicted for similarly long periods in the future.

Moreover, geological barriers are characterised by large thickness. They represent a robust system which has proven to be unsusceptible to varying influences in the past and therefore has safety reserves in its isolating effect over long periods of time.

If the safety case for a repository is based on an a long-term impermeable enclosure of the waste, then this will be primarily connected with the plastic/viscoplastic behaviour of a geological formation (clay/salt). Thus, the main burden in the barrier system is borne by the geological barriers and the favourable geological structures.

When considering the long-term safety, the assessment of the future behaviour of geological structures and formations is possible on the basis of traceable geological processes in the past. In such a case, the prognosis on the conditions in a repository region can be based on a known or determinable geological history. In this respect, natural analogue cases can deliver important information concerning various geological processes (see Chapter 2.2.4).

The presentation of relevant natural analogues contributes to the comprehensibility of the safety criteria on the one hand, and is to be regarded as integrative component of safety considerations and the continuous process of building confidence in the public, on the other hand. Especially the long periods of time in which natural processes take place and which are referred to for the prognosis on the repository safety are hardly imaginable for the general public. By using natural analogues as "geoscientific demonstration objects", uncertainties regarding the assessment of a safe repository can be relativised, and the understanding of the public can be increased.

The disadvantage of this concept alternative (geological barrier) is that geological formations and structures can be built very heterogeneously. Thus, their assessment requires a good understanding of the complex contexts which determine the quality of the geological barrier. With regard to the site exploration and the development of the database for the assessment of long-term safety, this means that measurement methods, partly requiring great effort, have to be applied to determine the geological setting.

The geological conditions and their long-term development can generally not be changed. As a consequence, it is not possible to improve the geological setting itself. Known deficiencies have to be accepted if they do not lead to the decision against the site.

A repository mine, whose safety case is mainly based on geological barriers, has however to be sealed with a geotechnical structure, the shaft barrier.

The essential element of the second concept alternative are the technical barriers (see Fig. 2.2). The host rock formations only form the long-term stable "scaffolding" for the installation and long-term efficiency of the technical barriers.

The advantage of the concept is that technical materials (e. g. the copper-coating of the waste containers) can be produced according to the safety requirements. Their composition (e. g. industrial bentonite as backfill material) can be standardised, i. e. it can be adjusted within narrow band widths. Thus, a model-like description of material behaviour is easier than it is for natural materials, whose properties have a larger variation range (e. g. argillaceous rocks).

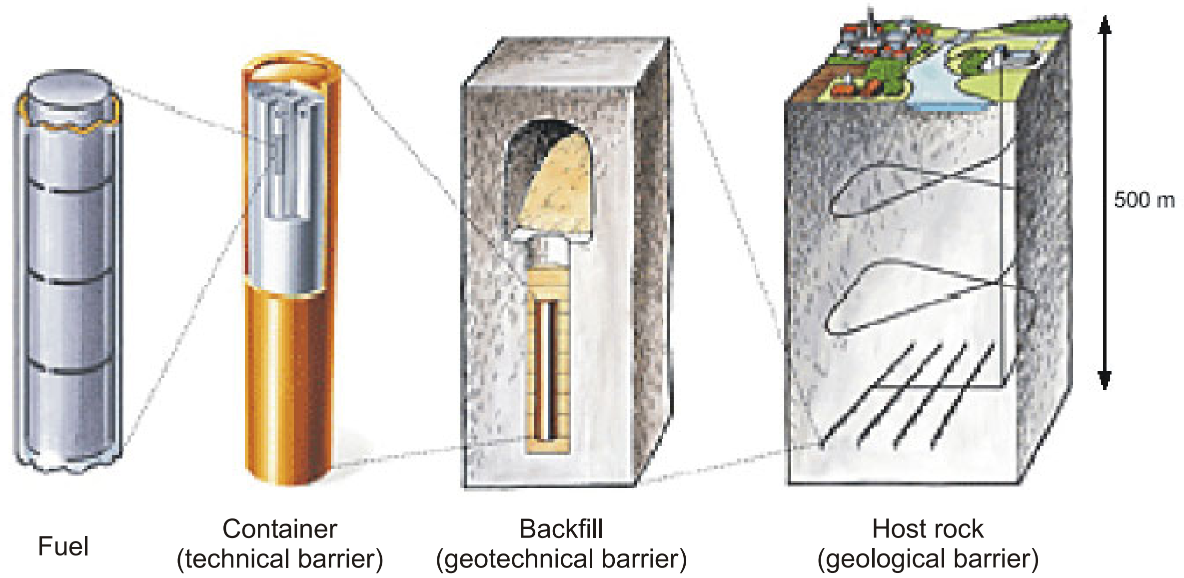

Fig. 2.2: Technical barriers are preferably installed where the geology alone cannot ensure safe enclosure (e. g. crystalline in Sweden; SKB)

The disadvantage of this concept alternative is that, in part, extensive research activities are required to demonstrate their robustness. Thus, the assessment of the efficiency of technical barriers is bound to the state of the art in material research, and is partly based on little experience regarding the long-term behaviour of the materials. Therefore, it is difficult (if possible at all) to extrapolate the safety-relevant properties of technical barriers in an order of magnitude of one million years.

Principally, only a complete and balanced barrier system is able to ensure the enclosure of contaminants in the repository in the long term. Having considered the presented advantages and disadvantages, the Committee drew the conclusion that the geological barriers and the shaft barrier shall form the main barrier with regard to long-term safety. Technical barriers can assume supplementing functions and provide additional safety. Further, it is easier to adapt technical barriers to the geological conditions than to search for an appropriate geology for them.

Regarding the selection procedure to be developed, the Committee therefore opts for the alternative, to firstly identify a favourable overall geological setting whose barrier effectiveness can be supplemented by appropriate technical barriers.

The geological conditions in Germany are multifarious and partly well explored. Therefore, the Committee is of the opinion that they offer the prerequisites for a successful selection of regions with favourable overall geological settings which also possess the necessary barrier properties.

2.2 International approaches and experiences

The mandate of the Committee includes the consideration of approaches and experience in other countries in the development of the site selection procedure. For this reason, the Committee dealt intensively with the development and implementation of selection procedures for repository sites abroad. The Committee commissioned the preparation of respective reports and sought a direct exchange of experiences with competent institutions and persons, especially in those countries where interesting developments in site selection have taken place in recent years.

The results of this work and the ensuing consequences for the Committee are summarised in the following. Here, a distinction is made between the general proceedings regarding site selection, the criteria applied, public participation and the inclusion of long-term safety assessments in selection procedures. Emphasis is laid on the disposal of high active waste and spent-fuel elements, respectively, because they place the greatest demands on the repository and the quality of the selection procedure.

2.2.1 International approaches to the selection of repository sites

In spite of agreement on the general objective of site selection procedures, i. e. to find sites for the long-term safe disposal of the wastes produced in the respective countries, different approaches are pursued to achieve this objective as regards the details. This results in more or less clear differences in the actual procedure with regard to the site selection. The causes are, for example,

- different political and legal requirements,
- different concepts on the classification of the wastes according to disposal paths and repository sites, respectively,
- different prioritisation regarding the identification of sites (e. g. emphasis on the availability of existing information),
- different requirements on the site to be selected (suitable, relatively best),
- different geological conditions in the area of exploration (national territory),
- different size of the area to be explored.

In many countries, as in Germany, activities targeted at the identification of repository sites were started in the nineteen-seventies. At that time, site selection was only regarded as a technical-scientific task practically everywhere. Intensive repository research with regard to the assessment of long-term safety and comprehensive understanding of the overall system “repository” was only at an initial stage.

All of the procedures initiated at that time were structured step-wise and included elements of the comparative assessment of geoscientific issues. However, the concrete objectives of the individual steps and comparative assessment, respectively, were different. So, e. g., it was initially intended in the USA to compare different types of host rocks within the framework of the site selection, whereas in Germany saliferous rock was selected as host rock (i. e. in salt domes) before the beginning of the selection procedure. Besides such preselection, the availability of geoscientific data or the necessity to acquire data prior to certain decisions was also decisive for the course of the procedure. In addition, the national legal and administrative requirements, such as the formal participation of certain institutes or local authorities, were and are of special importance for the selection procedure.

Transparency and traceability of the decision-making process generally played no or only a minor role in the conception and implementation of the procedures. Some procedures were so strongly influenced by external interference that not the predefined procedure, but other arguments were decisive for the selection. This lead to the procedures losing their technical traceability, and the institutions involved lost some of their credibility with parts of the public. Until today, none of the national selection procedures started in the nineteen-seventies has led to the commissioning of a repository for high active waste.

The negative experiences with selection procedures as well as social developments during recent decades have led to increased public participation in many countries. The site selection is no longer regarded as a mere technical-scientific process, but requires the consideration of certain social prerequisites and democratic legitimisation.

Internationally, traceability and transparency of the procedure, as well as acceptance of the selection results are regarded today as important prerequisites for successful site selection procedures. These have to fulfil the following social and methodical minimum requirements:

- Step-by-step approach, clear structure of the procedure with well-defined work and decision steps, as well as a licensing procedure in several steps,
- laying down the proceeding and criteria before performance of the respective procedure step,
- substantiated criteria,
- systematic inclusion of socio-scientific aspects,
- participation of the public and interested/concerned groups and persons in the procedure at an early stage (with binding character).

However, the national approaches in the individual countries to meet these requirements are still different, since the reasons for differences in the procedures stated above persist.

2.2.2 International approaches to the specification of criteria

Criteria for the selection and assessment of sites for the disposal of radioactive waste have already been developed world-wide by different countries and international organisations. A comprehensive report on standards, criteria and specifications for radioactive waste repositories in deep geological formations [IAEA 1994] was published within the frame of the IAEA Safety Series, which contains general rules on site selection and presents further aspects, such as safety, feasibility, social, economic and environmental aspects. In addition to the IAEA Guidelines, international recommendations of the European Union were published in 1992 [CEC 1992], which describe the requirements to be applied in parallel with regard to nuclear safety, radiation protection, environmental protection and sociological aspects.

In the national rules on site selection, the IAEA Guidelines are considered to different degrees. The degree of detail in the different countries is also different. The majority of the criteria serve to promote the long-term safety of the geological repository system and to simplify the safety analyses. In the national guidelines on site selection, exclusion criteria are only applied in a very limited manner. However, it is possible that equivalent criteria which may lead to the exclusion of areas already exist in other national guidelines.

After reviewing and evaluating the international geoscientific criteria on the assessment and selection of repository sites [BORK et al. 2001], the following picture was obtained:

The objective of disposal in deep geological formations is to safely isolate the radioactive waste from the biosphere for as long as possible. In most countries, the corresponding long-term safety assessment is performed for a period of 10,000 years as a minimum, with emphasis on the observance of the protection goals. Where necessary, the isolation capacity of the repository barriers will be predicted for periods of up to 1,000,000 years. For the disposal of high-active waste, most countries aim at an isolation period of 1,000,000 years. This aim is to be considered in the development of criteria.

Since the basic requirements are comparable to a large degree, there is international consensus on the criteria which are decisive for the selection of a repository site that is safe in the long term. The geology, the host rock, the hydrogeology and the geochemistry of the rock formations to be assessed, should meet the following requirements:

- **Geology**
  The repository site shall be located in a geologically stable region with the lowest possible tectonic, volcanic and seismic activity. The depth of the repository shall ensure the integrity of the geological barrier, so that erosion processes at the surface do not have an impact on the long-term development. In addition, extreme climatic conditions (e. g. ice ages) shall not impair the integrity of the repository in the future.

- **Host rock**
  The host rock has to be stable against geodynamic impacts (e. g. earthquakes/neotectonic movements). Host rock, adjoining rock and overburden shall assume the function of natural barriers in a multi-barrier system. Shape and extension of the host rock (including a protective zone) shall offer sufficient flexibility regarding configuration and design of the repository. The rock-mechanic properties shall enable a safe construction, operation and sealing of the repository. The host rock must have a good thermal conductivity and a low thermal expansion coefficient.

- **Hydrogeology**
  The disposal area shall be characterised by low groundwater movement and its surrounding area by long groundwater flow times. The hydrogeological setting shall be characterised by a generally low hydraulic gradient. The rocks in the surrounding area of the repository, in particular the barrier rocks of the isolating rock zone, must only have a low permeability.

- **Geochemistry**
  The physico-chemical and geochemical properties of the geological barriers shall limit the release of radionuclides. The hydrochemical and geochemical

environment in the repository shall be suitable for the isolation of radionuclides, support the sorption of radionuclides and impede the generation and the transport of organic or inorganic complexes, particles and colloids, respectively. It shall keep the degradation rates of the waste matrix and the corrosion rates of the container material as low as possible and prevent negative effects on other technical barriers.

Moreover, a site shall be preferred which has not been subjected to anthropogenic modification in the past, and for which the risk of human interference for future generations is as low as possible. The preservation of economically significant raw material deposits, including groundwater occurrences, has to be considered in the site selection procedure.

2.2.3 International experiences on public participation

The compilation and evaluation of international proceedings with regard to public participation and corresponding experiences in the selection of repository sites were commissioned [LENNARTZ & MUSSEL 2002]. The Committee obtained further information on the occasion of two journeys to Switzerland and Sweden. They showed that in these countries essential experiences have been gained which also should be considered in the procedure development in Germany.

In most of the countries, the largest deficiency regarding site selection still is the lack of public support and the poor acceptance of the legitimacy of the procedure by the public. However, approaches explicitly targeted at the participation of the citizens and protection of minorities may fail, as experiences in Canada show, if the procedure is politicised to a large degree. The lessons learnt in France show, above all, that even formally voluntary procedures, may fail without an intensive participation and information of the population.

It can be observed that success or failure of the site selection in different countries depends on the very specific legal and political basic conditions to be considered which are only applicable in any one country. The relation between the public opinion on nuclear energy and the attitude towards a repository shall serve as an example. In

Finland, the consideration of nuclear energy in the context of national independency in the years before 1990 still leads to a rather positive assessment of disposal. In Germany, however, many people see the issue of disposal in the context of disputes on the use of nuclear energy. However, this situation might change in the next years as the temporal distance to the disputes increases and the younger generation no longer establishes this connection. The policy of nuclear phase-out could also change the political context. Thus, each procedure proposed by the Committee refers specifically to conditions in Germany.

The lack of public support in the site selection which can be observed in many countries and the low degree of acceptance of the legitimacy of the procedure by the public are possibly due to the fact that the significance and the requirements related to a real public participation are often underestimated although their necessity in general is no longer disputed. Exceptions are above all Switzerland and Sweden as well as Finland to a certain degree. Regarding the application of international experiences to German conditions, it has to be noted that in contrast to Germany, in these countries the population accepts irrespective of adherence to a certain party, that the long-term safe disposal of radioactive waste is a national task to be solved collectively.

In Switzerland it becomes clear that transparency and openness of the procedure are a result of the balance of political powers. Due to the right to vote at a cantonal level concerning issues concerning mining law, in some cantons the citizens directly participate in the decision on the exploration of a repository site. This made it necessary to state clear test criteria for the assessment of the results from the underground exploration of the Wellenberg site (Canton of Nidwalden), envisaged for the disposal of low- and medium-active waste. However, the recent cantonal vote with the refusal of the planned exploration drift shows that this approach will not necessarily be successful either, if not initiated in due time.

How far monitoring of the storage facility over a longer period of time is decisive for the consent of the population to a repository cannot be estimated after the Wellenberg referendum. According to the Swiss disposal concept it is planned to examine the predictions on the behaviour of the radioactive waste and the technical barriers as well as approaches on radionuclide migration calculations in a special part of the planned repository. In this context it is also worth mentioning that the term “disposal“ has been dispensed with and replaced by “deep geological storage”. This disposal concept also allows the retrievability of waste. Since this clarification was not successful in the end either, it can be assumed that other aspects were decisive for the negative vote, that still have to be identified and analysed.

Both in Sweden and in Switzerland, the examination of sites according to a step-by-step procedure is regarded as an important prerequisite for the later consent of the citizens to a disposal concept or a repository site, respectively. In each step, there is a debate on the compliance with the criteria and the assessment of the procedure. A “step-by-step” procedure is the fundamental prerequisite for the verification by the public. This, however, can also lead to an early termination of the procedure, as happened in Switzerland.

The establishment of competence and the independent control of the processes by experts appointed by the public are essential regarding public participation. If both have a service-based relationship with the public, a participation can be developed that is oriented towards technical facts and resistant towards populist arguments.

In this context, it also becomes clear that the voting rights of the citizens and the principle of voluntariness are basic requirements for the willingness to participate. However, conflicts between local and regional interests, on the one hand, and the national interest to establish and operate a safe repository, on the other hand, have to be expected. In Sweden it is legally provided that a final decision is taken by the parliament if the conflict cannot be settled.

Irrespective of this formal regulation, especially in Sweden it became clear that a consensus on the responsibility for waste disposal is a prerequisite for the rapport between different groupings in the dispute about the disposal concept. The public discourse on necessities, possibilities, safety, risks and consequences for the future of a region where the site is located can contribute to the development of the responsibility for the safest possible disposal in that the ethical values of the different positions develop to form a common basis.

Internationally, the principle of voluntary participation of the communities concerned in the site identification is practised in different forms and supported by laws, financial and social programmes. However, the offering of money or other benefits to a municipality does not automatically ensure participation and consent. Thus, there is neither a guarantee for the success of a certain procedure nor a transferable procedure. The identification process requires time for the treatment of general issues and the necessary learning processes. Further, it has to enable learning processes at all sides.

In general, the conclusion can be drawn that public participation, supportability, flexibility and legitimacy are central aspects of the selection procedures abroad.

2.2.4 International experiences on long-term safety assessments

Internationally, the long-term safety assessment of the repository filled with radioactive waste and sealed is a prerequisite for licensing. This has to show that no detrimental effects for man and the environment can emanate from the repository for very long periods of time. With regard to the long-term isolation of the waste disposed of, the efficiency of the geological and technical barriers, as well as on the consequences of a failure of the barriers have to be assessed. Essential parameters for the assessment of the long-term safety are the calculated radiation exposures and risks resulting from the repository.

To support the works of the Committee, the BfS commissioned the evaluation of international long-term safety analyses for radioactive waste repositories in deep geological formations with regard to the criteria for the selection of sites [NAGRA et al. 2002]. The evaluation concentrated on the following topics:

- Advantageous and disadvantageous properties of the geological overall settings regarding site selection,
- advantageous and disadvantageous properties of the technical barriers,

- significance of the site properties and the technical barriers in long-term safety analyses, and
- influence of the site properties on the isolation capacity (isolation period) and quantity of radionuclide release from the repository system.

A total of 18 safety analyses performed in eleven different countries in the last 15 years was evaluated that comply with the present state of knowledge in science and technology and are adequately documented. They concern repository sites in crystalline rocks and different sedimentary rocks (including rock salt) and refer to different types of radioactive waste.

The main objective of the long-term safety analysis is the proof that a proposed site - together with the corresponding repository design - meets the prescribed safety requirements (including adequate safety reserves). However, the derivation of a quantitative ranking of the safety-relevant factors of a site, in particular of the geological and hydrogeological setting and other components of the repository system, is not feasible on the basis of long-term safety. This is due to the fact that the "resolution" (sensitivity) of the analysis in general is too coarse, e. g. due to insufficient process understanding, application of a conservative model approach with simplified assumptions and/or an uncertain data basis. These restrictions also apply to the performance of comparative long-term safety analyses for different sites in the same types of host rocks and of the same technical design when determining specific safety-relevant factors.

Within the framework of the different national repository programmes, the evaluated long-term safety analyses served different objectives. Until now, it has rather been the exception to the rule to attach central importance to the safety analyses in the site selection. Traditionally, they are a part of the verification of suitability both for conceptional planning of a repository and for the safety-related assessment of individual sites. In the comparative selection procedure with the subsequent decision on a site, the safety analyses have played a smaller role. Sweden (high active waste), Finland (high active waste) and Switzerland (low-/medium-active waste) are the exception to this, where the results of safety analyses particularly played or play a role in the final decision on a site. Moreover, the long-term safety analysis will gain in importance for the actual site selection, as developments, e. g. in Japan, Canada, France and Spain, show.

The evaluation of international long-term safety analyses showed that the multi-barrier system, i. e. the combination of geological and technical barriers, is of great importance for the long-term safety and its verification in all of the projects. Depending on the host rock, however, the following differences can be stated:

- In many studies on the long-term safety of crystalline host rocks and strongly consolidated (fractured) sediments, great importance is attached to the system of technical barriers for the enclosure and retention of the radionuclides.

- In the case of plastic-argillaceous sediments or sedimentary rocks, both the technical barriers and the barrier effectiveness of the geosphere are of significance to the safety case.

- For repositories in salt formations (salt domes or bedded salt), the enclosure of the waste results from the impermeable and homogeneous host rock in undisturbed conditions.

The significance of the geological barriers in the long-term safety analyses largely depends on safety-relevant properties, as well as on characterisability and predictability of the radionuclide transport.

Independent of the host rock under consideration, the aquifers, but in particular the groundwater or surface water of the exfiltration area (biosphere), often lead to a dilution of the activity released from the repository, which is important for the observance of the radiological protection goals.

In general, it becomes clear that the system of geological and technical barriers has to be assessed as a whole. The simplified approach pursued in the past according to which the “geological” search for an ideal site can be totally separated from the “technical” work on the repository design and the “physico-chemical” aspects of safety assessments on the basis of models is no longer the state of the art in science and technology.

Natural analogues can provide essential information on long-term geological processes. In numerous research projects it was shown that processes resembling the course of events in a repository in deep geological formations can be better depicted and understood by means of the characteristic properties of natural analogues. Therefore, the Committee commissioned a detailed evaluation of selected natural analogues to investigate examples of the behaviour of geological structures with radioactive substances already existing in nature [NIERSTE & BRÄUER 2001]. These examples can be helpful in identifying favourable geological configurations and in the development of criteria.

2.2.5 Conclusions for the work of the Committee

From the consideration of the international approaches to site selection, the development of criteria, public participation and to the application of safety analyses for the development of criteria and site selection, the following conclusions can be drawn that were taken into account by the Committee in the development of the site identification and selection procedure.

Apart from some exceptions, there is a trend in other countries to a clearer procedure structure with a distinctive step-by-step approach and the systematic inclusion of socio-scientific aspects - parallel to the geoscientific aspects that dominated in the past - and the early (binding) participation of the public or interested/concerned groups and persons regarding **site selection**. This also applies to the administrative and political decision-making process connected with the procedure. The structuring of the procedure pursued by the Committee and its considerations on a step-by-step approach (see Chapter 3), the international experiences and the current technical-scientific and socio-scientific discussions are taken into account.

The comparison at an international level also confirms the approach of the Committee with regard to the **development of criteria**. The scientific-technical catalogue of requirements on repository sites developed by the Committee corresponds with the present state of general safety requirements. With its proposal to use quantitative criteria for the identification and comparative assessment of “favourable overall geological settings”, it partly even exceeds the international level of generally formulated criteria.

Regarding **public participation**, the Committee drew essential conclusions from international experiences, in particular of Switzerland and Sweden, for the development and implementation of the procedure. A “step-by-step” approach with debates on the observance of the criteria and the assessment of the course of the procedure with the public is a minimum requirement for the transparency and traceability of the procedure. It shows that the transparency and openness of the procedure can be enhanced by the participation of the public in political decision-making processes. The experiences made, particularly in Sweden, make clear that the careful preparation, the extensive participation of the public and clear decision rights for the public considerably increase the chances of success in the identification of a site. In contrast, the chances to find a site decrease when transparency is lacking and when unfair relations exist between the implementer of the procedure and the public, as e. g. differences in the technical competence.

Citizens' voting rights and the principle of willingness to participate are basic requirements for a fair procedure. The unavoidable conflict between local and regional interests on the one hand, and the national interest in a safe disposal of the waste on the other hand must be solved by a public discourse on necessities, possibilities, safety, risks and consequences for the future of a region where the site is located.

The Committee has recognised the problems related to public participation and considered suitable solutions with regard to the specification, agreement on and implementation of the selection procedure and also with regard to the mentioned balance of interests.

From the results of different **long-term safety analyses** from other countries, the Committee derived the following generally applicable findings and took them into consideration in the development of criteria:

The significance of geological and technical barriers for the long-term safety of repositories and their assessments is dependent on the host rock and the repository concept with a close interdependency between these two. Therefore, conceptional aspects dependent on the rock type also have to be considered for the identification of a favourable overall geological setting, as soon as the respective site properties are known. This interdependence has to be taken into account for during the formulation of the geoscientific selection and test criteria.

Additionally important for the long-term safety assessment are, in particular, the characterisability and predictability of the geological barrier and the parameters determining a potential radionuclide transport through the geological barrier, for which suitable criteria are to be laid down.

2.3 Principles of public participation

The Committee considers the active participation of the general public in each phase and each procedure step indispensable. The proposals of the Committee for the involvement of the public for the individual phases and steps are presented in the following chapters. However, the leading basic principles and arguments in the development of the procedure are already presented briefly in this chapter.

- The dialogue

  All forms of participation proposed by the Committee are based on the model of the dialogue[1]. This approach is not about raising the acceptance of a stipulated procedure via particular events or participation steps. At least, the purpose of the dialogue is not only to increase the legitimacy of decisions, but rather to achieve a balance of interests and commonly supported perceptions and assessments. The

[1] **Dialogue:** Communicative process for the purpose of exchanging experiences, opinions and knowledge, making decisions, solving problems and conflicts. Dialogue processes represent systematically developed concepts and their implementation structured according to specific dialogue objectives, dialogue participants and dialogue subjects.

dialogue includes the equivalence of thesis and antithesis. Conflicts are understood as driving force for the achievement of a better understanding of differences and agreements in the matter and its assessment.

- Transparency

  All information has to be accessible to all from the outset. All criteria and each step of the procedure have to be made public before their implementation. Changes have to be communicated in a timely manner. Time pressure does not justify neglecting the information policy.

- Fair allocation of competence

  Until now, the search for a suitable site has been a matter of natural and engineering sciences. Their expertise shall help to determine the suitability of potential sites for a repository and ensure the highest possible safety of disposal. Until now, there has been a considerable difference in competences between the public and the experts. Even if natural sciences are supported by social sciences, this situation will not change. If the control of the procedure and the public's influence on it shall be of significance, the citizens involved must be provided with a competence that puts them into a fair position compared to the experts.

- Participation as control

  Very often, procedures are obstructed or fail because a part of the people involved are under the impression that particular information was withheld, that certain decisions were based on other reasons than the stipulated criteria, that certain examinations were not carried out as agreed upon, or measurement results were falsified. For this reason, the procedure and the fulfilment of criteria have to be controlled from the outset. The public has the right to receive all information. This is the only way to ensure that the credibility of the procedure can be developed and maintained.

- Participation as influencing factor on future developments

  A potential repository site cannot be viewed as isolated from the development of the potential site region. A repository can have negative and positive effects on a region. In order to recognise disadvantages and advantages, hazards and chances created by the development, public participation is necessary. Concepts for the future can only be developed, sustained and then integrate the different interests in a region if the public takes part in their development.

- Participation also requires assuming responsibility

  The participation in decision-making processes requires the people involved to assume responsibility. The citizens can and should participate in the development of a procedure for the selection of a repository site. It shall control the fulfilment of the stipulated criteria and participate in the decisions regarding the future development of a potential site region. This also entails an obligation to reduce the hazard emanating from an open storage of high-level radioactive waste by means of the safest possible disposal.

Civil society as reality and perspective

The question why the public shall actively and intensively be involved in the search for a repository site can easily be answered. Until now, all attempts to determine a site failed due to the resistance of the public, not only in Germany but in most of the countries trying to identify a site for a repository. Meanwhile, there are more or less intensive attempts in some countries to involve the public in the search for sites, and in two cases first positive results have been registered. The reasoning behind the decision of the Committee is therefore completely pragmatic. The involvement of the public is most likely the only way to realise a repository, even if this way seems to involve great efforts and many difficulties.

In addition to the representative and formalised democracy, a rather informal and situative kind of democratic development of an informed opinion and protection of interests has emerged in the last decades.

On the one hand, the institutionalised and formalised democratic structure exists and works: the system of parliaments and government, the independent legislations and the intermediary organisations, e. g. the trade unions, associations and lobbyists, whose specific interests are considered in the decision-making processes. On the other hand, however, rather informal civil associations at all levels (from districts to regions up to global centres of power), try to influence the decisions.

This formation of civil self-organisation has its origin, at least in the recent history of democracy, in the social movements of the sixties and seventies, but is now widely spread throughout all political camps and tends to transcend the traditional patterns of left-wing, right-wing or liberal. At the same time, the civil self-organisation is not only a an alternative to the representative democracy, but is only politically effective through and in reference to it. The articulation of its interests have to be covered by the media and will then show an effect via elections - this also means via political parties and associations - on the decisions of the parliaments and the enforcements of the executive authority.

This development within the civil society has led to new forms of participation. Participation no longer means that the public is informed and has formal right of objection. Participation rather develops towards conflict management to overcome the blocking of developments and to actively influence future developments. Accordingly, participation no longer (only) aims at obtaining the acceptance of the public for plans and decisions, to partially integrate everyday knowledge into the experts' planning, to avoid erroneous planning; the objective is rather co-operative planning of developments. The purpose of co-operation brings together specialists, lobbyists, government, administrative representatives, legislators and citizens who try to solve conflicts and to develop future concepts or concrete plans. New methods were developed in accordance with these new tasks. In mediation procedures at future search conferences or citizens' forums, conflicts are addressed and concepts are developed by means of communication techniques such as "Metaplan" [LENNARTZ & MUSSEL 2002].

Public view on the participation of the citizens

To determine the public view on the participation of the citizens, the Committee suggested the conduction of representative polls, which were commissioned by the Federal Office for Radiation Protection [STOLLE 2002].

In case of large-scale projects which, of course, include the construction of a repository, large parts of the population demand and expect the consideration of their interests and a participation. In that context, the number of people demanding participation increases the more controversial and risky a project is in the public eye. In this respect, the main demand is the information and participation at an early stage. Obviously, the public does not want to be presented with a fait accompli but to participate in the process of planning and decision making.

Many citizens demand intensive participation (see Fig. 2.3), but only a small number of those questioned actually have experience with forms of participation. Accordingly, 69 % of those questioned have never participated in a discussion at a public meeting, while 11.5 % have participated in citizens' initiatives.

This demand for participation is accompanied by a strong sense of mistrust towards the political and social institutions. Apparently, there is a particularly low level of trust in this area. A significant part of the population, ranging between 10 % and nearly 30 %, has very little or no faith at all in the various institutions Only environmental protection groups, the judiciary, the police and sciences enjoy a relatively high level of credibility.

This mistrust concretises with regard to information about nuclear energy. Here, environmental research and protection associations as well as citizens' initiatives are regarded as particularly trustworthy (see Fig. 2.4).

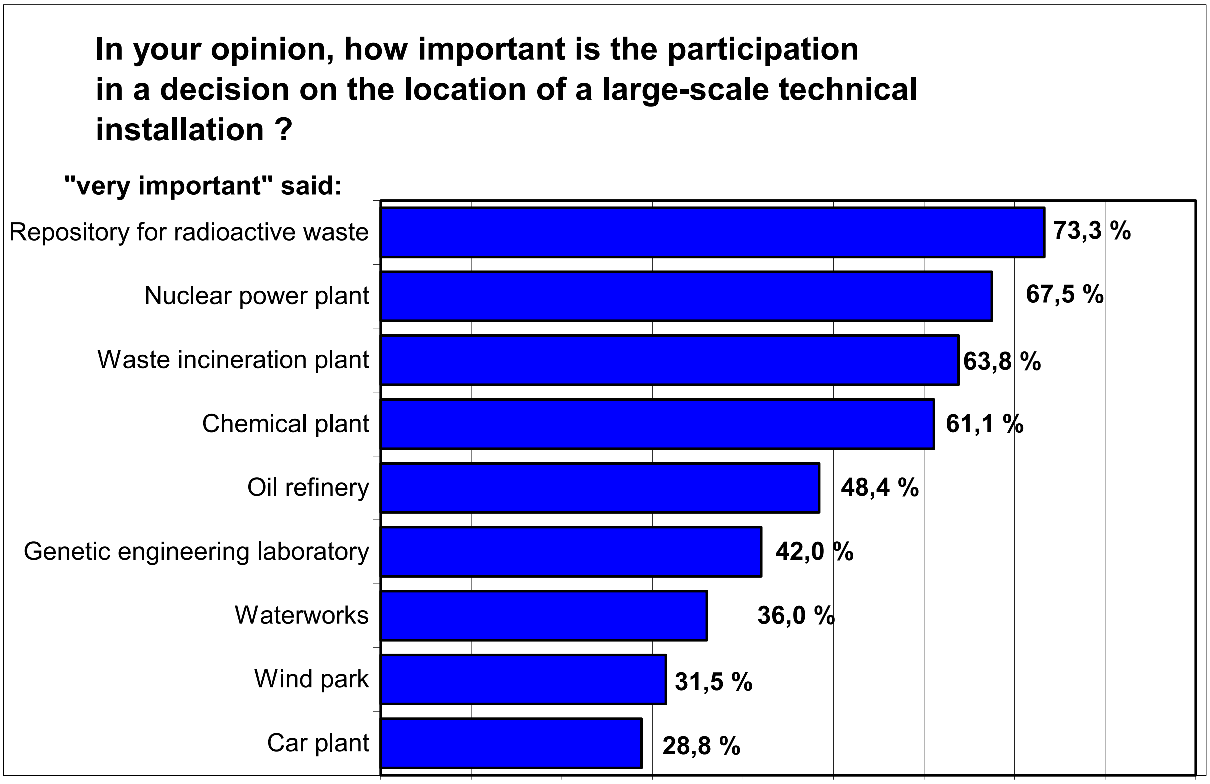

Fig. 2.3: Large-scale projects and participation

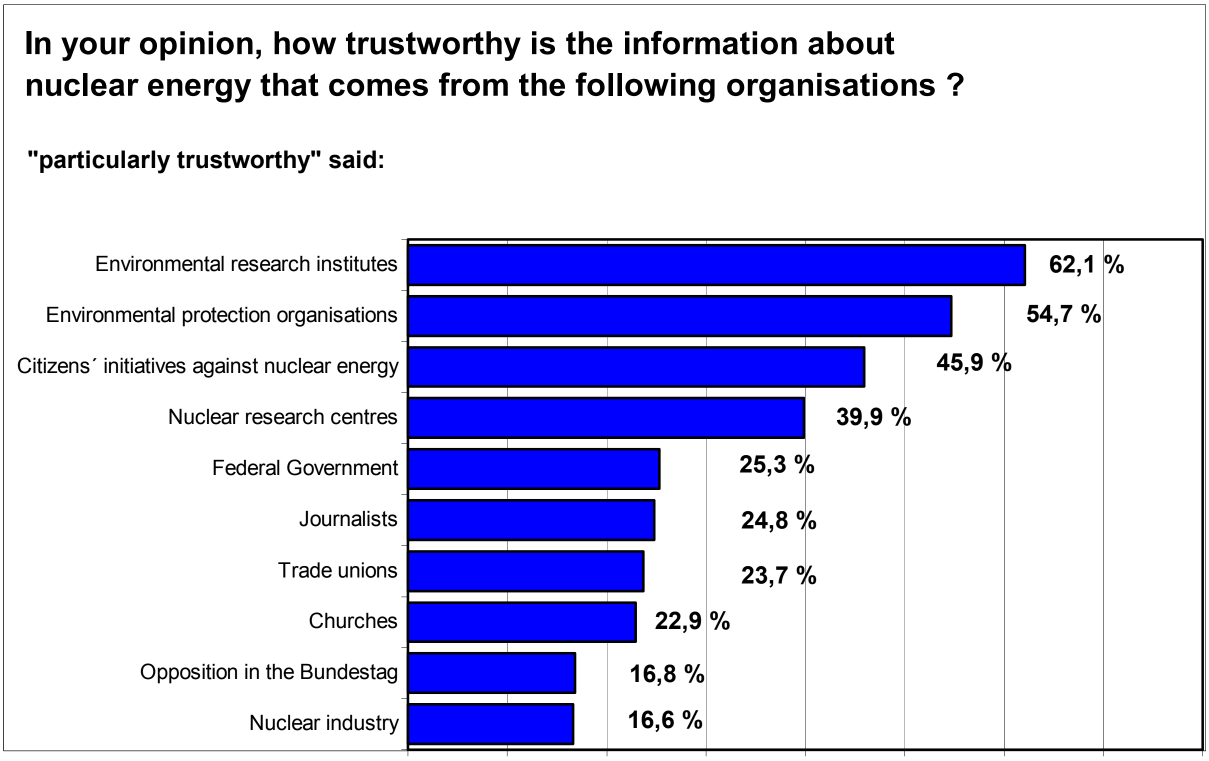

Fig. 2.4: Confidence in information about nuclear energy

The constellation of opinions and experiences with public participation also show the difficulties that are to be expected apart from voicing one's opinions concerning participation. On the one hand, there are great demands regarding an early and active involvement in important projects. On the other hand, the mistrust towards the political institutions and associations makes co-operation difficult. Considering that only a minor part of the population has experience with active forms of participation, beyond the signing of petitions, it becomes clear that the realisation of an active and intensive participation requires careful preparation and a step-by-step approach .

Participation and responsibility

As a general rule, the civil society can only advance their perspectives if the demand for participation in planning and decision making is linked with the responsibility for society as a whole. Hence, it is not only a matter of bringing in one's own interests into planning and decision making, but rather to consider long-term, sustainable and general interests.

With regard to the safe disposal of radioactive waste, this dilemma becomes apparent. More than 70 % of those questioned see the problem of disposal as very urgent (51 %) to urgent (22 %). More than 60 % of those questioned favour a solution of the problem of disposal within the next ten years. If, however, a repository would be built in one's own region, 80 % of those questioned would be against it. Likewise, decisions of the *Bundestag*, the *Landtag* or of the local council would not be accepted. The same applies to decisions on the basis of a national referendum, a referendum at Land level, or a regional referendum (see Fig. 2.5).

In order to avoid this dilemma, at least 69 % of those questioned think that a solution at EU level would be appropriate, and 22 % also think that a repository outside EU borders could be the right solution. (However, many of those questioned do not answer this questions, perhaps because they do not feel sufficiently informed). Should the issue be transferred to a foreign country, the majority of those questioned demand that the same safety requirements for a repository as in Germany be applied there.

The view of those questioned on the described dilemma – urgent solution to the problem of disposal, but not in my region, little trust in institutions – shows that traditional approaches including referendums in all likelihood cannot solve the conflict between personal interests and the responsibility for a decision serving the purpose of general safety. The decision making process has to take place step-by-step, including the possibility of correcting errors. Verifiable information, transparent criteria, rules of procedure and of the dialogue are necessary to find a solution that is supported by the citizens as well. The concept of active and intensive public participation, as developed and proposed by the Committee, shall meet these requirements.

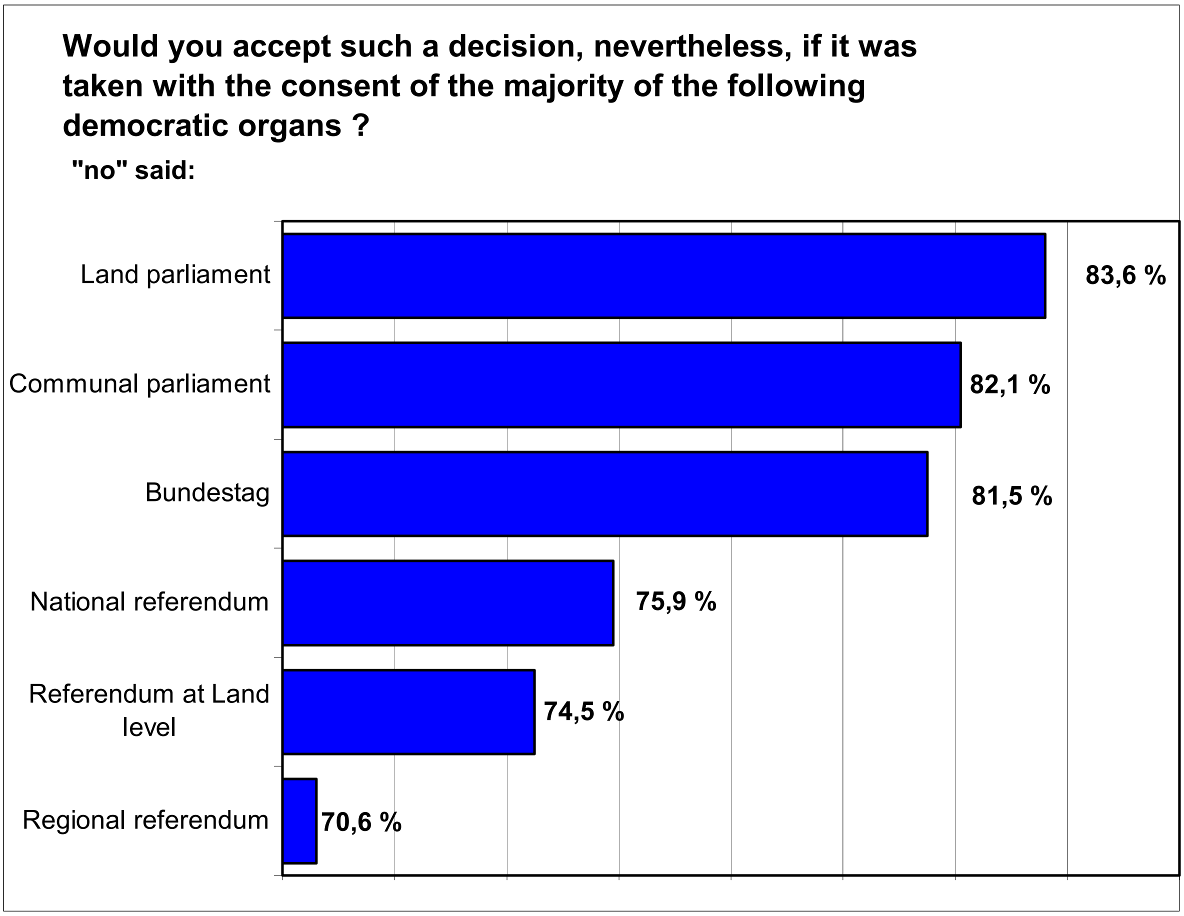

Fig. 2.5: Acceptance of political decisions

For the development of the concept, international experiences, described in Chapter 2.2 in detail, were of great importance to the Committee. This applies both to experiences made due to failures and experiences representing successful intermediate steps.

The experiences made in Sweden were of utmost importance for the development of the Committee's concepts. The Committee obtained very concrete ideas from the Swedish procedures and was able to apply some of them, adapted to German conditions, for its own concepts.

Participation and chances of success in the search for a repository site

Of course, participation does not guarantee the success of the procedure when searching a repository site. A public participation procedure, as recommended by the Committee, has never been conducted to this extent and with this intensity in either Germany or other countries.

On the timeline, the proposal also covers the far future. Within thirty years, many changes in the societal and technological conditions may occur that cannot be predicted by social sciences. It is therefore advisable to keep the option for corrections open. Therefore, the Committee recommends control of each step and a feedback of the results in due time.

Further, the proposal is imbedded in the international discussion. Internationally, there is great consensus that a lack of possibilities to participate is one of the main reasons for the failure of many of the procedures started thus far. It could be formulated this way: Participation does not guarantee success in finding a repository site, but a lack of participation increases the chances of failure.

3 Selection procedure

This chapter presents the way to an operable repository, divided into different phases, and describes the general characteristics as well as individual steps in the site selection procedure for repository sites as proposed by the Committee. Since it is a criteria-based procedure, the assessment principles, the handling of findings from investigations and data uncertainties, as well as the availability of data in general play an important role.

The way to an operable repository comprises the three phases of the selection procedure, the subsequent nuclear licensing procedure and the construction of the repository.

Phase I: Procedure development (mandate of the Committee)

In this phase, which has currently been completed, the Committee developed a procedure for the selection of a site. The procedure was not agreed upon during this phase. The interested public was informed via the Internet (www.akend.de) and involved in the discussion. The discourse with the experts took place in discussions, lectures and publications. In annual workshops, the Committee addressed the general public. With the submission of its recommendations to the Federal Ministry of the Environment at the end of 2002, the Committee concluded its task.

Phase II: Agreement on the procedure

The aim of this phase is the political / legal establishment of the selection procedure. In this phase, the criteria developed and procedures proposed by the Committee are discussed by the experts and the other groups (i. a. from environmental organisations, the energy industry, authorities and politics) involved in the subsequent process of site selection in a framework which fulfils the criteria of technical, social and political representativity and legitimacy. This phase will have to result in a broad social and political consensus on the further process of the site selection procedure. From the Committee’s point of view, Phase II shall also include an international review of the results from Phase I. Phase II should not exceed a period of two years.

Phase III: Implementation of the procedure

In this phase, the site selection procedure which has been agreed upon in Phase II will be implemented. The procedure ends with the decision for one particular repository site. The Committee recommends that at least two repository sites should be explored underground with regard to their suitability before a decision is made on the repository site. A period of around ten years will have to be scheduled for the underground exploration; however, the exploration period depends on the geological conditions at the site. This decision will have to consider the geoscientific and socio-scientific criteria, with the safety of the repository having top priority.

Following the conclusion of the Phase III, the implementer of the procedure will present the safety case for the repository in the subsequent nuclear licensing procedure. The licensing authority will check whether the planned facility fulfils all legal requirements for a safe and environmentally compatible repository. Even if the licensing authority should demand no further exploration or analyses, a period of approximately five years still needs to be scheduled for the licensing procedure during which the application documents are thoroughly examined.

Once the license has been granted, the repository can be built and operated. The construction of the repository can be scheduled to take three to five years.

The aim of the current Federal Government is to have a repository for all types of radioactive waste by the year 2030. The way to an operable repository, which has many obstacles, can only lead to success if all parties involved comply with their social responsibility to ensure the safe long-term disposal of radioactive waste.

3.1 Assessment principles

The most important principle that has to be considered in the selection procedure is the priority of safety over all other aspects, because long-term safety and maximum possible safety are the main objectives with regard to disposal. Moreover, the selection procedure must not only fulfil the basic conditions formulated in Chapter 2.1, but it also has to provide general specifications or regulations for the evaluation of the investigation results and related aspects. This is necessary in order to have a well-defined framework for the criteria-based selection procedure for assessments to be performed at each step of the procedure that is also clear for persons not involved. The consideration of the assessment principles is a necessary precondition for actually being able to comprehend the corresponding decisions, to achieve the intended largest possible social and technical consensus, and that the responsible boards and authorities obtain confidence in decision making. In particular, the regulations serve to limit scientific scopes of interpretation or even speculations on different procedural steps, for these scopes or speculations alone could be used to impose ideological, political, economic or other convictions and interests on the selection procedure with allegedly objective arguments - unworthy of the safety-relevant, social and political significance of the selection procedure and surely not promoting the chances of success in the search for a repository site.

The assessment principles concern the following aspects:

Definition of the assessment criteria

The assessment criteria comprise, above all, of the criteria applied during the selection procedure, namely the geoscientific and socio-scientific criteria. They have to be defined unambiguously with regard to their function (exclusion or weighing criteria) and their formulation (among other things, the fulfilment functions serving the actual assessment). Further, regulation is required on how to proceed in the case of an overall assessment with simultaneous consideration of several criteria. This concerns the weighting of the individual criteria, the kind of aggregation of individual assessments, as well as the methodical approach selected for the comparative assessment of areas, regions and sites. As far as subjective views are necessary in formulating definitions (e. g. in the weighting of criteria), they have to be identified as such.

The assessment criteria always have to be defined **before** their implementation into the procedure steps. This will prevent the consideration of irrelevant arguments in the assessment, or that the assessment is later modified or adapted to the findings that are to be evaluated. This is the basic prerequisite for the traceability and acceptance of the decisions resulting from the steps of the selection procedure.

Likewise, the actual aim of the selection step and the related assessment, as far as agreements are required that exceed those made in Phase II, also has to be defined **before** implementation of any such selection step (see Chapter 7). The consequences of a procedure step that may result from the assessment also have to be defined **in advance**.

Information requirement

The implementation of the procedure and assessment steps requires the availability of specific information. This information requirement determines - starting from the information already available - the scope and degree of detail of the investigations still required for the performance of an assessment step.

Thus, the qualitative and quantitative minimum of information required for the implementation of each selection step has to be determined. This depends on the respective procedural step and the requirements resulting from the criteria steering the step. Here, the information has to be available for all areas or sites to be assessed or must be transferable or derivable from experiences or other areas. Regarding the development of criteria the Committee paid attention to whether the information needed for the application of the criteria can be made available at all.

Dealing with investigation results

In the case of investigation results leading to controversial technical interpretations the matter has generally to be clarified. This can be done by a targeted additional investigation. As a general rule, information gaps on procedure-relevant aspects have to be filled. If they cannot be filled for methodical reasons or due to completely unreasonable time and cost expenditure required by such investigations, then substantiated assumptions can be made in individual cases that do not lead to an overestimation of the isolation capacity.

Handling of uncertainties

In each procedure step, uncertainties arise, which have to be described and considered in the decision-making processes. These are due to

- a limited state of knowledge of the geological past, the current geological conditions, and the characteristic properties of partial areas, site regions and sites,
- an incomplete knowledge of the safety relevance of geological circumstances,
- the limited capability to predict geological developments in view of the long periods of time to be considered,
- the different quality of the respective data on partial areas, site regions and sites used for the comparative assessment.

Regarding the implementation of the site selection procedure, sources of uncertainties have to be identified and their handling has to be agreed upon at the end of each step of the procedure. This includes, e. g., the clarification in which way uncertainties identified can be reduced, uncertainties are taken into account in the procedure, or in which cases findings from the consideration of uncertainties entail reconsiderations of decisions already taken.

According to the respective step of the procedure, the uncertainties have to be reduced adequately by means of targeted analyses. If uncertainties within a step of the procedure cannot be reduced adequately, the decision has to be based on conservative assumptions. An assumption is conservative if it leads to a less favourable appraisal with regard to a parameter to be evaluated. Here, the above mentioned regulations on the handling of findings from investigations are to be considered. New findings leading to the reduction of uncertainties may entail a modification of decisions from previous steps of the procedure (see the errors and omissions exception below). This reconsideration has to take place according to an iterative process. Remaining uncertainties can be accepted if it can be proven that they do not have an influence on the assessment of whether a site fulfils the required properties or not.

Errors and omissions exception

Since the degree of information increases from the first step of the selection procedure until the detailed exploration from the surface and underground exploration, the result of the application of the criteria is consequently also based on models and assumptions (this concerns, above all, geoscientific aspects). The decisions made on this basis are subject to errors, because it may turn out that during the course of the selection procedure and especially during exploration from the surface and underground exploration that a partial area, a site region or a site does not fulfil or not completely fulfils the predefined requirements. In this case, decisions from preceding procedure steps have to be reconsidered and revised, if necessary. This means that requirements for a safety proof formulated in previous procedure steps remain valid for a site and at the same time that they have to be continuously monitored in the course of the procedure with regard to their compliance.

Thus, the safety-related geoscientific requirements on particularly favourable partial areas or repository sites formulated before and during the selection procedure in general and for the sites short listed at a later stage in particular remain valid for the procedure until the finalised comprehensive safety assessment for the site. This applies especially to minimum requirements and exclusion criteria, but also with regard to the result of decisions based on comparative assessments of different partial areas or sites. Therefore, the exception of errors and omissions does not refer to the requirements and assessment criteria but to the findings to be assessed (i. e. only new insights or findings can lead to a reassessment).

Observance of the weighing requirement

In the selection procedure, the weighing requirement has to be observed. It serves the purpose of maintaining a balance between the different interests at an early stage and also contributes to minimise conflicts. This is the only way that a traceable decision and legal security can be achieved, in addition to the required fairness. The weighing requirement is concretised in the sense of a best possible achievement of goals through comparative site assessment (assessment of site alternatives).

Therefore, a comparative assessment has to be performed for site alternatives at an appropriate stage of the selection procedure.

3.2 Proposed procedure structure

3.2.1 General procedure characteristics

Step-wise and criteria-based approach

The selection procedure consists of five consecutive procedure steps. They form the "backbone" of the procedure. Each step includes certain criteria with the help of which it is decided which regions remain in the further selection procedure and which are deferred or abandoned. The step-by-step procedure structure fulfils the requirement for transparency and traceability, which is eventually important with regard to public participation. The selection procedure is guided by geoscientific and socio-scientific criteria. Only this method enables the fulfilment of the safety requirements, whilst allowing for the active participation of the general public. For this purpose, certain forms of public participation are allocated to the individual procedure steps (see Table 3.1).

In the course of the development of the selection procedure, there were several changes in the procedure structure. They concern the number of procedure steps, the assignment of different criteria types to the individual steps and the conclusion of the selection procedure. These changes reflect the processes of understanding and discussion that took place within the Committee as well as with the public and that led to the optimisation of the selection procedure.

No spatial preselection

The starting point for the procedure is the entire geographical area of Germany. This means that there is no preselection or even exclusion of areas from the procedure in advance. The project rather starts with a "white map of Germany". All areas are dealt with equally.

In order to give priority to safety, only geoscientific criteria are applied in the first two steps of the procedure, because these criteria relate in particular to (long-term) safety-relevant characteristics. This ensures that most of the possible underground areas that are particularly suitable for disposal sites are identified at the beginning of the selection procedure.

No preselection of a host rock

Regarding site identification, there is no preselection of a certain host or barrier rock (e. g. clay, salt), since a suitable repository site is not only determined by the host or barrier rock alone, but by a favourable overall geological setting. Thus, the selection procedure aims at the identification of such a favourable overall geological setting.

Exclusion and weighing criteria

In the procedure, both exclusion and weighing criteria are used. The exclusion criteria and minimum requirements are to be observed during the entire duration of the procedure. They serve the purpose of excluding non-suitable areas.

The weighing criteria serve the comparative assessment of areas. They enable the identification of areas or sites, respectively, with favourable conditions for disposal. Moreover, they enable the compliance with the weighing requirement, which is to be observed regarding site selection. Only the relatively more favourable areas or sites continue to be considered, all others will be deferred.

Possibility to go backwards

The procedure provides the possibility to go backwards to previous procedure steps, if required. However, this is only possible from the third procedure step onwards, since this allows steps back to partial areas or site regions worthy of investigation. The possibility of going backwards is necessary to avoid the procedure coming to a dead end at an early stage if their are unexpected new findings or there is an unwillingness to participate in all site regions. It has then to be ensured that there is the possibility to go backwards to a previous secured procedure step and that partial areas or site regions, not deferred for safety-related reasons, can be considered again in the procedure. This proceeding is justified, since these deferred partial areas or site regions do not have to be less suitable than those which first seemed to be more suitable, and which, however, have not been confirmed after more detailed investigation.

The possibility to go backwards is not to be confused with “arbitrariness” of the procedure, as the requirements on areas and sites in the form of criteria specified before implementation of the procedure remain applicable.

3.2.2 Procedure steps

In the following the five procedure steps are presented. For Steps 2 to 4 it is stated how many areas/site regions/sites are to be selected and explored for the following reasons:

- The objective of the selection procedure is to identify the best suitable site. According to the definition of the Committee, this means the site identified in a weighing process between alternatives and not the absolutely best site. The weighing process is based on geoscientific and socio-scientific criteria.

- The risk of a failure of the selection procedure shall be minimised. The greater the number of partial areas, regions and sites to be considered or explored, respectively, the smaller the risk of failure of the procedure. Therefore, it is recommendable to have a largest, but also practicable, number of partial areas, regions and sites available for Steps 2 to 4. This also reduces the economic risk.

- It is regarded as favourable if not all of the sites identified have the same geological structure. With an increasing number of partial areas and site regions under closer consideration the probability increases that different geological structures remain in the procedure.

In the **first procedure step** (see Table 3.1), areas are identified that are obviously not eligible for a repository. These areas have to be excluded from the further procedure by means of exclusion criteria and the minimum requirements to be fulfilled.

The geoscientific exclusion criteria serve to identify areas with obviously unfavourable geological conditions. These criteria refer to natural processes (e. g. seismic or volcanic activities), which may impair the barrier system of a repository within the required isolation period in the order of magnitude of one million years.

In addition, those areas will be excluded which do not fulfil the geoscientific minimum requirements. These minimum requirements mainly refer to the properties of the isolating rock zone which is to ensure the isolation of radioactive waste. The minimum requirements are also defined in form of criteria.

Thus, only those areas remain in the selection procedure at the end of the first procedure step that fulfil none of the exclusion criteria and all of the minimum requirements.

The participation of the general public is mainly ensured through detailed information of all participants in the procedure and through the control of the course of procedure. For this purpose, an information platform and a control committee are established. The control committee monitors the due implementation of the procedure according to the regulations. These elements of public participation will remain active in all subsequent procedure steps.

The objective of the **second procedure step** is to limit the areas remaining after the first step to smaller partial areas with particularly favourable geological conditions for disposal. This is done by weighing the geoscientific results by means of weighing criteria.

Only partial areas with particularly favourable geological conditions remain to be considered in the procedure. These partial areas are to be assessed as equally suitable regarding their safety. Areas for which the data available are not sufficient for a geoscientific weighing are deferred in the procedure. The public participation in this step corresponds to that of the first step.

In the **third procedure step**, site regions are identified in the partial areas with particularly favourable geological conditions. The Committee recommends to select, if possible, five, but at least three site regions for exploration from the surface.

At the beginning of Step 3, the existing or planned land-uses, objects of protection and natural resources subject to a particularly strict legal protection are identified for the partial areas. With the help of the planning-scientific exclusion criteria, the respective areas are excluded from the partial areas after examination of each individual case. They then take no further part in the procedure.

The central point of the third step is the vote of the citizens in the site region on whether to allow the above-ground site exploration, planned for Step 4. Only those regions declaring their willingness to be involved in the performance of surface investigations on their territory remain in the procedure. Thus, the willingness of the citizens to participate determines the procedure regarding limitation and selection of the site regions, i. e. the search has to be for regions which regard themselves as site regions and are willing to permit investigations in their area. The declaration of the willingness to participate in this step does not automatically mean that the corresponding region is “captured” in the procedure. The declaration of willingness to participate can be withdrawn at the end of Step 4.

This willingness to participate is closely related to a series of additional measures, such as the performance of socio-economic potential analyses in the regions signalling their willingness to participate or requesting the performance of a potential analysis. The potential analysis serves to determine potentially positive and negative effects of a repository on the social and economic conditions and the long-term development prospects of the site region. In order to be able to actually use the development potentials of site regions, regional development concepts shall be established additionally with the participation of the public. In the end, the programmes for the exploration from the surface and the assessment criteria for the evaluation of the results of the exploration from the surface are also laid down in agreement with the population.

In a weighing process, it is decided where exactly the potential repository sites shall be located within the site regions, which mainly aims at the minimisation of use conflicts or interference with objects of protection or resources. In this respect, the planning-scientific weighing criteria are of primary importance, and, where applicable, also socio-economic and mining aspects.

If less than three site regions declare their willingness to participate regarding exploration from the surface, the selection procedure is halted, and further action will have to be reconsidered. There is, for example, the possibility to go backwards in the procedure to the end of Step 2.

Public participation in the third and the following procedure steps is mainly characterised by the criterion of the willingness to participate (see Chapter 5.2). In this respect, the citizens' forum is a central element. It organises the active participation of the public at site region level in the determination of the willingness to participate, the establishment of the regional development concept and the discussion of all other questions related to the selection procedure. The citizens' forum makes recommendations to the local council (or local councils, respectively), which is, in the end, in charge of deciding on the further procedure.

The main tasks in the **fourth procedure step** are the exploration from the surface and the agreement on at least two sites for the underground exploration provided in Step 5. The results of the exploration from the surface have to be evaluated. Here, the assessment criteria for exploration from the surface developed in Step 3 are applied. Sites not fulfilling these criteria are excluded from the procedure. Should less than two sites fulfil the assessment criteria, a step backwards to the procedure Steps 3 or 2 becomes necessary.

If the results of the programme for exploration from the surface are assessed positively, the willingness of the site regions to participate is polled a second time, this time for the underground exploration. In association with this, test criteria are developed for underground exploration, also with the participation of the citizens.

The survey of the willingness to participate is preceded by the information that at the end of Step 5 a decision by the German *Bundestag* in favour of one of the few sites remaining in the procedure after the fourth step is very likely if the results of the underground exploration are positive. A site region fulfilling the assessment criteria but not willing to participate with regard to the underground exploration, is deferred in the procedure.

If less than two site regions consent to underground exploration, then the Committee recommends that the German *Bundestag* should rule how the procedure should continue.

The elements of public participation correspond to those in the third procedure step. According to this, the underground exploration programme and the test criteria for the assessment of the exploration results are, among other things, specified in agreement with the public.

In the **fifth procedure step**, the decision about the repository site is made for which the subsequent licensing procedure is to be performed. For this purpose, underground exploration is performed for two sites identified in the fourth step which are then assessed by means of test criteria and safety analyses. The site not fulfilling the test criteria is to be excluded. The safety analysis is also used for the comparative assessment of the sites in order to clearly see the strengths and weaknesses of the sites before the final decision.

The underground exploration is continuously monitored by the citizens' forum. Assessments with regard to the fulfilment of site-specific test criteria are performed within the framework of the instruments of public participation provided, which are described in more detail in Chapter 5.2.1.

At the end of the fifth step, the assessment of the procedure implementer, the control committees and the citizens' forum (supported by the centre of competent experts) as well as the assessment of the development potential are available for each site subjected to underground exploration. On this basis, the citizens at the site are polled for their vote on the construction and operation of the repository at this site. This information will help guide the German *Bundestag* in its final site selection decision.

Table 3.1: Criteria, assessments and instruments of citizens' participation in the individual steps of the selection procedure

Procedure steps	Proceeding, criteria, assessments	Instruments of citizens' participation
1st Step **Objective: Identification of areas fulfilling specific minimum requirements**	**For Step 1** • Geoscientific exclusion criteria and minimum requirements	**For the overall procedure (Steps 1 - 5)** Participation by information and control: • Establishment of an information platform • Control committee verifies adherence to the rules of the procedure
2nd Step **Objective: Selection of partial areas with particularly favourable geological conditions**	**For Step 2** • Geoscientific weighing	
3rd Step **Objective: Identification and selection of site regions for exploration from the surface** **Step backwards, if required ↑**	**For Step 3** • Planning-scientific exclusion criteria • Socio-economic potential analysis • Planning-scientific weighing criteria • Specification of programmes for exploration from the surface and corresponding assessment criteria • Willingness to participate regarding exploration from the surface • Geoscientific and mining aspects	**As from Step 3** • Citizens' forum as a central element of participation • Centre of competent experts supports citizens' forum • Round table of stakeholders • Determination of willingness to participate in Steps 3, 4 by vote • Preparation of regional development concepts • Local council / councils take/s final decision • Orienting vote of the public and local councils at the end of Step 5
4th Step **Objective: Determination of sites for underground exploration** **Step backwards, if required ↑**	**For Step 4** • Exploration from the surface and assessment • Orienting safety assessment • Willingness to participate regarding underground exploration programmes • Development of test criteria	
5th Step **Objective: Decision on a site** **Step backwards, if required ↑**	**For Step 5** • Underground exploration and its assessment • Safety case • Comparison of the different sites explored	
Repository site **for licensing procedure**		

3.3 Available Data

3.3.1 Geoscientific data

The execution of the individual procedure steps is controlled by criteria. These are implemented to examine whether areas, partial areas, site regions and finally repository sites have certain characteristics.

This examination requires a certain minimum of knowledge and data. In particular with regard to the application of geoscientific criteria, the following questions have to be answered:

- Are data available covering the whole geographical area of Germany?
- Is the data of uniform quality?
- Shall areas with significant information and data deficits be excluded?
- Do the deficits have to be removed before the procedure can be continued?
- Which efforts shall be taken, and to which extent, to possibly acquire new data?

For the application of the five geoscientific exclusion criteria, use is made of the data available on large-area uplifts, seismic activity, volcanic activity, active fault zones and groundwater age. Such data are not available for the whole geographical area of Germany, but for large partial areas. Thus, data are available on uplifts, seismicity and volcanism, whereas data for the identification of active fault zones are only partially available . Data on the age of groundwater in the deep underground is only available in some discrete cases.

As regards the application of exclusion criteria it is to be noted that these remain effective throughout the entire procedure. This means that data newly acquired during the procedure can still lead to the exclusion of areas from the further procedure.

For the data on geological structures which are of special interest for the identification of favourable overall geological settings the following variations in quantity and quality are observed:

- Salt structures

  The major part of the data is based on borehole data and the results of geophysical measurements of the oil and gas industry as well as on the experience of the potash and rock salt mining industry. In general, it can be stated that all salt structures, including the small ones, are known. All structures are crossed by at least one profile line of seismic measurements and most of them were explored by one or more boreholes into the upper areas of the salt structure.

  By special use of extensive geophysical analyses the usefulness of these results could be improved to some degree.

- Clay formations

  As in the case of salt structures, the data on clay formations are mainly based on borehole data and geophysical measurements of the oil and gas industry. Here a "data decline" can be observed between Northern and Southern Germany. In Northern Germany the data density is not always homogenous but a large amount is available. The major part of the data for exclusion and weighing criteria are already available in processed form.

  In Southern Germany, the data density is very heterogeneous and altogether significantly lower. Only some areas, as e. g. the Upper Rhine Valley and Molasse Basin, currently allow for modelled cross sections of geological structures at a small scale (1:500,000, 1:200,000) (see Fig. 3.1). Detailed investigations will most probably require considerable efforts.

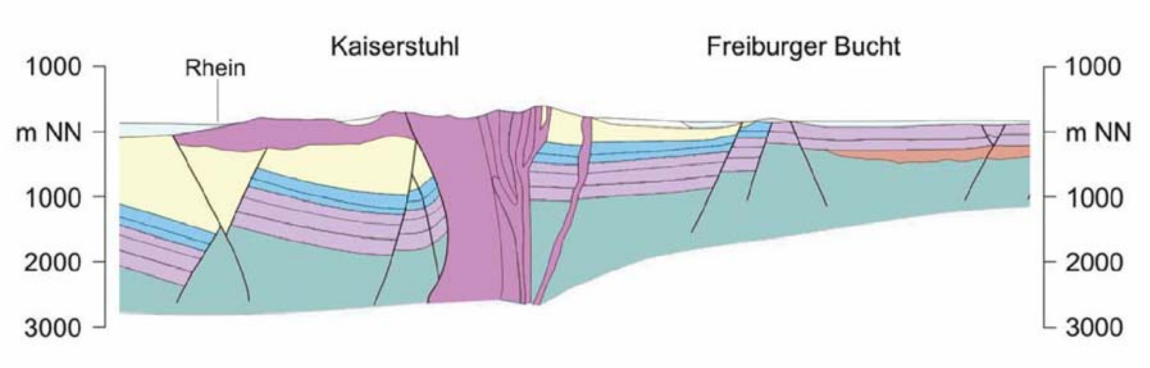

Fig. 3.1: *Example of block faulting (geological cross section of the Southern Upper Rhine Valley)*

- Crystalline rocks

  For crystalline rocks, the data density is very low. It directly depends on the former and current interests concerning mineral deposits. For an exhaustive characterisation of large regions of crystalline rocks, the situation at greater depth is usually extrapolated from outcrops, and a transfer of data is attempted as, for example, from the Black Forest to the crystalline rocks in the subsurface of Northern Switzerland. As this example shows, this is connected with substantial inaccuracies and uncertainties. An exhaustive determination of data from regions of crystalline rocks is therefore associated with excessive investigations and considerable time effort.

Conclusion and recommendation

For the application of geoscientific exclusion criteria and minimum requirements in Step 1 of the selection procedure, data are required that can be made available with relatively little effort. This does not apply, in general, to the data on the age of groundwater in deep geological formations.

The weighing criteria, however, show gaps in the quantity and quality of data. The filling of these gaps for the whole geographical area of Germany would partly require a great deal of time and effort and could lead to considerable delays in the site selection procedure. On the other hand, the exclusion of areas only due to knowledge and data deficits contradicts the principle of justice. To solve the dilemma, the Committee recommends the following proceeding:

The Committee recommends that all relevant geoscientific data acquired in Germany and needed for the selection procedure for repository sites shall be made available. This partly concerns data from industry which, however, may be subject to special protection, and partly data available from the authorities and institutions of the Federal Government and the *Länder*.

In Step 1 of the procedure, those areas are excluded for which the information and data available are sufficient for exclusion.

In Step 2 it is examined whether the available database allows an identification of at least five partial areas with particularly favourable geological conditions. If this is the case, there are sufficient alternatives for the subsequent procedure steps. Areas with substantial information and data gaps are deferred.

If it is not possible to identify at least five partial areas in Step 2 on the basis of sufficient data, a decision has to be taken whether further data shall be acquired and which areas with an insufficient database shall be further investigated. Here, economic aspects and also expectations regarding the favourable geological properties have to be taken into consideration, which can be justified on the basis of the information available.

3.3.2 Socio-scientific data

Specific databases related to the search for a repository site are not available from social sciences. For this reason, the Committee suggested several projects for obtaining relevant data.

First of all, this concerns two representative polls determining the public opinion on questions related to participation, the relation to the region and disposal [STOLLE 2002]. In addition, studies were commissioned on public participation and regional planning.

Further, several studies on public participation in other areas of activities are also significant to the search for a repository site. Here, different experiences in the development of participation models regarding contaminated sites, waste dumps and other large-scale projects were evaluated.

However, it must be stressed that most of the socio-scientific data can only be acquired once the search for a repository site has started. This, of course, refers to the public's willingness to participate, but also to the investigation of development potentials and the impact which a repository might have on the development of these potentials.

Regarding the planning-scientific criteria, the situation is different. The necessary data for the application of these criteria are available nation-wide from the responsible authorities and offices.

4 Criteria for the selection of repository sites

According to the procedure structure presented in Chapter 3.2, the selection procedure is divided into procedure steps the performance of which is steered by the application of geo- and socio-scientific criteria. The presentation of the criteria is the subject matter of this chapter.

Exclusion criteria have been developed both in the geo- and the socio-scientific area. On the basis of the general requirements, minimum requirements were derived for the geological setting of the areas to be assessed. In addition, weighing criteria have been developed for the weighing of results in the geo- and socio-scientific areas.

4.1 Geoscientific criteria

4.1.1 Fundamentals and definitions

For the presentation of the geoscientific criteria, the following terms are defined:

Geological barriers: Geological units between the emplacement area and the biosphere which hinder or prevent the spreading of harmful substances.

Isolating rock zone: Part of the geological barrier which at normal development of the repository and together with the technical and geotechnical barriers has to ensure the confinement of the waste for the isolation period.

Host rock: The rock in which the waste is emplaced.

Repository area: Rock zone of a repository that is surrounded by the geometrically enveloping area around the repository mine.

Emplacement area: Area of a repository where waste is emplaced with subsequent isolation from the remaining mine.

Favourable overall geological setting: A favourable overall geological setting is given if the general requirements of disposal can be fulfilled in all probability by the site properties identified with geoscientific methods.

Repository system: The repository system consists of the repository area and the geological barriers.

4.1.2 Exclusion criteria

The Committee agreed that before the selection of sites with particularly favourable conditions for the suitability as a repository site, those areas should be identified that obviously show particularly unfavourable conditions by means of exclusion criteria.

These are areas in which the barrier system will be considerably adversely affected at a depth of about 1,000 metres during the isolation period, or whose development cannot, within practical reason, be predicted.

For the identification of these areas, the following effects of geological and geophysical processes on a repository with its barrier system were considered:

- Erosion of the geological formations with denudation of the repository
- Reduction of the geological barrier
- Changing of groundwater conditions
- Creation of flow paths by geological faults and fractures
- Gas/brine entering the repository
- Magmas entering the repository
- Covering by surface water

To which extent the effects of all of the developments can be assessed depends on the respective existing knowledge. Therefore, it was necessary for the derivation of criteria to check the available information base and to take into account existing indicators. After clarification of this prerequisite, the Committee identified the following five criteria whose non-fulfilment leads to the exclusion of areas from the site selection procedure:

- **Large-area vertical movements:** The repository area must not show large-area uplifts of more than one millimetre per year on average during the predictable period.

- **Active fault zones:** There must not be any active fault zones in the repository area

- **Seismic activity:** In the repository area, the seismic activities to be expected must not exceed Earthquake Zone 1 according to DIN 4149.

- **Volcanic activity:** In the repository area, there must neither be any quaternary nor any expected future volcanism.

The consideration of the following fifth criterion (groundwater age) requires a comprehensive overall interpretation of the hydrochemical and isotope-hydrological groundwater conditions at a site. Old groundwater indicates low groundwater movement and thus a favourable overall geological setting. The necessary detailed information is available at best coincidentally at a few sites. However, the existence of certain environmental isotopes (tritium, carbon-14), which can be relatively simply determined and interpreted, are good indicators of young groundwater. The reverse inference, however, is not possible (see Chapter 4.1.2.5).

- **Groundwater age:** The isolating rock zone must not contain any young groundwater. Thus the groundwater must contain no tritium and/or carbon-14.

The derivation of these criteria clearly showed the dependence on the respective state of knowledge and the database. In addition, it turned out that the implications connected with the criteria are closely interrelated, and that a separate examination of the geological processes involved cannot be made in all of the cases.

The problems related to the demarcation of the areas concerned also became obvious [BRÄUER & JENTZSCH 2001]. Therefore, it was necessary for the identification of the areas to be excluded from the site selection procedure, to examine the applicability of each of the five mentioned criteria to the demarcation of individual areas.

4.1.2.1 Large-area vertical movements

Basis for the identification of areas with vertical movements of more than one millimetre per year in Germany are the maps of the Federal Agency for Cartography and Geodesy (BKG) and maps of the geological offices of the *Länder*, as well as scientific publications on special areas (e. g. the Rhenish Shield, coastal regions).

Vertical movements are an expression of geodynamic activity and thus represent a potential hazard to a repository. In small areas, they can also occur in connection with groundwater lowering and underground flooding (mainly by mining activities).

When identifying clearly unfavourable areas for the construction of a repository with increased vertical movements, distinction has to be made between natural and anthropogenic movements, i. e. induced by human activities. For the identification of the areas to be excluded for the construction of a repository, the main large scale, natural and irreversible vertical movements are referred to first.

Assuming constancy and simultaneous erosion, tectonic uplifts of one millimetre per year would uncover a repository at a depth of 1,000 metres in one million years. Consequently, areas with large natural uplift of this order of magnitude are considered to be unfavourable for the selection of a repository site by the Committee. These areas should be excluded from the site selection procedure.

Problems may arise with the exact and applicable demarcation of the unfavourable areas. This applies, in particular, in connection with anthropogenic movements. Vertical movements of an area are closely related to the occurrence of geodynamic activities and should be interpreted in connection with earthquakes and the distribution of fault zones. Adjacent areas and minor depression areas (e. g. areas of subrosion) should be subjected to a special investigation.

4.1.2.2 Active fault zones

The term "active fault zone" means both the process itself and the result of the process. In the broadest sense, a disturbance is defined as a tectonic or atectonic process that changes the primary stratification structure that was formed during the genesis of the rocks. Thus, this term comprises both plastic and fracture deformation. Fracture deformation can either cause faults (with rock dislocation) or fractured zones.

Faults with distinctive rock dislocation are identified and documented by conventional geological mapping or seismics. Fractured zones can generally not be identified by traditional mapping methods. In this respect, special methods are required, as e. g. remote sensing or resistivity measurements to register moisture anomalies or other geophysical methods.

In many areas, the temporal and spatial genesis of geological faults or fault zones has not been clarified satisfactorily. In general, the database on geological facts is only sufficient for a very rough reconstruction of the movements that have taken place.

"Active geological fault zones” generally means disturbances with movements in the neotectonic period. This period extends to the present time and begins with the basis of the Neocene (Miocene to Pliocene) or the basis of the Rupel (Sub-Oligocene), respectively, whose marine reference area has an absolute age of 34 million years. This geological formation can be found, e. g. in Northern Germany, over extended areas. The younger, quaternary (pleistocenary) fracture-tectonic movements, however, can hardly be identified, since their base does not represent a clear time mark according to which the movements can be traced. If Neocene or Rupel sediments are missing, as e. g. in large parts of Southern Germany, attempts are made to reconstruct recent vertical movements by means of geomorphologic data (e. g. mapping of fluvial terraces).

The Committee agreed that all geological faults are to be regarded as neotectonic “active geological fault zones” with safety relevance for a repository,

- where movements took place verifiably or took place to all probability in the Rupel period until today,
- which are clearly related to seismic events, and
- where verifiable fluid transport takes place.

Besides the dislocation values which can be measured today at the earth's surface and dislocations observed in the layers, differences in the thickness at both sides of the geological faults in identical formations are also regarded as indicators for tectonic movements.

The presumed widths of fault zones have to be estimated individually. Since an exact zone extension generally cannot be determined, an "additional safety reserve" of some kilometres at both sides of the identified zones should be applied for the identification of areas with particularly unfavourable conditions.

4.1.2.3 Seismic activity

The basis for a demarcation of areas in Germany with earthquake risk is the map of earthquake zones in Germany (DIN 4149) (see Fig. 4.1). In this respect, zones were demarcated according to the maximum credible earthquake in a period of about 500 years. This was based on the historical German earthquake catalogue that lists all earthquakes in Germany since the year 800, the map of seismotectonic regions in Germany, and the distribution of earthquakes causing observable damage in Germany. The map also includes assumptions on maximum credible earthquakes in the respective areas.

Regarding the demarcation of an obviously unfavourable area for the construction of a repository, it has to be taken into account that the zones defined refer to damages to surface structures. The impact of earthquakes on underground structures, however, is generally estimated to be minor.

Against this background, the Committee came to the conclusion that a demarcation of unfavourable areas is only reasonable for Earthquake Zone 2 of DIN 4149 and higher. This corresponds to a maximum observed earthquake intensity of 7.0 and more at the surface. This is the intensity at which noticeable damage to buildings begins. Depending on the building, earthquakes with smaller intensities have only little or no damaging effect. Regarding the exact demarcation of the unfavourable areas, border areas should be subjected to individual examinations.

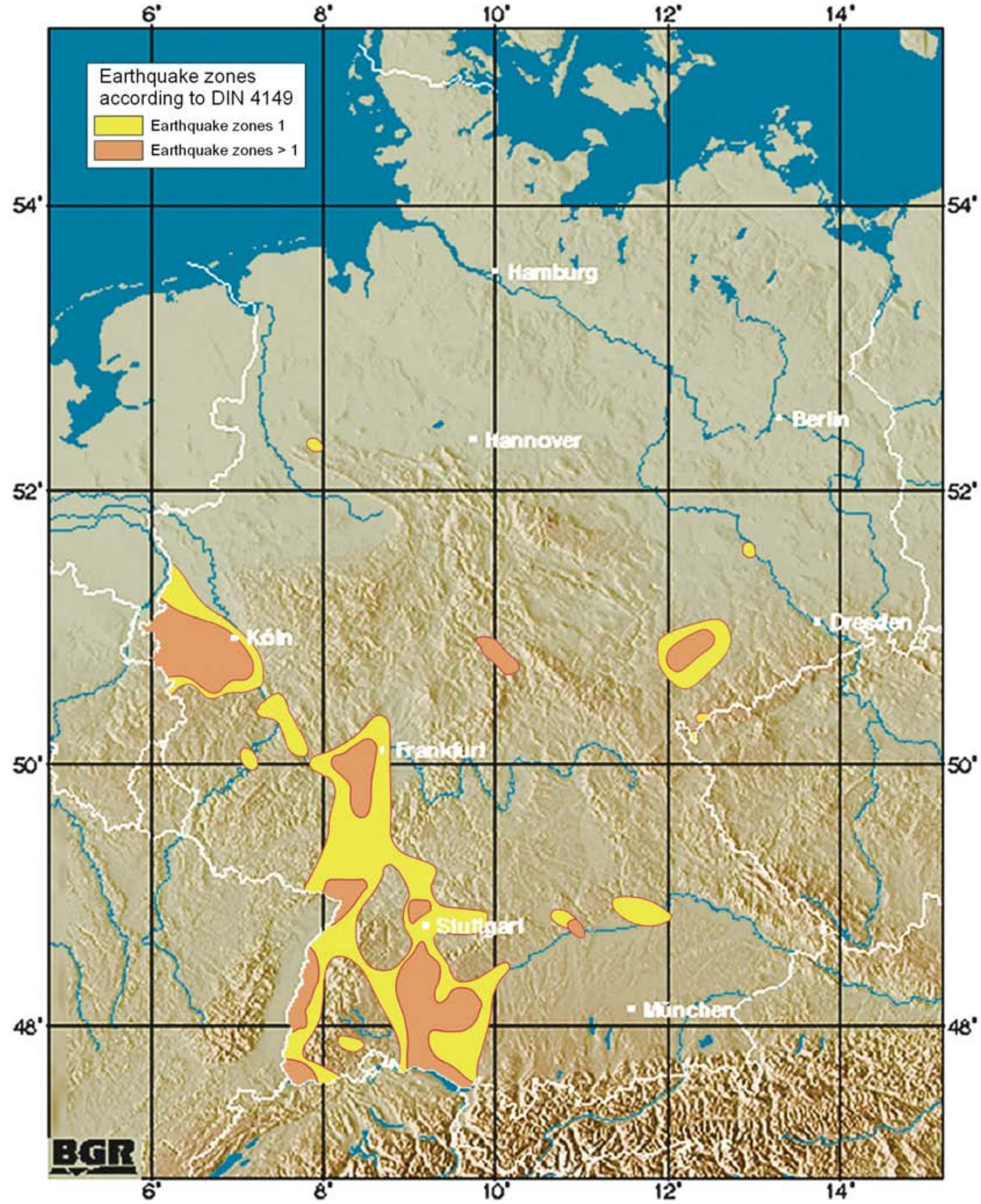

Fig. 4.1: Map of earthquake zones in Germany according to DIN 4149 (source: BGR)

The seismic activity of an area is closely related to the occurrence of active geological fault zones. It is clear that, with regard to all data on seismic hazards of an area, a prediction only based on earthquakes registered from the year 800 on cannot be made for a period of one million years.

4.1.2.4 Volcanic activity

The assessment of volcanic hazards in Germany is based on a survey of experts [JENTZSCH 2001], according to which the following questions were to be answered:

1. Up until now, the Eifel and the Vogtland/Egergraben were named as regions with quaternary volcanism. Can volcanic activities occur in a prediction period of one million years, has this statement to be made with reservations, or do further areas have to be taken into consideration?

2. Which probability has to be expected regarding the resurgence of volcanism in a period of one million years?

3. Where is the centre of a potential eruption to be assumed, how large can the radius of direct effects be?

4. Which other effects would be possible?

5. How large could the area affected be?

6. How do other countries handle the issue of volcanic hazards?

All experts consulted stated that in Germany, except for the Eifel and Vogtland/Egergraben regions, no further areas with volcanic hazards have to be specified (see Fig. 4.2).

The resurgence of volcanism in the Eifel in the prediction period of one million years is to be definitely expected. Indications for an impending eruption should be noticeable in a period of about one to two years before the event.

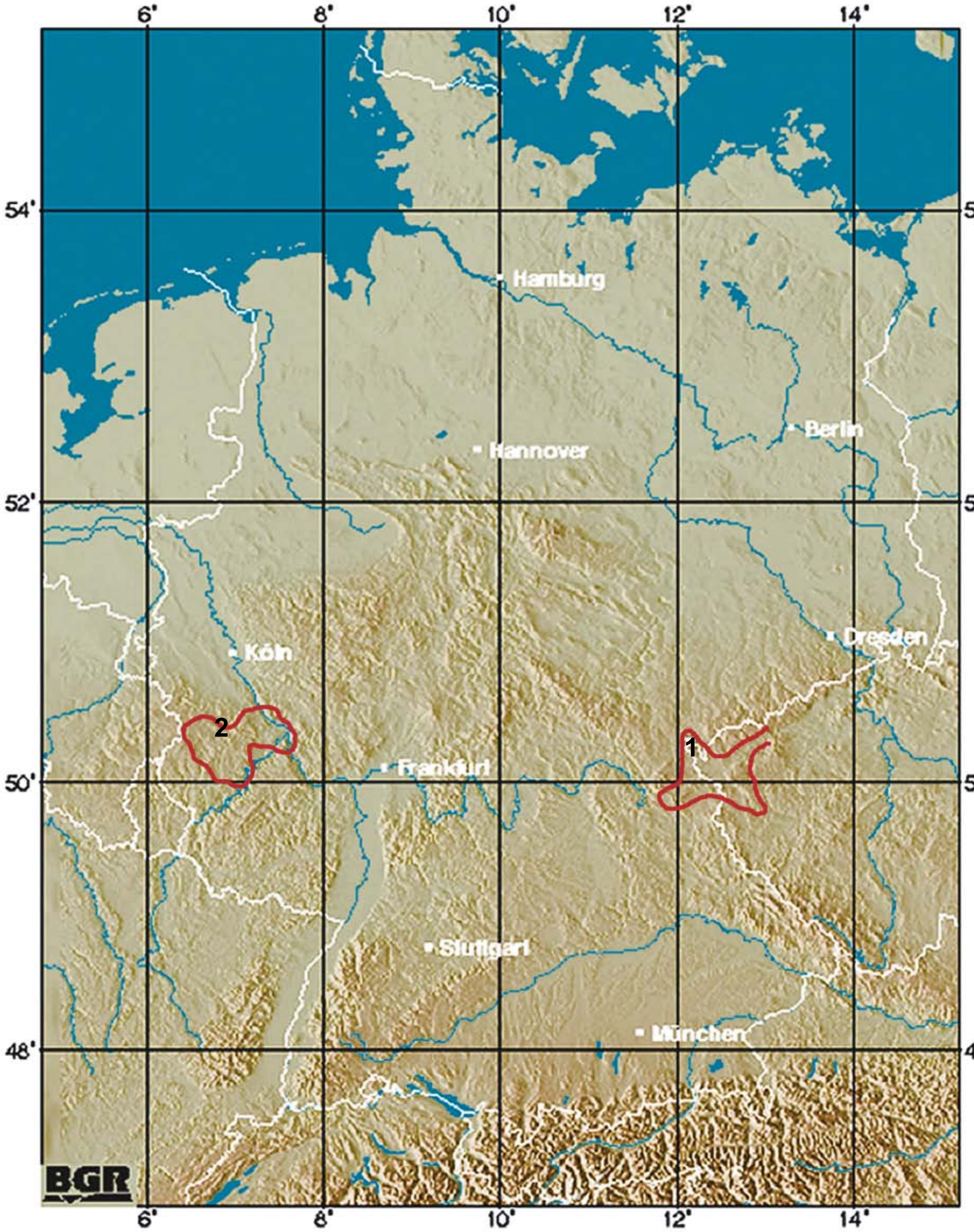

Fig. 4.2: *Map of areas in Germany with volcanic hazard. 1 = Vogtland/Egergraben, 2 = Eifel (source: BGR)*

According to the present state of knowledge, there is a probability of about 50 % for the resurgence of volcanism in the Vogtland region in the Western part of the Eger Rift for the prediction period.

As effects of volcanic activity at the surface, the following is assumed: uplifts (potential impact on dams), volcanic tremor, forest fire (by eruption), and formation of maars (explosive). Uplift processes would affect an area of about 500 km² to 1,500 km², forest fires could extend to an area of about 50 km² to 200 km², and maars can develop in a region of about 50 km² to 200 km². The vicinity, up to a distance of about 5 kilometres from the eruption centre, is endangered by highly explosive magma-water eruptions and their accompanying blast waves. Lava streams and lahars (massive flows of mud and debris) can fill up valleys over many kilometres (in the Eifel up to about 10 km).

Even if magmatic intrusion into a repository is very improbable, underground effects still have to be mentioned: thermal stresses, volcanic tremors and induced movements at geological faults may impair the integrity of the repository and reduce the barrier effectiveness by the intrusion of groundwater.

Regarding the underground effects of volcanic activities, model studies show that thermal stresses only occur in the direct vicinity of an active volcanic vent (to a distance of 1 km approx.), which may cause fracturing after several thousands of years.

In the USA, those volcanic activities are classified as unfavourable conditions in the NRC guidelines [NRC 2000] that might alter the groundwater system so strongly that it impairs the barrier effectiveness of the geological environment of the repository.

The Committee decided that future volcanic activity should also be considered for the selection of a repository site in Germany, as well as an additional safety margin of 10 km around potentially endangered areas with regard to the exclusion of areas with volcanic activity.

4.1.2.5 Groundwater age

Groundwater of a very old age must have had a very long residence time in the aquifer and thus, most probably, does not participate in the active hydrological system or if so then only to a small degree. Groundwater of a very old age is therefore an indicator for long-term low groundwater movement (and stable hydrochemical groundwater conditions).

However, only the comprehensive interpretation of the hydrochemical and isotope-hydrological groundwater conditions at a site (in a region) allows substantiated statements on the groundwater age. The detailed information required is available at best coincidentally from a few sites (regions) only and cannot be obtained for all sites (regions). However, from relatively simply determinable and interpretable concentrations or concentration conditions, respectively, of specific environmental isotopes, conclusions can be drawn for a favourable or unfavourable overall geological setting with regard to the groundwater age.

Tritium, deuterium, carbon-14 and oxygen-18 belong to the environmental isotopes, which are analysed relatively frequently. From these, only deuterium and oxygen-18 can be considered, in a very limited manner, for statements on the groundwater age:

The ratio of δ(deuterium) to δ(oxygen-18)[2] corresponding to the so-called "global meteoric water line" characterises the isotope composition of today's precipitations, and thus possibly also of new groundwater from precipitation. Ratios of δ(deuterium) to δ(oxygen-18) essentially deviating from the global meteoric water line indicate the generation of groundwater under special climatic conditions, the change of isotope composition by exchange processes in the aquifer, or principally different generation conditions (e. g. marine water). Only if the influencing factors are known, can conclusions be drawn on the groundwater age from the ratio of δ(deuterium) to δ(oxygen-18).

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[2] δ(deuterium) and δ(oxygen-18) are concentrations referred to a standard value.

On the other hand, the concentrations of tritium and carbon-14 are quite reliable indicators for young groundwater, compared to the required isolation period in the order of magnitude of one million years. The existence of tritium and carbon-14 characterises groundwater with ages of some decades to a few ten thousands of years. From this, the following conclusions can be drawn:

- The groundwater in host rocks and the isolating rock zone of a site (of a region), as well as the safety-relevant areas of their surroundings must not contain any tritium and/or C-14.
- However, the fulfilment of this criterion alone does not give sufficient evidence of sufficiently old groundwater, and thus of a favourable overall geological setting. It only has the effect that the respective sites (regions) remain in the site selection procedure.

4.1.3 Minimum requirements

For the identification of areas where the geological structures can fulfil the requirements with regard to the isolation capacity and necessary depth, minimum requirements have been developed. Areas not fulfilling these criteria are excluded from the procedure. Areas fulfilling the minimum requirements regarding a favourable overall geological setting remain in the procedure. If the data for the examination of a minimum requirement are not sufficient, the areas remain in the procedure for the time being. The decision whether and when the missing data shall be acquired is taken in later steps of the procedure. The check on fulfilment of the minimum requirements is performed in all procedure steps.

The minimum requirements are derived from the general requirements as follows:

To guarantee the isolation of radioactive waste, only low groundwater movement may exist in the rock formation of the isolating rock zone. This is determined by the field hydraulic conductivity and the existing pressure gradient. In the case of rock types with very low field hydraulic conductivity, low groundwater movement can be assumed from the outset. If there are mainly rock types with a field hydraulic conductivity above 10^{-10} m/s in an area, the required low groundwater movement cannot be expected. Therefore, a minimum requirement for the limitation of the groundwater flow is that a geologically favourable situation must mainly involve rocks that permit only limited groundwater movement due to low field hydraulic conductivity. The field hydraulic conductivity of the isolating rock zone must therefore not exceed 10^{-10} m/s and its thickness must be at least 100 m.

Moreover, the spatial extension of the respective rock formations must be so large that it will be possible to construct a safe repository. Taking into account the heat generation of the waste and the infrastructural requirements for a repository mine, this means that 3 km^2 in salt and 10 km^2 in clay or granite are required.

The depth of the top of the required isolating rock zone must be at least 300 m to protect the repository sufficiently against natural influences from the earth's surface. Mining operation at greater depths requires considerable technical efforts due to correspondingly increasing rock temperatures. Therefore, the repository mine must not be located any deeper than 1,500 m.

From the rock-mechanic point of view, the host rock must not be vulnerable to rock burst in order to guarantee the necessary safety during the construction and operation of a repository.

The determined safety-related geoscientific conditions and thus the effectiveness of the geological barriers must last for the period taken as a standard in the safety assessments. Therefore, there must be no findings or data which give rise to doubts as to whether the geoscientific minimum requirements regarding field hydraulic conductivity, thickness and extent of the isolating rock zone can be fulfilled over a period of time of the order of magnitude of one million years.

The criteria on the minimum requirements are summarised in Table 4.1:

Table 4.1: Minimum requirements

Minimum requirement
The isolating rock zone must consist of rock types to which a field hydraulic conductivity of less than 10^{-10} m/s can be assigned.
The thickness of the isolating rock zone must be at least 100 m.
The depth of the top of the required isolating rock zone must be at least 300 m.
The repository mine must lie no deeper than 1,500 m.
The isolating rock zone must have an areal extension that permits the realisation of a repository (e. g. approximately 3 km^2 in salt or 10 km^2 in clay or granite).
Neither the isolating rock zone nor the host rock must be at risk from rock burst.
There must be no findings or data which give rise to doubts whether the geoscientific minimum requirements regarding field hydraulic conductivity, thickness and extent of the isolating rock zone can be fulfilled over a period of time in the order of magnitude of one million years.

4.1.4 Criteria for the determination of particularly favourable partial areas

4.1.4.1 General requirements and weighing process

Regarding the suitability of a repository site, the Committee is of the opinion that not only the host rocks are decisive but also a favourable overall geological setting, which ensures the isolation of the waste from the objects of protection for a period of the order of magnitude of one million years and also gives reason to assume that there will be no inadmissible releases in the time after this period.

A favourable overall geological setting is given when - with regard to the site properties identified with geoscientific methods - the general requirements of disposal, as required in Chapter 2, can be fulfilled with a high probability.

General requirements on repository sites

A favourable overall geological setting is characterised by the fulfilment of the following general requirements on repository sites; in this respect, not every single requirement has to be fulfilled completely. The quality of the geological overall setting rather depends on the degree of fulfilment of the requirements on the whole:

- **No or slow transport with groundwater at repository level**

  Requirement of low migration of harmful substances out of the isolating rock zone, long groundwater flow times and radionuclide transport times

- **Favourable configuration of host rock and isolating rock zone**

  Requirement of a large volume of the isolating rock zone, large safety distances to water-bearing formations, and safety in the case of the failure of single barriers

- **Good spatial characterisability**

  Requirement of high reliability regarding the safety assessment, high planning reliability for the repository, and low exploration effort

- **Good predictability**

  Requirement of high reliability regarding the safety assessment for long periods of time, sound justification of the scenarios for the release and spreading of harmful substances, and the reduction of uncertainties

- **Favourable rock-mechanic conditions**

  Requirement to minimise damage to the barrier systems resulting from the construction and operation of the repository mine

- **Low tendency of the formation of water flow paths**

  Requirement of a robust behaviour of the barrier rocks of the isolating rock zone in the case of loads and stresses, i. e. requirement of a low probability of the formation of water flow paths or of a high self-healing capacity

- **Good gas compatibility**

  Requirement to control the gas generation of the waste so that there are no concerns about the integrity of the isolating rock zone

- **Good temperature compatibility**

  Requirement to reduce the effects of heat input on the isolating rock zone and to prevent impairment due to thermal or thermomechanical loads

- **High radionuclide retention capacity of the rocks**

  Requirement of good radionuclide sorption characteristics of the rocks

- **Favourable hydrochemical conditions**

  Requirement to reduce the release and transport of radionuclides

To which extent the general requirements regarding a favourable overall geological setting are fulfilled is assessed by means of weighing criteria. For this purpose, properties, i. e. characteristic site-/groundwater-/rock-features, are assigned to the general requirements and transformed into criteria. The criteria establish the logical or mathematical link between the assessment standard and the related parameter. For their derivation, the following conditions have to be applied:

- The properties to be analysed have to be relevant to the suitability of the site.
- The information necessary for the application of a criterion has to be available for all sites or collectible within the procedure and interpretable in a reliable manner.

The knowledge about regional geological conditions in Germany is not homogeneous. This fact must be taken into account in the selection procedure. Additionally, it may occur that the assessment parameters originally to be taken as a basis cannot be determined due to lacking or insufficient data. In this case, indicators with criteria related to them have to be used instead in order to be able to carry out a corresponding assessment with sufficient reliability.

Indicators

Indicators are substitutional parameters that are used for assessment purposes if the properties to be checked cannot be determined directly or have not yet been determined. The following example illustrates the application of indicators:

In general, details on the field velocity of the groundwater as assessment parameter for the requirement “slow transport with groundwater” are not available for all areas. If a very low field velocity is required (as in the case of disposal), the problem of direct and representative measuring arises. The characteristic hydraulic groundwater and rock properties for the above requirement are a low hydraulic gradient as well as a low field hydraulic conductivity and effective porosity of the geological system. If these characteristic parameters are known, the field velocity can be estimated on the basis of models. In general, measured data on field hydraulic conductivity and porosity are not available for all areas. Here, empirical values of comparable rock types are of help, which can be used as indicators allowing an estimation of the field hydraulic conductivity and porosity. Rock types that indicate a field hydraulic conductivity of clearly less than 10^{-10} m/s and which show no penetrating fissures (fractures) are an indicator of field velocities of less than 1 mm per year.

The process of weighing

After having excluded those areas from the selection procedures in Step 1 of the procedure that do not come into question for the disposal of radioactive waste for obviously geoscientific reasons (see Chapters 4.1.2 and 4.1.3), partial areas with particularly favourable conditions for disposal are determined in Step 2 of the procedure. They are identified within the framework of a weighing process, including the following elements:

- The examination by means of weighing criteria (see Chapters 4.1.4.2 to 4.1.4.11) to which degree the general requirements on a favourable overall geological setting and the related criteria are fulfilled by the partial areas considered.
- The different weighting of the requirements and criteria considered in the identification of particularly favourable partial areas according to their significance with regard to long-term safety.
- The aggregation of the results of the weighted individual criteria in a general statement, as to which of the partial areas analysed are to be considered as

particularly favourable and as being equivalent from a safety-related point of view and which are not.

To justify the classification "particularly favourable", a partial area has to show the following advantages – considering all criteria – when compared with other partial areas:

- Higher reliability with regard to the assessment of the isolation capacity,
- less uncertainty in the assessment of the properties required,
- presence of major safety reserves.

Weighing criteria

During the weighing process, the degree of fulfilment of the requirements specified in the weighing criteria is determined for the partial areas considered. For this purpose, ordinally scaled fulfilment functions have been derived for the situations and conditions to be examined on the basis of safety considerations. These fulfilment functions are classified according to three (in exceptional cases also only two) assessment categories, i. e. “favourable”, “relatively favourable” and “less favourable”. On the basis of the available geoscientific information and findings for every partial area each criterion is assigned to one of the three (in exceptional cases two) assessment categories. A summary presentation of the weighing criteria with the corresponding fulfilment functions is included in Table 4.3.

Weighting of the general requirements

The requirements of a favourable overall geological setting and the corresponding situations and conditions to be assessed by means of the weighing criteria are of different significance for the long-term safety of a repository and the successful proof of long-term safety. This has to be taken into account when aggregating the individual results to an overall assessment. Accordingly, the Committee differentiates between three weighting groups to which the above-mentioned requirements (and the related criteria) are assigned to as follows:

Weighting Group 1 - Quality of the isolation capacity and reliability of proof

- no or slow transport with groundwater at repository level
- favourable configuration of the rock formations, in particular of the host rock and the isolating rock zone
- good spatial characterisability regarding the properties searched for
- good predictability of the long-term stability of the favourable conditions

Weighting Group 2 - Assurance of isolation capacity

- favourable rock-mechanic conditions
- low tendency of the formation of water flow paths

Weighting Group 3 - Other safety-relevant characteristics

- good gas compatibility
- good temperature compatibility
- high radionuclide retention capacity of the rocks
- favourable hydrochemical conditions

Site-specific knowledge and information about the repository concept must be on hand particularly for the determination of the characteristic "favourable hydrochemical conditions" which will be made available in Step 4 of the procedure at the earliest (see Chapter 4.1.4.11).

The weighting and the assignment of the requirements and criteria to the weighing groups are based on the experience-based assessment made by the members of the Committee.

For this classification, the overall quality of the overall geological setting mainly depends on the quality of the isolation capacity and the reliability of proof (Weighting

Group 1). Here, the isolation capacity is characterised by the groundwater movement and the configuration of the safety-relevant rock formations (barrier thickness, degree of enclosure, depth and volume of the isolating rock zone, existence of rock formations with elevated hydraulic potential). The reliability of proof, however, depends on the spatial characterisability and the predictability of the overall geological setting.

The requirements summarised in Weighting Group 2 (favourable rock-mechanic conditions, low tendency of the formation of water flow paths) serve to verify the isolation capacity of the overall geological setting. In the overall assessment, less weight is given to them than the criteria of Weighting Group 1.

- The other requirements of Weighting Group 3 (good gas compatibility, good temperature compatibility, high radionuclide retention capacity of the rocks, favourable hydrochemical conditions) and related criteria are of the lowest significance in the assessment of the overall quality. In most cases, their safety significance can only be assessed in connection with the detailed repository planning and on the basis of site-specific exploration results.

Aggregation

Following the application of the weighing criteria, a comprehensive set of individual assessments is available for each of the partial areas examined. To ensure that the criteria are considered in the overall result with their due weight and that they allow the desired differentiation between particularly favourable and not particularly favourable partial areas, the proceeding is as follows:

The requirements and criteria of Weighting Group 1 are given their intended weighting in the summarising assessment by the fact that the particularly favourable partial areas that one is hoping to find have to comply with these requirements and criteria to a particularly high degree. That is the case if they are assessed as "favourable and only in a few cases as "relatively favourable" with the criteria of this group. The application of the criteria of Weighting Group 2 leads to a differentiation of the overall assessment result if those partial areas that came off similarly well in

Weighting Group 1 show any differences with regard to the fulfilment of the criteria of Weighting Group 2. Any "particularly favourable" partial areas will also have to have good results in Weighting Group 2. The same applies with regard to the weighting of the criteria in Weighting Group 3.

The Committee has not established any formalised rule for the aggregation of the individual results of the weighing process according to the specified criteria. Owing to the heterogeneity of the aspects influencing the assessment and due to the status of information at the time of the weighing process, the Committee considers it rather more appropriate that the aggregation of the individual assessment results from the three weighting groups should be done in a verbal-argumentative form.

The identification of partial areas with particularly favourable geological conditions for disposal is the outcome of this process.

The following Tables 4.2 and 4.3 present a summary of the contents from the following Chapters 4.1.4.2 to 4.1.4.11 with regard to the requirements, criteria, criteria properties relevant for the assessment, the assessment parameters or the indicators and the weighing criteria.

Table 4.2: Weighting groups, requirements and criteria

Requirement	Criterion
Weighting Group 1: Quality of the isolation capacity and reliability of proof	
1. No or slow radionuclide transport with groundwater at repository level	The field velocity of the groundwater in the isolating rock zone should be as low as possible, i. e. clearly below 1 mm per year. The isolating rock zone should consist of rock types which, according to experience, show low field hydraulic conductivity. The effective diffusion coefficient in the isolating rock zone should be as low as possible (less than 10^{-11} m^2/s).
2. Favourable configuration of host rock and isolating rock zone	The barrier rocks of the isolating rock zone must have a thickness that ensures the isolation of radionuclides for a period in the order of magnitude of one million years. The repository area and the host rock body should be surrounded by barrier rocks of the isolating rock zone. The top of the required isolating rock zone should be as deep as possible. The spatial extension of the isolating rock zone should be larger than the required volume calculated for the repository. The specific hydraulic gradient in the isolating rock zone should be low (less than 10^{-2}).
3. Good spatial characterisability	The rock types and their characteristics should spatially be as evenly distributed as possible within the isolating rock zone. The geological structure should show as little tectonic imprinting as possible. Its extent is derived from the structural situation with consideration of fault and fold tectonics. Salt rock structures should show large-scale folding of strata with different mechanical and hydraulic properties. Areas are favourable where the rocks of the isolating rock zone are uniform or very similar across an extensive area.
4. Good predictability	The features "thickness", "extent" and "field hydraulic conductivity" of the isolating rock zone should not have changed essentially for several million years.
Weighting Group 2: Assurance of isolation capacity	
5. Favourable rock-mechanic conditions	There should be a low tendency to mechanically induced secondary permeability outside a contour-near deconsolidated border zone around the repository excavations.

Requirement	Criterion
6. Low tendency of the formation of water flow paths	The representative field hydraulic conductivity should be the same as the representative matrix hydraulic conductivity. The barrier effectiveness of the rock mass against the migration of liquids or gases (under geogenic and in part also under anthropogenic impacts) should be derivable from geoscientific, geotechnical or mining experience. Under in-situ conditions, the rock should naturally show a plastic-viscous deformation ability without dilatancy. Upon stress inversion (increasing isotropic stress and decreasing deviatory stress), fissures/fissure systems in the rock should be closed in a geohydraulically effective manner. Following fissure closure, fissures/fissure systems in the rock should be healed in a geomechanically effective manner.
Weighting Group 3: Other safety-relevant characteristics	
7. Good gas compatibility	Gas generation of the waste under disposal conditions should be as low as possible. The pressure build-up due to the expected gas generation of the waste should be low.
8. Good temperature compatibility	In the rock immediately surrounding the emplacement cavities, no mineral changes that would exert an inadmissible influence on the barrier effect of the isolating rock zone must occur if temperatures lie below 100 °C. The tendency to thermomechanically induced secondary permeability outside a contour-near deconsolidated border zone should be as much spatially restricted as possible.
9. High radionuclide retention capacity of the rocks	The sorption capacity of the rocks should be as high as possible. The Kd-value for the majority of the long-term-relevant radionuclides should be greater than or equal to 0.001 m^3/kg. The rocks of the isolating rock zone should have the highest possible contents of mineral phases with a large reactive surface.
10. Favourable hydrochemical conditions	The deep groundwater in the host rock and in the isolating rock zone should be in chemical equilibrium with the rocks. Deep groundwater should have a pH value of 7 - 8. Favourable redox conditions should prevail in deep groundwater. The content of colloids in deep groundwater should be as low as possible. The content of complexing agents and the carbonate concentration in deep water should be low.

Table 4.3: Fulfilment functions for geoscientific weighing criteria

Criterion property relevant for assessment [dimension]	**Assessment parameter of the criterion or indicator** [dimension]	**Assessment group**		
		Favourable	**Relatively favourable**	**Less favourable**
Requirement: No or slow transport with groundwater at repository level (Weighting Group 1); (Chapter 4.1.4.2)				
Groundwater flow	Field velocity of the groundwater [mm/a]	< 0.1	0.1 - 1	> 1
Groundwater availability	Field hydraulic conductivity [m/s]	< 10^{-12}	10^{-12} - 10^{-10}	
Diffusion velocity	Effective diffusion coefficient [m^2/s]	< 10^{-11}	10^{-11} - 10^{-10}	> 10^{-10}
Requirement: Favourable configuration of host rock and isolating rock zone (Weighting Group 1); (Chapter 4.1.4.3)				
Barrier effectiveness	Barrier thickness [m]	> 150	100 - 150	50 -100
	Degree of enclosure of the host rock by the isolating rock zone	Complete	Incomplete	
Robustness and safety reserves	Depth of the top of the required isolating rock zone [m below earth's surface]	> 500	300 - 500	
Volume of the isolating rock zone	Areal extension for a given thickness [multiple of the required minimum area (e. g. 3 km^2 for salt and 10 km^2 for clay)]	> Twofold	Twofold	< Twofold
Existence of rock formations with elevated hydraulic potential	Specific hydraulic gradient (for a field hydraulic conductivity of 10^{-10} m/s and an effective porosity of 0.1)	<< 10^{-2}	Approx. 10^{-2}	>> 10^{-2}
Requirement: Good spatial characterisability (Weighting Group 1); (Chapter 4.1.4.4)				
Possibility of determining rock types within the isolating rock zone	Spatial distribution of rock properties in the isolating rock zone	Constant	Continuous spatial variation	Discontinuous spatial variation

Criterion property relevant for assessment [dimension]	**Assessment parameter of the criterion or indicator** [dimension]	**Assessment group**		
		Favourable	**Relatively favourable**	**Less favourable**
	Extent of tectonic overprint on the geological unit.	Mainly unfaulted (fault spacing > 3 km); low inclination of layers	Sparsely faulted (fault spacing 100 m to 3 km); flexures	Intensely faulted (closely blocked, fault spacing < 100 m); intensely folded
	For salt:	Large oval salt structures		Small round or narrow elongated salt structures
Transferability of the properties of the isolating rock zone	Rock shape (rock facies)	Facies regionally uniform	Facies variation with known pattern	Facies variation with unknown pattern
Requirement: Good predictability (Weighting Group 1); (Chapter 4.1.4.5)				
Long-term stability of the favourable conditions	Temporal change of the features “thickness”, “extension”, and “field hydraulic conductivity” of the isolating rock zone	No significant change of the considered features over periods longer than 10 million years	No significant change of the considered features over periods of 1 to 10 million years	No significant change of the considered features over periods up to 1 million years
Requirement: Favourable rock-mechanic conditions (Weighting Group 2); (Chapter 4.1.4.6)				
Tendency to mechanically induced secondary permeability outside a contour-near deconsolidated border zone	Depth of the repository relative to the graph of the maximum admissible depth, which is dependent on the rock mass’ compressive strength (Figure 4.9: Consolidated rocks with no or marginal creep behaviour; Figure 4.10: Consolidated rocks with distinct creep behaviour)	The depth under evaluation lies beneath the graph of the maximum admissible depth, which is dependent on the rock mass’ compressive strength	The depth under evaluation lies moderately above (> 10 %) the graph of the maximum admissible depth, which is dependent on the rock mass’ compressive strength	The depth under evaluation lies clearly above (> 10 %) the graph of the maximum admissible depth, which is dependent on the rock mass’ compressive strength

Criterion property relevant for assessment [dimension]	**Assessment parameter of the criterion or indicator** [dimension]	**Assessment group**		
		Favourable	**Relatively favourable**	**Less favourable**
Requirement: Low tendency of the formation of water flow paths (Weighting Group 2); (Chapter 4.1.4.7)				
Changeability of the field hydraulic conductivity	Ratio representative field permeability / representative matrix permeability (measured as hydraulic conductivity in m/s)	< 10	≤ 100	> 100
	Experience on the barrier effectiveness of the rock formation	On the basis of single or multiple fields of experience, the rock formation/rock type is directly/indirectly identified as impermeable or poorly permeable even under geogenic/techno-genic stress.	The rock formation/rock type cannot directly/indirectly be identified as impermeable or poorly permeable due to lack of experience.	The rock formation/rock type is directly/indirectly identified as not sufficiently impermeable due to experience from a single field.
	Ductility of the rock	Ductile / plastic-viscous behaviour	Brittle-ductile to slightly elasto-visco-plastic	Brittle, linear-elastic
Self-healing capacity of fissures	Degeneration of secondary permeability	In principle, total closure of fissures with adaptation of surface roughness due to ductile behaviour of the rock.	Fissures are closed mechanically in connection with secondary processes, e. g. deformation due to swelling.	Incomplete closure of fissures (e. g. brittle failure; roughness of fissure surfaces; asperity contacts).

Criterion property relevant for **assessment** [dimension]	Assessment parameter of the criterion or **indicator** [dimension]	Assessment group		
		Favourable	**Relatively favourable**	**Less favourable**
	Recovery of mechanical properties	Healing of fissures due to geochemically dominated processes with reactivation of atomic bonding forces between fissure surfaces.		Healing of fissures only due to crystallisation of secondary mineral phases (mineralised fluids in pore and fracture spaces; secondary mineralisation).
Summary assessment of the tendency of the formation of water flow paths on the basis of the assessment of each indicator:		Assessment mainly "favourable": No or marginal tendency of formation of water flow paths	Assessment mainly "relatively favourable": Marginal tendency of formation of permanent water flow paths	Assessment mainly „less favourable": Formation of permanent secondary water flow paths has to be expected
Requirement: Good gas compatibility (Weighting Group 3); (Chapter 4.1.4.8)				
Gas generation	Availability of water in the host rock	Dry	Wet and impermeable (field hydraulic conductivity < 10^{-11} m/s)	Wet
Pressure build-up	Field hydraulic conductivity [m/s]	> 10^{-9}	10^{-9} - 10^{-10}	< 10^{-10}
Requirement: Good temperature compatibility (Weighting Group 3); (Chapter 4.1.4.9)				
Temperature stability of the rock	Temperature at which mineral reactions commence [°C]	> 120	100 - 120	< 100

Criterion property relevant for **assessment** [dimension]	Assessment parameter of the criterion or **indicator** [dimension]	Assessment group		
		Favourable	**Relatively favourable**	**Less favourable**
Thermally induced secondary permeability	Extension of the thermomechanically disturbed rock zone around the emplacement cavities [m]	< 10	10 - 50	> 50
	Tensile strength [MPa] in the near field (about 10 m to 50 m) of the repository at a contact temperature of 100°C for granite claystone rock salt	 > 13 > 8 > 2	 ≥ 8 ≥ 4 1 - 2	 < 8 < 4 < 1
Requirement: High radionuclide retention capacity of the rocks (Weighting Group 3); (Chapter 4.1.4.10)				
Sorption capacity of the rocks in the isolating rock zone	Kd-value for long-term relevant radionuclides ≥ 0.001 [m^3/kg]	Uranium, Protactinium, Thorium, Plutonium, Neptunium, Zirconium, Technetium, Palladium, Iodine, Caesium, Chlorine	Uranium, Plutonium, Neptunium, Zirconium, Technetium, Caesium	
	Mineral phases with large reactive surface	High contents of mineral phases with large reactive surfaces such as clay minerals, Fe- and Mn-hydroxides and -oxihydrates		

4.1.4.2 Transport with groundwater at repository level

Regarding the disposal of radioactive waste, the hydrogeological situation is classified as “favourable” if both the groundwater supply to the waste and the groundwater movement in the isolating rock zone are limited. A restricted groundwater supply limits, e. g., the corrosion of the waste containers and thus the release of radionuclides from the waste. Restricted groundwater movement is a condition for slow advective transport of harmful substances out of the isolating rock zone.

Field velocity of the groundwater

Subject matter

The requirement of "no or slow radionuclide transport with groundwater at repository level" characterises a favourable hydrogeological setting. A setting is referred to as favourable if there is only low groundwater movement in the repository formation. This meets the requirements for low radionuclide transport through the isolating rock zone. The assessment parameter for this requirement is the field velocity of the groundwater. This is calculated from the distance that the groundwater travels within one unit of time.

Criterion: The field velocity of the groundwater in the isolating rock zone should be as low as possible, i. e. clearly below 1 mm per year.

Weighing: Field velocity in the isolating rock zone:

Field velocity in mm/a	< 0.1	0.1 - 1	> 1
Assessment group	favourable	relatively favourable	less favourable

Indicator for the non-existence of groundwater movement is permanently dry rock.

For water-bearing rocks, several indicators for low groundwater movement are examined in the following with regard to the development of criteria.

Indicator: Field hydraulic conductivity of rock types

A property of the rock formations of the isolating rock zone of special importance regarding groundwater movement and advective transport of radionuclides is the field hydraulic conductivity, i. e. the water permeability of the natural rock association. The relevant parameter is the hydraulic conductivity coefficient or k_f-value. Rock formations are looked for with low field hydraulic conductivity, i. e. that impede groundwater movement and thus the transport of radionuclides.

The field hydraulic conductivity can only be determined by specific in-situ tests. Usually, so-called packer tests are performed in boreholes to this end. Within the framework of a site selection procedure, this cannot be realised in advance for all of the rock formations to be considered. However, it is normally known at an early stage of the procedure, which rock types are involved in the structure of the favourable overall geological setting to be considered. This means that if certain rock types can be assigned to characteristic bandwidths of field conductivity, the rock type of a rock formation can serve as indicator for its field hydraulic conductivity.

Basic principles

From applied geosciences, in particular water resources management and hydrocarbon extraction, wide experience is available on the correlation between rock type and field hydraulic conductivity. However, this mainly relates to such rock types that are not suitable for the disposal of radioactive waste due to their relatively high field hydraulic conductivity. Therefore, a systematic documentation and evaluation of available results from in-situ tests on rock types with relatively low field hydraulic conductivity was performed [APPEL & HABLER 2001 and 2002]. The hydraulic conductivity coefficients (k_f-values) recorded and documented on the basis of these tests, were primarily derived from exploration programmes on the disposal of radioactive and conventional waste. Altogether, they cover the depth range between 5 m and 9,066 m below the site surface. The values for rock salt, however, exclusively refer to the intended repository depth between 300 m and 1,500 m below site surface (decisive for the specification of the depth is the middle of the test interval).

On the basis of about 2,600 analysed measurements, the following results have been achieved for the rock types clay/claystone, marlstone, granite and gneiss, which also exist in Germany to a degree of extension that is sufficient for disposal, as well as for rock salt. The results are applicable to all of these rock types:

- Except for rock salt, the hydraulic conductivity coefficients of all rock types show very large bandwidths (in some cases more than ten orders of magnitude). The bandwidths of different rock types overlap strongly (see Table 4.4).

- At a depth interval of 300 m to 1,500 m below the site surface, which is envisaged for disposal (see Chapter 4.1.3), the bandwidths of the measured values for marlstone, granite and gneiss are also very large. The bandwidth of claystone, however, is even smaller than that for rock salt. Likewise, the median values of the hydraulic conductivity coefficients for rock salt and claystone are considerable smaller compared to other rock types (see Table 4.5 and Fig. 4.3). Statistically, the difference is significant.

Table 4.4: Field hydraulic conductivity of different rock types

Rock type	Average test depth below site surface (m)	Number of measured values	Field hydraulic conductivity (k_f-values in m/s)	
			Bandwidth	Median value
Rock salt	300 - 841	75	9.81×10^{-17} - 2.94×10^{-10}	5.50×10^{-14}
Marlstone	9 – 1,856	199	5.00×10^{-14} - 1.00×10^{-03}	6.67×10^{-11}
Clay/clay-stone	5 – 1,474	676	5.50×10^{-15} - 1.04×10^{-04}	1.20×10^{-06}
Granite	11 – 3,485	891	2.23×10^{-15} - 1.64×10^{-01}	3.16×10^{-08}
Gneiss	15 – 9,066	472	4.70×10^{-15} - 8.68×10^{-05}	3.99×10^{-09}

Table 4.5: Field hydraulic conductivity of different rock types at a depth range of 300 m to 1,500 m below site surface

Rock type	Average test depth below site surface (m)	Number of measured values	Field hydraulic conductivity (k_f-values in m/s)	
			Bandwidth	Median value
Rock salt	300 - 841	75	9.81×10^{-17} - 2.94×10^{-10}	5.50×10^{-14}
Marlstone	304 – 1,104	157	5.00×10^{-14} - 3.00×10^{-05}	3.07×10^{-11}
Clay/clay-stone	313 – 1,474	36	5.50×10^{-15} - 2.05×10^{-10}	9.50×10^{-13}
Granite	302 – 1,480	605	2.23×10^{-15} - 4.00×10^{-04}	2.80×10^{-08}
Gneiss	301 – 1,498	271	4.70×10^{-15} - 1.20×10^{-05}	3.00×10^{-10}

When considering the hydraulic conductivity coefficients with respect to different sites and depths, the following results are achieved for the individual rock types:

As expected, the permeability values for **rock salt** are very low; the bandwidth of the values is small. Rock types associated with rock salt, in particular anhydrite rock, are generally characterised by higher water permeabilities.

With **clay/claystone** the hydraulic conductivity coefficient is clearly dependant on the depth of the test interval below the surface. Above a depth of 150 m to 200 m, the total bandwidth is found with an emphasis on higher values. At the intended repository depth, however, only values of around 10^{-12} m/s are found (+/- two orders of magnitude).

For **marlstone**, the dependence on depth is unclear. Irrespective of this, two different value groups can be determined: one group with mainly high values (approx. 10^{-9} m/s +/- several orders of magnitude) and one with mainly low values (approx. 10^{-12} m/s +/- several orders of magnitude). The major part of the high values refers to highly calciferous marlstone banks or marlstone with lime banks.

The characteristic hydraulic conductivity coefficient feature of **granite** is the continuously large bandwidth over the total depth range covered by the measured values. Only at a few sites do low values prevail.

For **Gneiss**, a general decrease of the hydraulic conductivity coefficients with the depth of the test intervals can be observed. This is due to the fact that the percentage of low measurement values increases with depth, although high values still do occur over the total depth range measured.

Interpretation

The band widths of the hydraulic conductivity coefficients of all considered rock types, except rock salt, are generally large and show a strong overlap. This is mainly due to the fact that measurements have been taken for both, undisturbed rock matrix with low permeability and fractured areas with increased permeability. Fractures may be produced during the formation of the rock (e. g. in the case of igneous rocks during the cooling of the molten rock) or resulting from mechanical (tectonic) impacts on the rock. However, the causes of fracture formation and their relevance to field hydraulic conductivity differ from rock type to rock type.

At the envisaged repository depth of 300 m to 1,500 m below the earth's surface, **rock salt** and **claystone** generally have low hydraulic conductivity coefficients. This is due to the characteristic geomechanical properties of both rock types. In the case of claystone, they lead to the formation of a fracture network near the surface permeable to water, and at larger depths they lead to the sealing or "healing" of possible fractures. In the case of **marlstone**, the carbonate content, and particularly in form of jointed carbonate-rich inclusions (limestone banks) have a differentiating effect on the permeability. Such inclusions represent an individual rock type within the marlstone beds with higher permeability. Open fractures apparently persist in them at all depths considered. The properties of marlstone with a low lime content and without such inclusions are, however, similar to those of claystone.

In the case of the crystalline rocks **granite** and **gneiss**, an increased permeability is also related to fractures, but not to inclusions of another rock type. The fractures can be open over the total depth range examined, i. e. also at the envisaged maximum repository depth. In addition, relatively high k_f-values are also measured in rock sections without clearly visible structural disturbances.

Consequences for the derivation of a criterion on field hydraulic conductivity

Regarding the derivation of a criterion "rock type as indicator for the field hydraulic conductivity of rock formations" (at the envisaged repository depth), the following consequences can be drawn on the basis of the results available:

In general, the permeability values for **rock salt** are low. Rock types with higher hydraulic conductivity associated with rock salt have to be avoided.

Claystone, marlstone, granite and gneiss can have areas with the desired low permeability, but only in the case of **claystone** are there generally favourable conditions for the identification of such areas.

However, the existence of fractures and thus of zones with increased field hydraulic conductivity has to be assumed in case of marlstone and, in particular, granite and gneiss. In the case of **marlstone**, critical inclusions of highly calciferous banks, especially of limestone banks, have to be reliably excluded. For this purpose, adequate verification procedures are available. It was not possible to verify a clear quantitative relation between lime content and k_f-values on the basis of the available data.

In the case of **granite and gneiss**, it is difficult and expensive to provide evidence of a large rock formation with low hydraulic conductivity, i. e. without troublesome faults that is suitable for the construction of a repository. Therefore, there are considerable problems connected with these rock types regarding identification and the required accurate description of the favourable overall geological setting.

According to the minimum requirements formulated in Chapter 4.1.3, the isolating rock zone has to consist of rock types to which a field hydraulic conductivity of less than 10^{-10} m/s can be assigned. Within the framework of the geoscientific weighing, rock types with a characteristic field hydraulic conductivity of more than < 10^{-12} m/s are classified as "favourable" and those with a characteristic field hydraulic conductivity between 10^{-12} m/s and 10^{-10} m/s as "relatively favourable". If these requirements are applied to the median values and bandwidths of the k_f-values (see

Table 4.5), that are available for the different rock types from the admissible depth interval for a repository, the following picture is obtained:

The rock types **rock salt** and **claystone** can certainly be regarded as indicators of a low field hydraulic conductivity. For both rock types, the median values and by far the largest part of the measured values are below 10^{-10} m/s. Likewise, the 95-%-confidence interval of the median values is clearly below 10^{-10} m/s (see Fig. 4.3). Therefore, the probability that rock formations of these rock types fulfil the minimum requirements and, moreover, are to be classified at least as "relatively favourable" within the framework of weighing (see the assessment function under “Weighing” in the following) is very high. In the case of rock salt, even a classification as "favourable" is probable.

Marlstone with a low lime content and, in particular, without limestone banks, is to be judged as similar to claystone, although the lowest k_f-values measured for marlstone exceed those for claystone by one order of magnitude.

In the case of **granite** and **gneiss**, the median values are considerably higher than the characteristic maximum k_f-value permissible according to the minimum requirement. The maximum values are about six or five orders of magnitude higher. Thus, both rock types cannot be referred to as indicator for a low field hydraulic conductivity. This assessment is also valid under consideration of the fact that the investigations of granite and gneiss are often directly targeted at water-permeable zones, such as fractures or fault zones. As a consequence, high values are over represented in the database in comparison with the actual conditions.

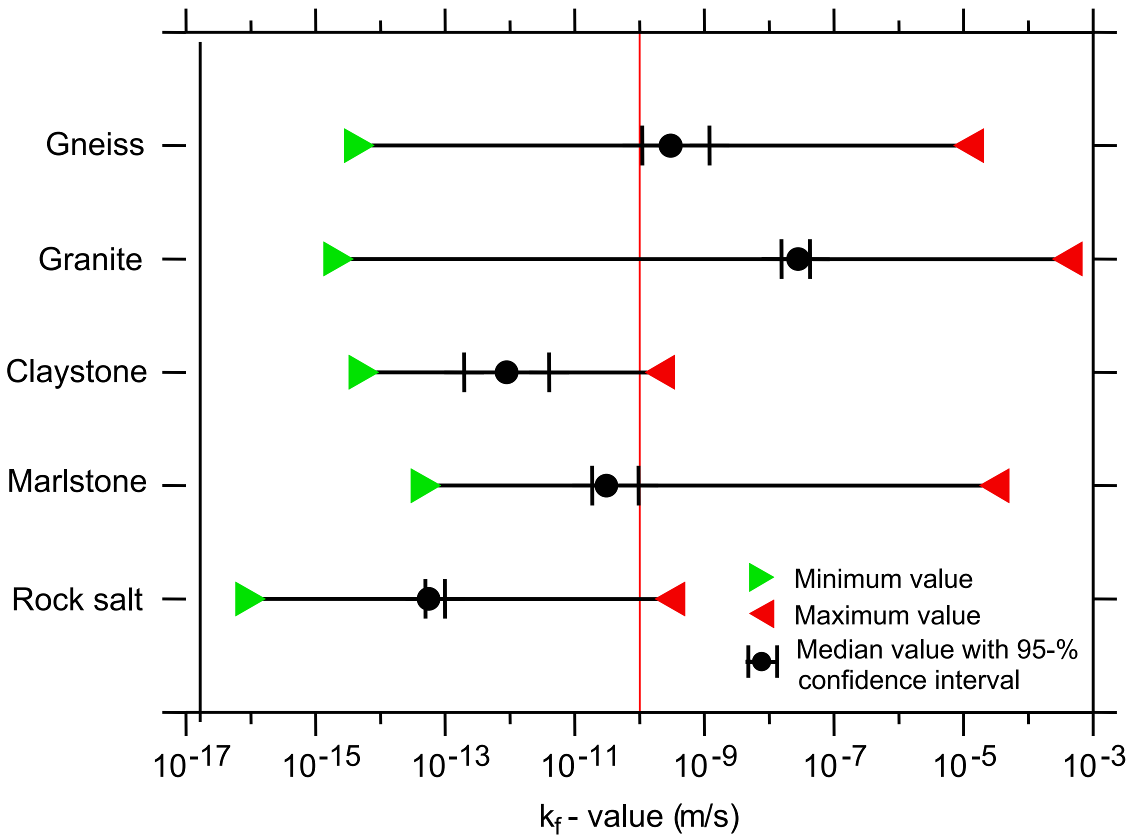

Fig. 4.3: *Bandwidths and median values (with limits of the 95-%-confidence interval) of the k_f-values of rock types at the envisaged repository depth (300 m - 1,500 m below site surface)*
Vertical line: k_f-value of 10^{-10} m/s not to be exceeded according to minimum requirement (see Chapter 4.1.3)

Derivation of a criterion:

The rock type of the isolating rock zone is the indicator for the field hydraulic conductivity and thus, at the same time, for the groundwater availability and groundwater velocity.

Criterion: The isolating rock zone should consist of rock types which, according to experience, show low field hydraulic conductivity.

Weighing: Characteristic field hydraulic conductivity of the rock type:

Field hydraulic conductivity in m/s	$< 10^{-12}$	$10^{-12} – 10^{-10}$
Assessment group	favourable	relatively favourable

Indicator: Temperature distribution in the deep underground

Subject matter

The temperature distribution deep underground is very sensitive to groundwater movements, since, besides solutes, heat energy is also transported by groundwater flow. Even minor flow velocities show up in this way in a temperature field that is generally determined by heat transfer. Under certain circumstances, the results of temperature measurements performed in boreholes can be used to demonstrate these movements. Using this approach, regional thermal anomalies caused by underground water flows can be identified. Temperature measurements in deep boreholes are at least abundant in the sediment basins, even though not always in the desired quality.

The possibilities and limits of an analysis of the temperature distribution deep underground were examined on behalf of the Committee as an indicator for groundwater flow in a “geothermal raster analysis” [CLAUSER et al. 2002] study.

The central task in this study was the development and application of a method for the determination of groundwater velocities deep underground. Here, the dominating physical effects regarding the underground temperature distribution are to be identified, separated from other influences and quantified to a sufficient degree. In this context, the main mechanisms of heat transport are the stationary heat transfer, which dominates under normal conditions, the time-dependent changes of the surface temperature (paleoclimate) as well as the advective heat transport resulting from groundwater flow. In this case, the latter is the actual parameter to be determined among the mentioned overlapping effects.

Temperature measurements in boreholes verify the simple thermal model that, under the assumptions that the earth's upper crust is of homogenous material, that there is a constant heat flow at the base of the earth's crust and a constant temperature at the earth's surface, the temperature rises linearly with increasing depth. However, this simple correlation can be overlapped by effects caused by underground inhomogeneities , anisotropic properties and the variable natural heat production of the rocks. Other influences result from changes of the average temperature at the earth's surface, which diffuse as a dynamic temperature signal into the subsurface, as well as the advective heat flow resulting from groundwater flow. The advective heat flow may serve as an indicator for groundwater flow.

Thus, the method analysed in the study is based on the identification of flow-induced anomalies in the underground temperature field not caused by heat conduction or paleoclimatic variations (see Fig. 4.4).

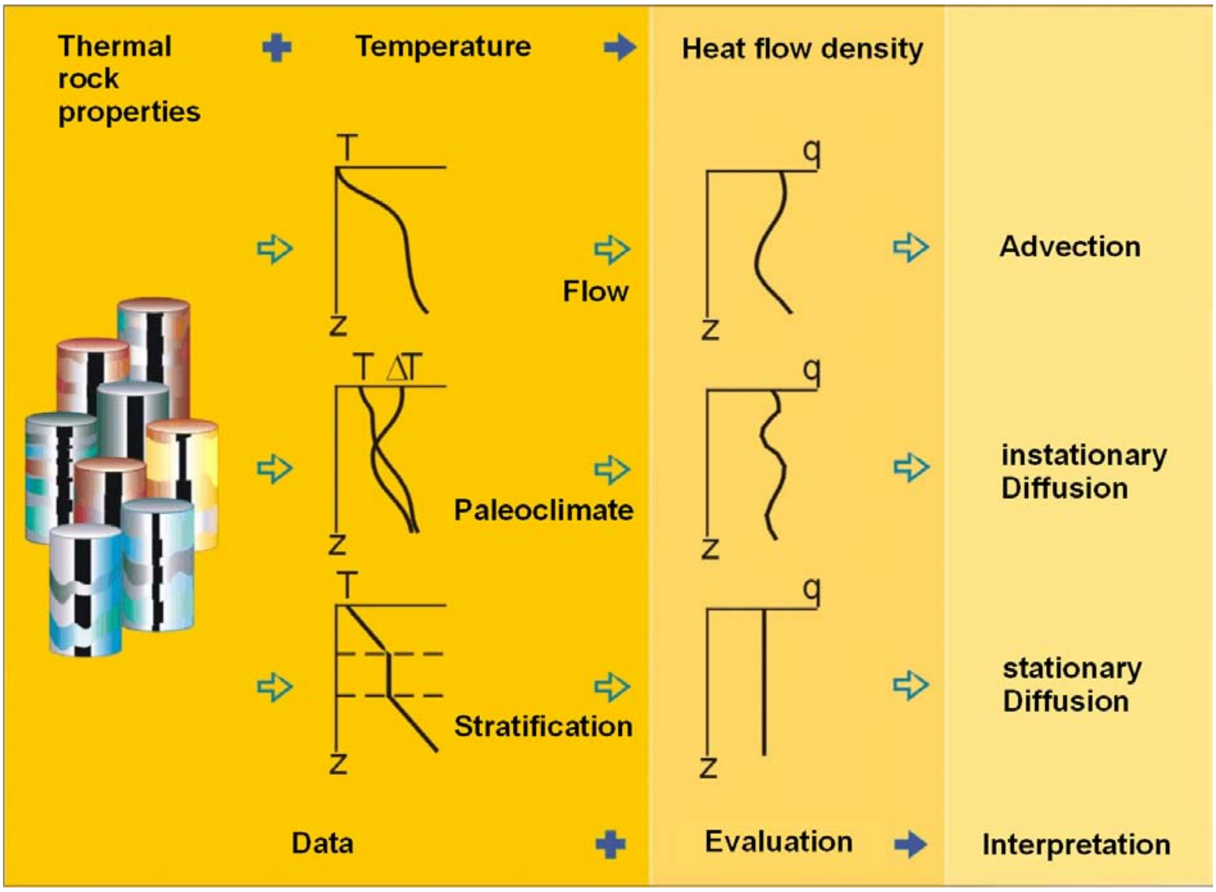

Fig. 4.4: Identification and quantification of flows by means of temperature distribution in the deep underground

The existence and adequate quality of the temperature and petrophysical data, which are only available for certain regions in the German sediment basin, are of special importance for the analysis of the thermal effects of groundwater flows.

For the development of methods, the Western Molasse basin in Southern Germany was selected as a suitable test region, taking into account amount, quality and distribution of data. For this region, a reference model was developed based solely on heat conduction and on known geological structural information. The thermophysical properties of the most significant rock layers were identified on the basis of measurements from drill cores, reconstructions from geophysical logs and published data.

The application of the method showed that it was possible to both register the paleoclimatic effects and to determine the temperature distribution resulting from heat conduction with sufficient accuracy. Quantitative statements on existing flows could be made by an estimation of the vertical filter velocity by means of a Péclet number analysis (ratio of advective to conductive heat flow). Under favourable conditions, this method allows the identification of flows with a vertical filtration velocity of at least 1 mm/a. With horizontal flows, the thermal effect is considerably smaller. However, it was possible to determine regional mean values in the range of 30 m/a for one of the most significant, known aquifers at a depth of about 1,500 m in the investigation area. These correlate with the results of direct hydraulic tests (see Fig. 4.5).

Comparably slow flow velocities, identified by means of geothermal method, cannot be determined by any other means. Especially here - as also for tracer tests which are hardly feasible at a regional scale and at large depths - a direct effect of the flow leads to an estimation of its velocity without referring to other physical processes.

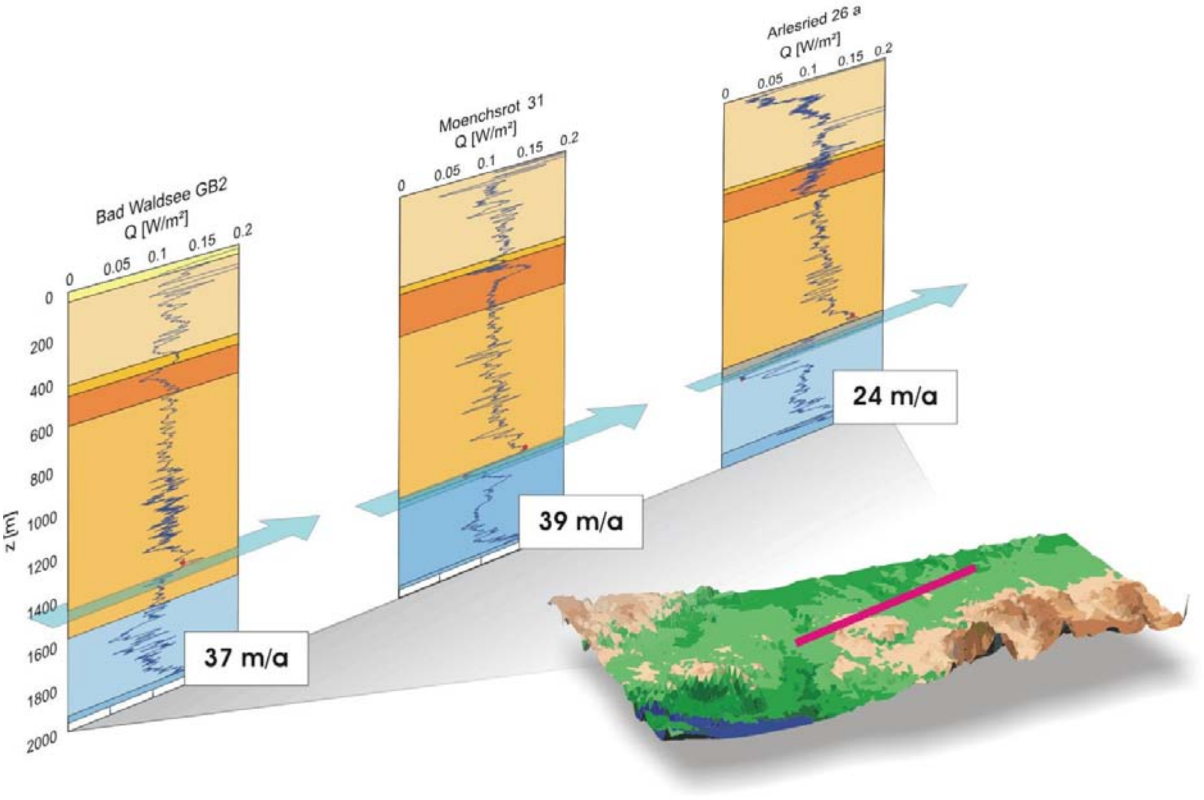

Fig. 4.5: *Regional layer-wise analysis of the flow conditions for a test area in Southern Germany*

Derivation of a criterion

Previous exploration has demonstrated the great potential of geothermal methods for the identification of areas with significant groundwater flow in deep rock layers as well as for the quantification of the contribution and the direction of such flows. However, the identification of the contribution of groundwater flow to heat transport requires, in addition to the modelling of relevant coupled processes, a validation of the developed model.

Within the framework of the future selection procedure, the temperature distribution in areas can be used, on the basis of a database that is adequate with regard to quantity and quality, as a clear indicator for the existence of groundwater flow.

In this respect, it is to be noted that the successful application of the geothermal method also depends on the geological situation (inhomogeneity, anisotropy).

However, it is not possible to draw the direct conclusion that in the case of no signals there is no groundwater flow. Not all flow systems lead to a corresponding temperature signal. Such flow paths are unlikely, but cannot be excluded. With regard to groundwater flow, unfavourable areas for disposal can thus, when incorporating the temperature distribution, be identified reliably by this method. Favourable areas, however, cannot be identified reliably by analysis of the temperature distribution alone. Thus, the derivation of a criterion is not possible.

Indicator: Depth-dependent increase of the groundwater density

Subject matter

To answer the question if or for which geological conditions extensive, depth-dependent mineralisation or corresponding salt content distribution can serve as indicator for the groundwater flow velocity, the published literature on the chemistry of deep groundwater and the hydraulic properties of the corresponding aquifers in different, large regions of Germany was researched [BRASSER & BREWITZ 2001].

The research produced the following results:

Increasing mineralisation with depth is a widespread fact, for which, however, there are in most cases only qualitative descriptions. Quantified linear gradients have only been identified or derived for a few sites.

Mostly, there are only general statements on lower permeabilities deep underground, and also on a general decrease of the hydraulic conductivity with increasing depth. A quantifiable direct coupling between increasing groundwater mineralisation on the one hand and decreasing hydraulic conductivity on the other hand could not be investigated up until now, except at the Konrad mine.

Derivation of a criterion

According to the investigations performed up until now, a clear interpretation of salinity-/depth relations cannot be made. Consequently, it is not possible to derive a corresponding criterion. The questions still to be answered, ranging from the definition of linearity and specification of required data density and quality to the uncertain relationship between depth, salinity and hydraulic properties, lead to the conclusion that the indicator "depth-dependent mineralisation / salt content" cannot generally be regarded as relevant to the fulfilment of the general requirement "no or low groundwater movement (at repository depth)". Moreover, a linear salinity increase can only be identified within the framework of site-specific analyses due to the small databases generally available and is therefore less suitable as indicator for a national “survey screening”. If an adequate data density is given, “depth-dependent mineralisation / salt content” might be referred to as a supporting indicator. But also in this case, applicability is only given in the pretertiary and undisturbed overlying layers of saliferous structures, which can represent a defined source for a diffusion-initiating concentration difference.

Diffusion velocity

Subject matter

Even if there is no groundwater movement, radionuclides may enter the adjacent rocks through diffusion via the isolating rock zone and be transported from there into the biosphere. The extent of the isolating rock zone has to correspond to the diffusion capacity of radionuclides through the barriers in such a way that the migration times through the isolating rock zone conform with the required isolation period as far as possible. With regard to this requirement, rocks with a small diffusion coefficient, i. e. with a slow diffusion velocity, are searched for.

The assessment of the diffusion velocity is based on a model assuming a barrier with a thickness of 50 m, which is loaded at one side with an increased initial concentration of an ideal tracer. Slow diffusion velocity means that the concentration of a tracer when leaving the barrier remains 1 % below the initial concentration over a period of one million years. This is the case for an effective diffusion coefficient of $< 10^{-11}$ m^2/s.

Derivation of a criterion

The diffusion of radionuclides through a water-saturated rock decisively depends on the concentration gradient of the radionuclides and the effective diffusion coefficient of the rock. The diffusion velocity is directly proportional to the effective diffusion coefficient for the rock. The effective diffusion coefficient, in turn, depends on the diffusion coefficient in water, reduced by the effects of rock properties that constrain diffusion. Diffusion through a water-saturated rock takes place via the pore channels. Their form, e. g. windings, constrictions, hinders the migration, in contrast to diffusion in free water, by elongation of the migration path. The degree of this hindrance is primarily determined by the grain size distribution of the rock and - in case of sedimentary rock - by the degree of the diagenetic consolidation. With an increase in the fine-grained proportion and increasing consolidation the diffusion delay increases compared to that in free water.

Criterion: The effective diffusion coefficient in the isolating rock zone should be as low as possible (less than 10^{-11} m^2/s).

Weighing : Characteristic effective diffusion coefficient of the rock type at expected rock temperature in the isolating rock zone:

Diffusion coefficient in m^2/s	< 10^{-11}	10^{-11} - 10^{-10}	> 10^{-10}
Assessment group	favourable	relatively favourable	less favourable

The effective diffusion coefficient for rocks, as a parameter for diffusion velocity is not widely available. The rock type can be used as an indicator.

Depending on the rock types, different characteristics are relevant.

In the case of sedimentary rocks, low permeability and low porosity are characteristic for a low effective diffusion coefficient.

Example “claystone”

For claystone, these are the absolute porosity and the diagenetic degree of consolidation. The respective criterion for clay rock is as follows:

Criterion: The rock should have a low absolute porosity and a high diagenetic degree of consolidation.

Weighing: Characteristic absolute porosity and characteristic degree of consolidation of the rock type:

Absolute porosity	< 20 %	20 % - 40 %	> 40 %
Degree of consolidation	claystone	solid clay	semi-solid clay
Assessment group	favourable	relatively favourable	less favourable

For other rock types corresponding weighing criteria have to be developed within the selection procedure.

4.1.4.3 Configuration of the rock bodies

In addition to the properties of the rock bodies of the geological barrier influencing the spreading of radionuclides and the hydraulic and hydrochemical groundwater conditions, the configuration of the rock bodies in the geosphere also contributes to a favourable overall geological setting. Thus, safety relevant characteristics of the configuration have to be considered in the site selection procedure.

In the following paragraphs, first the term “configuration” will be defined and the principally possible configuration types of host rock and isolating rock zone described and assessed with regard to their significance for a favourable overall geological setting [a) Configuration types]. Finally, configuration-related criteria are derived from essential safety-related characteristics of configurations [b) Configuration-related criteria].

a) Configuration types

Definition

The term “configuration” mainly refers to the extension and function of the rock body being decisive for a favourable overall geological setting, or – in case of more than one rock body – the geometric configuration of the rock bodies involved, characterised by their extension and function. Further, it comprises the depth of the isolating rock zone within the geosphere as well as the potential impairment of its barrier effectiveness due to the proximity of rock formations with elevated hydraulic potential. In general, the extension, configuration and depth of rock bodies can be determined with less difficulty than specific rock properties or the hydraulic and hydrochemical site conditions. Thus, the configuration of safety-relevant rock bodies in the geological barrier is of special importance as an early identifiable characteristic of a “favourable overall geological setting” within the framework of the site selection procedure.

Functional differentiation host rock/isolating rock zone

Within the geological barrier of the multi-barrier system “repository”, the isolating rock zone, according to its definition, has to make the decisive contribution to the isolation of the waste for the required isolation period. Thus, it has to consist of rocks with high barrier effectiveness and must be characterised by a maximum possible extension. According to the general knowledge about the characteristic properties of specific rock types and their distribution in Germany and the results of differentiated evaluations of data on the hydraulic conductivity of specific rock types, respectively (see Chapter 4.1.4.2), the sedimentary rocks rock salt and claystone (or similar rock types) have to be primarily taken into consideration.

On the other hand, the main function of the host rock is to take up the waste. Therefore, it has to allow, above all, the construction and operation of a repository mine. This function must not be impaired by the effects of the waste, in particular heat input into the rock and gas generation. According to the general knowledge of the (in particular) mechanical properties of rock types, the following rock types can be taken into consideration: plutonic rocks (e. g. granite), regional-metamorphic rocks (gneiss) and sedimentary rocks (sand stone or petrographically similar rock types, carbonate rocks, rock salt, possibly anhydrite rock and rocks in special facies with favourable properties).

In consideration of the functional differentiation between the host rock and the isolating rock zone, two main types of their configuration within the geological barrier can be derived (see Fig. 4.6):

Type A: Regarding its barrier effectiveness, the host rock is a safety-relevant component of the isolating rock zone

In this case, the host rock and the isolating rock zone are part of one and the same rock formation (or more than one rock formation with the same barrier-effective properties). Primarily, this rock formation has to possess the functional properties of the isolating rock zone, but also has to allow the construction of a repository.

Type B: Regarding its barrier effectiveness, the host rock is not a safety-relevant component of the isolating rock zone

Host rock and isolating rock zone are different rock formations with different barrier-effective properties: Above all, the host rock formation has to possess favourable mechanical properties for the stability of repository cavities, and has to be unsusceptible to the effects of the waste, whereas the surrounding isolating rock zone has to have favourable barrier-effective properties and a large extension.

Since at least two rock types with different properties are part of this configuration type and corresponding configurations may have formed in different ways, Type B has a larger number of generally possible configuration variants. However, all these variants can by assigned to two sub-types of Type B, depending on the degree of enclosure of the host rock body by the isolating rock zone:

Type Ba: The host rock formation is completely enclosed by the isolating rock zone

Type Bb: The host rock formation is not completely enclosed by the isolating rock zone

Both sub-types can further be subdivided, e. g. according to their mode of formation or the geometrical configuration of the rock bodies in detail. Within Type Bb, sub-types can be divided in particular according to which extent the host rock is enclosed by the isolating rock zone, or which barrier effectiveness the rock zone has within such a configuration (see Fig. 4.7).

Consequences

The considerations on favourable configurations of rock formations lead to the following consequences for the development and application of a selection procedure for repository sites:

- The different functions of the host rock and the isolating rock zone result in specific requirements on the rock bodies in being part of a configuration and of the corresponding geological structure. For the identification of a favourable overall geological setting, the function-related rock properties searched for have to be considered from the outset. In this respect, the main emphasis always has to be placed on the isolating rock zone. Here, only a few types of sedimentary rocks with low hydraulic conductivity can be taken into consideration (especially claystone and similar rock types and rock salt). Regarding the requirements of the isolating rock zone, there is a conflict of objectives between the prevention or hindrance of the advective radionuclide transport with groundwater and the prevention of the impairment of the barrier effectiveness by gas production from wastes.

- Due to the potential geometrical arrangements of the host rock and the isolating rock zone, a distinction can be made between two main types of configurations and different sub-types. Regarding their comparative assessment, distinction is to be made between the prevention or hindrance of the advective radionuclide transport and the avoidance or reduction of negative effects of gas production from wastes (see b) Configuration-related criteria).

- Irrespective of the configuration type, for each configuration a sedimentary rock body, in particular rock salt or claystone, with high barrier effectiveness and large extension is necessary as an isolating rock zone. Therefore, it is always necessary to identify occurrences of these rock types with particularly large extension and thickness, and to describe them with regard to their barrier-effective properties. They always conform to Configuration Type A. In order to use possible configurative advantages of the Configuration Types Ba or Bb in a well directed way, it has to be examined whether the sedimentary rocks identified are associated with other rock bodies in such a way that there are configurative advantages with regard to the advective radionuclide transport with groundwater or to the handling of the problem related to gas generation.

- In the case of rock salt, it has to be examined if salt domes are in line with the approach “favourable overall geological setting", and if, besides salt domes, salt pillows or bedded salt formations can also be taken into consideration.

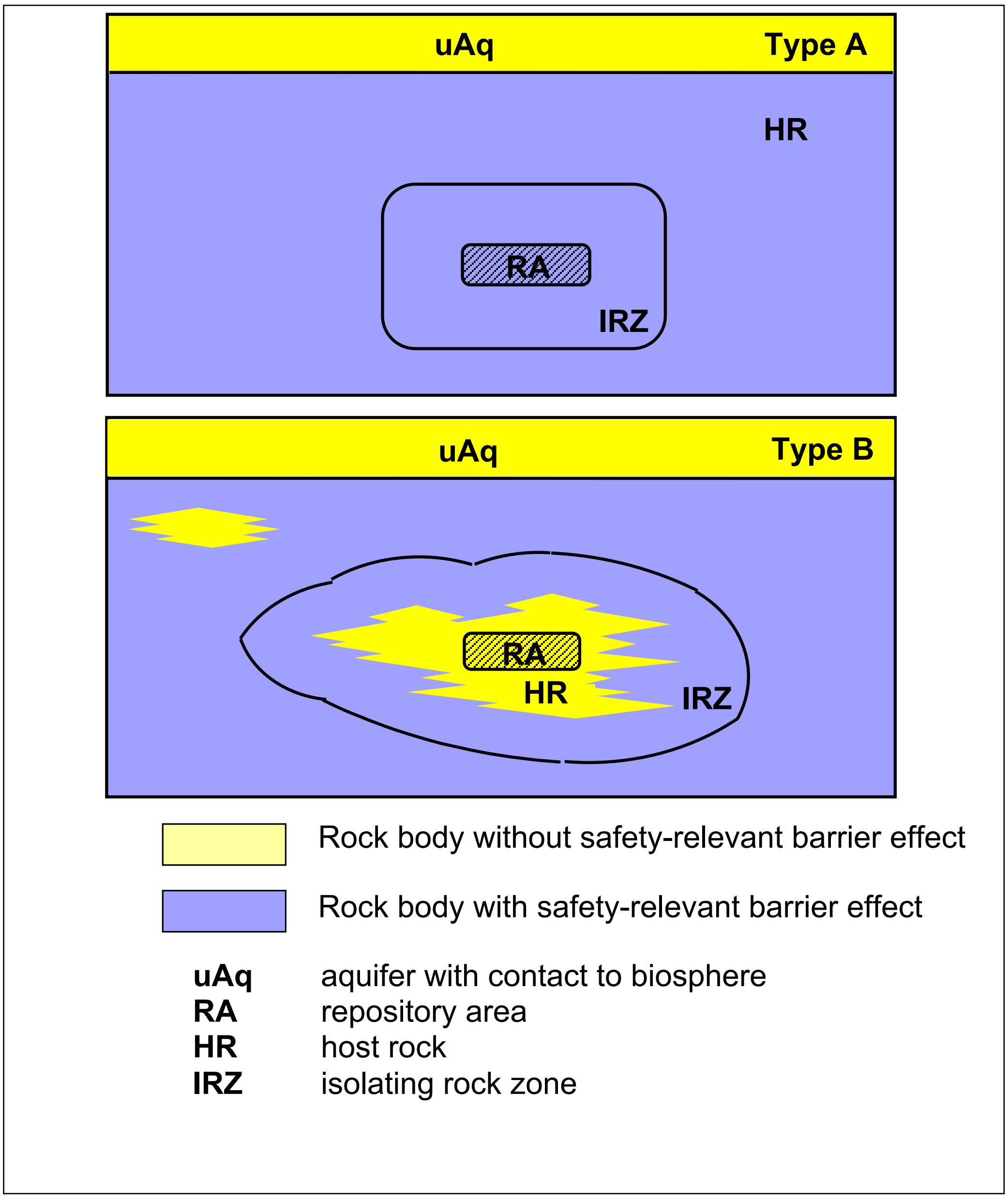

Fig. 4.6: Main types of configurations between host rock and isolating rock zone

Type A: Host rock is a safety-relevant part of the isolating rock zone

Type B: Host rock is <u>not</u> a safety-relevant part of the isolating rock zone

(the illustration corresponds to Type Ba)

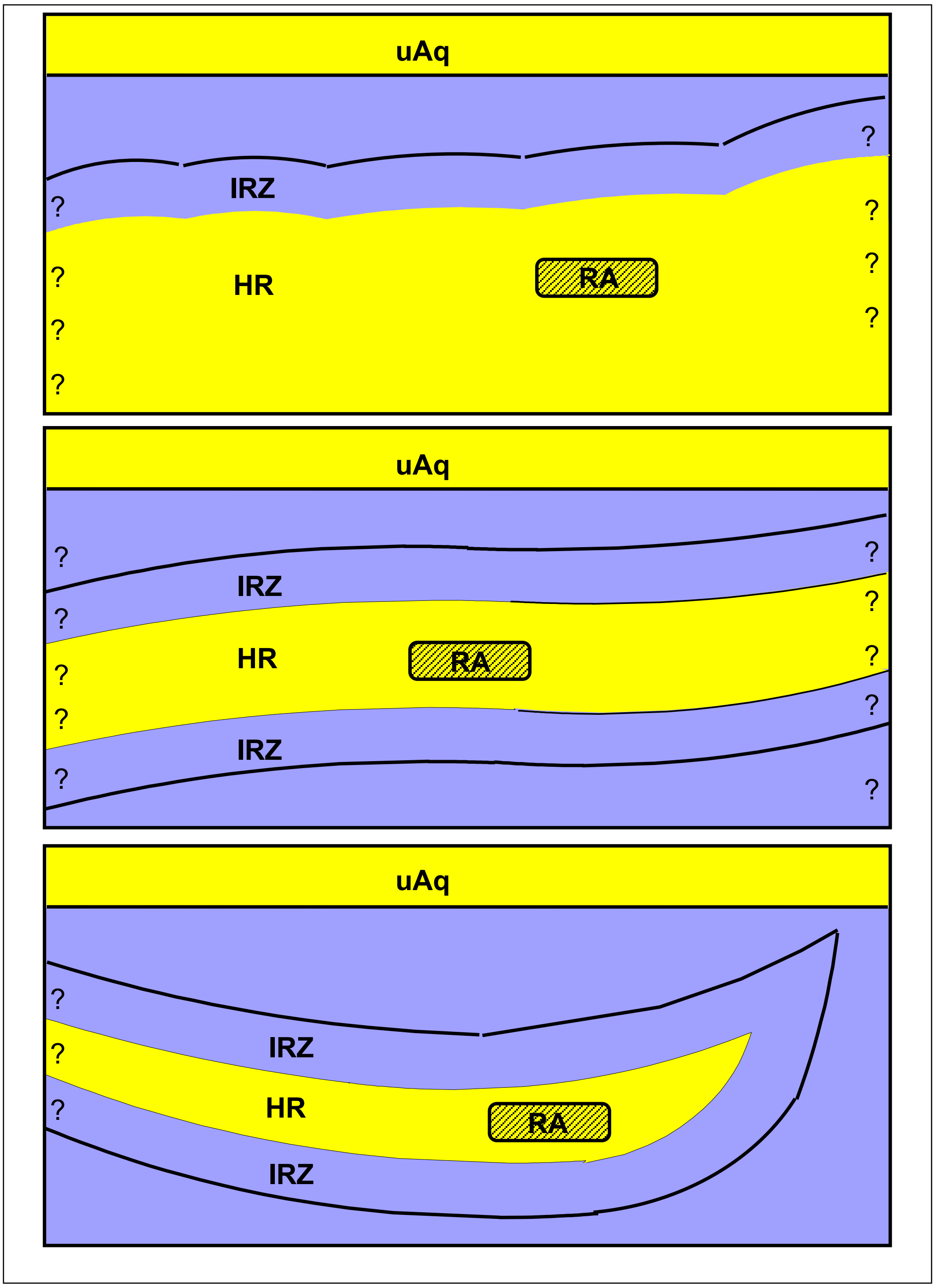

Fig. 4.7: Configuration Type Bb: Geological structures with different degree of enclosure of the host rock by the isolating rock zone (schematic, without scale, "?" means further extension unknown, for legend see Fig. 4.6)

b) Configuration-related criteria

Minimum barrier effectiveness of the isolating rock zone

As per definition, the configuration of the rock bodies forming a favourable overall geological setting is determined by their functionally different respective properties (isolating rock zone and host rock) and extensions (see a) Configuration types). Being a parameter known or determinable at a relatively early stage in the selection procedure, the minimum extension of the isolating rock zone, indispensable in ensuring the minimum barrier effectiveness, i. e. the enclosure of radionuclides, is essential to the identification of suitable sites. It depends on the hydraulic conductivity of the rocks of the isolating rock zone, their effective porosity and the hydraulic gradient in the area of the site. If these parameters are known, the minimum extension can be calculated.

According to the general requirements presented in Chapter 2.1, the isolation period for radionuclides in the isolating rock zone shall be in the range of one million years. This means, that radionuclides must not be transported beyond the outside margin of the isolating rock zone within this period.

In rock bodies of very low permeability, which are thus dry (e. g. rock salt), there is no groundwater for the transport of radionuclides. Thus, the following considerations refer to water-saturated rock formations.

From radionuclide travel times of an order of magnitude of one million years by advective groundwater transport, an exemplary calculation of the minimum extension of the isolating rock zone can be performed using characteristic data on the hydraulic conductivity and the porosity of barrier rocks and for representative hydraulic conditions at the repository level. As a starting point of this consideration, an ideal rock barrier with a hydraulic conductivity coefficient of 10^{-12} m/s and an effective porosity of 5 % are postulated. At this rock barrier, a hydraulic gradient of 0.05 shall be effective. To simplify the calculation of groundwater velocities it is postulated that Darcy’s Law is also applicable to very small hydraulic gradients and hydraulic conductivity coefficients. This postulation leads to an overestimation of the groundwater velocity.

The hydraulic conductivity coefficient of 10^{-12} m/s roughly represents the dividing line between advective and diffusive (i. e. independent of the groundwater movement and thus inevitable) radionuclide transport in groundwater. Real values of this order of magnitude are used for the different rock types envisaged internationally for disposal (see a) Configuration types). The values stated for the porosity and the hydraulic gradients are based on experience of hydraulic conditions deep underground.

If the hydraulic conductivity coefficients and the gradient are varied, the following exemplary values of the minimum extension of the isolating rock zone are calculated for a radionuclide travel time through the ideal rock barrier of an order of magnitude of one million years (see Table 4.6).

Table 4.6: Minimum extension of the isolating rock zone

Hydraulic conductivity coefficient [m/s]	**Porosity [%]**	**Gradient [m/m]**	**Calculated minimum extension [m]**
10^{-12}	5	0.05	33
5×10^{-12}	5	0.05	160
10^{-11}	5	0.005	33

Derivation of a criterion

The thickness of the barrier-effective rock body of the isolation rock zone serves as criterion in the weighing process. The basis for the assessment is the ideal barrier effectiveness at a field hydraulic conductivity of 10^{-12} m/s (see above).

The Committee formulated the following weighing criterion for the barrier thickness:

Criterion: The barrier rocks of the isolating rock zone must have a thickness that ensures the isolation of radionuclides for a period in the order of magnitude of one million years.

Weighing: Thickness of the geological barriers of the isolating rock zone in metres (ideal barrier effectiveness at a field hydraulic conductivity of 10^{-12} m/s):

Thickness in m	> 150	100 - 150	50 - 100
Assessment group	favourable	relatively favourable	less favourable

The barrier rock bodies of the isolating rock zone must have a thickness that exceeds the calculated minimum thickness of 50 m.

Enclosure of the host rock by the isolating rock zone

Under the aspect "favourable configuration with regard to the radionuclide transport with groundwater" alone, the described configuration types can be ranked regarding their significance to a "favourable overall geological setting" as follows:

1. **Configuration Type Ba** represents the configurative optimum of a "favourable overall geological setting"; since configurations are possible in which the host rock and the isolating rock zone fulfil the respective functional requirements particularly well.

2. **Configuration Type A** corresponds to the conventional approach for the selection of repository sites where an adequately large or largest possible rock body of a rock type with favourable barrier properties is searched for. With regard to the barrier effectiveness, this type largely corresponds to that of Configuration Type Ba. However, rock types with favourable barrier properties may be less suitable for the construction and operation of a repository mine and/or react sensitively to the impacts of the emplaced waste. Therefore, the functional deficits, compared to Type Ba, due to the lack of a favourable host rock have to be compensated by technical measures according to circumstances.

3. In the case of **Configuration Type Bb**, the configuration alone does not contribute sufficiently to the "favourable overall geological setting". At least, the barrier-effective function of the isolating rock zone cannot be derived from the

arrangement and the extension of the rock bodies involved without further effort. The "favourable overall geological setting" rather has to result essentially from configuration-independent additional properties of a site. These are, in particular, favourable hydraulic conditions (lacking/low hydraulic potential) and large depth of the repository. For this reason, Configuration Type Bb clearly has disadvantages compared to Type Ba and Type A. In a first approximation, the barrier effectiveness of such a configuration is probably dependent on the extent to which the host rock is enclosed by the isolating rock zone, and on the hydraulic position of the aperture(s) in the isolating rock zone.

If emphasis is placed on aspects other than the advective radionuclide transport, another assessment of the configuration types follows. For Configuration Type Ba, difficulties may arise, particularly in the case of a complex configuration of the rock formations involved, regarding the required reliable spatial characterisability and explorability of the configuration (see Chapter 4.1.4.4), whereas advantages may result in this respect for the Configuration Type A, depending on the rock type.

Derivation of a criterion

At least in the early phases of the site selection, a differentiated evaluation of the interactions presented cannot be made. However, the isolation capacity of the isolating rock zone with regard to the advective radionuclide transport with groundwater depends on how far the host rock or (if host rock formation and isolating rock zone are identical) the repository area is enclosed by the isolating rock zone. From this, the following weighing criterion can be derived:

Criterion: The repository area and the host rock body should be surrounded by barrier rocks of the isolating rock zone.

Weighing: Degree of enclosure:

Degree of enclosure	completely	incompletely
Assessment group	favourable	relatively favourable

Depth of the isolating rock zone

Subject matter

With increasing depth of the repository within the geosphere, the distance between waste and biosphere becomes greater. In general, this is also connected with decreasing groundwater movement and increased protection of the repository against exogenous, e. g. climate-induced processes or man-induced impacts. The latter is also applicable to the functional efficiency of the isolating rock zone. Thus, greater depths mean greater protection.

Derivation of a criterion

The decisive assessment parameter is the depth of the top of the required isolating rock zone below the site surface. It is indirectly limited by the required minimum and maximum depth of the repository (see Chapter 4.1.3). Moreover, it is to be considered that for some rock types, rock-mechanic disadvantages arise with increasing depth (see Chapter 4.1.4.6). The required isolating rock zone results from the required minimum extension (see above). From this, the following weighing criterion can be derived:

Criterion: The top of the required isolating rock zone should be as deep as possible.

Weighing: Depth of the top of the required isolating rock zone below surface:

Depth in m	> 500	300 - 500
Assessment group	favourable	relatively favourable

Volume of the isolating rock zone

Subject matter

Large volumes of the isolating rock zone enable a flexible repository layout and design. The required volume of the isolating rock zone is derived from the areal extension of the repository area, the required barrier thickness and the required extension of the barriers around the repository mine. In the case of a single-floor design of the emplacement cavities, the minimum area required for the construction of a repository was estimated, for example in salt, at 3 km^2 and in clay or granite at 10 km^2. For rocks of very low permeability, the need of gas storage cavities (see Chapter 4.1.4.8) is to be considered additionally.

Derivation of a criterion

Assessment parameter is the areal extension of the rocks of the isolating rock zone at the envisaged repository depth, expressed as multiple of the required minimum area.

The larger the areal extension of the rocks, the greater the chance to be able to fulfil the requirements on safe disposal.

Criterion: The spatial extension of the isolating rock zone should be larger than the required volume calculated for the repository.

Weighing: The areal extension of the rocks of the isolating rock zone at the envisaged repository depth should be a multiple of the required minimum area for, e. g. salt, 3 km^2 and clay 10 km^2:

	> twofold	twofold	< twofold
Assessment group	favourable	relatively favourable	less favourable

Rock formations with elevated hydraulic potential

Subject matter

Especially with regard to disposal in sedimentary rock, the isolating rock zone may be over- or underlain by water-conducting formations with elevated hydraulic potentials (potential-bearing formations). Under certain conditions, this might lead to the induction or intensification of groundwater flow through the repository area and thus also of the transport of radionuclides. If the existence of hydraulic potential-bearing formations is possible, their impact on the radionuclide transport therefore has to be assessed under consideration of the barrier thickness of the isolating rock zone. With regard to false estimations of the field hydraulic conductivity, safety reserves should exist. A field velocity of 1 mm/a should be observed even if the field hydraulic conductivity only complies with the minimum requirement of 10^{-10} m/s and if a value of 0.1 is assumed for the effective porosity.

The calculation of the induced field velocity is based on the specific hydraulic gradient across the barrier thickness of the isolating rock zone which, in turn, is calculated on the basis of the largest difference of the hydraulic potential across the repository area between the outer boundaries of the isolating rock zone and the total thickness of the barrier masses between them.

To estimate whether individual aquifers in the neighbourhood of the isolating rock zone bear noteworthy potentials, it has to be determined which layers are connected to areas of increased potential and how large the hydraulic conductivity contrasts between barrier layers and the aquifer are. Further, the degree of hydraulic resistance within the aquifer has to be examined. The hydraulic resistance is calculated from the field hydraulic conductivity of the aquifer and the distance between the high-potential area and the repository area (see Fig. 4.8).

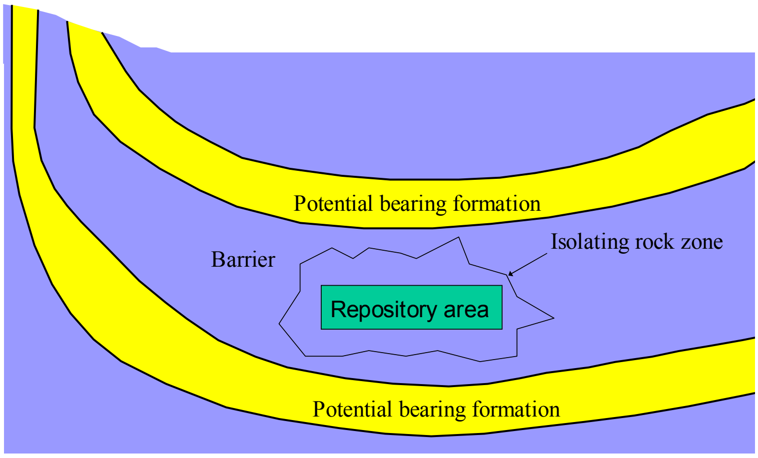

Fig. 4.8: *Scheme of areas of hydraulic potential and repository area*

For the proof of long-term safety, the spatial location of the layer of increased potential in relation to the isolating rock zone is of importance. A direct contact of both is to be assessed "less favourable" in case of a barrier thickness without major safety reserves compared to a barrier thickness with large safety reserves. The decisive assessment parameters are the potential contrasts in the surroundings of the isolating rock zone. On this basis, the following weighing criterion can be derived:

Criterion: The specific hydraulic gradient in the isolating rock zone should be low (less than 10^{-2}).

Weighing: Specific hydraulic gradient (valid at a specified field hydraulic conductivity of 10^{-10} m/s and an effective porosity of 0.1):

Hydraulic gradient	<< 10^{-2}	about 10^{-2}	>> 10^{-2}
Assessment group	favourable	relatively favourable	less favourable

The following applies to the calculation of the specific hydraulic gradient: field hydraulic conductivity of the isolating rock zone 10^{-10} m/s, effective porosity 0.1.

In early phases of the selection procedure, the information necessary for the application of this criterion might not be available. In this case, the following indicators with corresponding criteria can be referred to for the assessment of potential contrasts:

Indicator:

- Connection of layers in the neighbourhood of the isolating rock zone to a high hydraulic potential

Criteria:

- If possible, there should be no connection to a high potential.
- The hydraulic resistance of the conductive layer between potential connection and repository position should be large, i. e. the transport length should be large and the field hydraulic conductivity small.

4.1.4.4 Spatial characterisability and explorability

In international concepts, the two requirements of “good characterisability” and “good predictability” (see Chapter 4.1.4.5) belong to the main criteria. The leading aspect when specifying these requirements is that it cannot be sufficient to identify favourable local geological conditions but that it also has to be ensured that these conditions endure in a favourable overall geological setting both spatially and within the envisaged timescale.

The requirement of a good spatial characterisability of a favourable overall geological setting primarily concerns the reliability and quality of the statements on geological parameters that shall be used in the later safety analysis. These refer to the safety relevant properties of the rock formations of the isolating rock zone. When selecting partial areas in Step 2 of the procedure, the corresponding examination may only cover rock types of these rock formations due to the lack of information. The rock type is the indicator for essential safety-related properties of the rock formations. The reliability of statements on the existence of specific rock types and their safety-related properties depends on

- the **determinability** of the rock types and their characteristic properties in the isolating rock zone, and
- the **transferability** of the properties of these rock types.

Determinability

Subject matter

The determinability concerns the question whether the rock types of the isolated rock zone can clearly be determined so that their characteristic properties can be derived in a reliable manner. Essential aspects in this respect are the spatial distribution of the properties and the geological structure to which the isolating rock zone belongs. These aspects are therefore considered in the assessment of determinability. This, however, is also connected with the questions of technical prerequisites for the explorability of a partial area and the availability of suitable exploration methods and techniques.

The criterion for the assessment of the determinability is:

Criterion: The rock types and their characteristics should spatially be as evenly distributed as possible within the isolating rock zone.

Weighing: Spatial distribution of the rock types and their characteristics in the isolating rock zone:

Distribution of the rock types and their characteristics	Constant	Continuous spatial variation	Discontinuous spatial variation
Assessment group	favourable	relatively favourable	less favourable

Regarding the structure of the geological unit, which includes the isolating rock zone, those processes have to be examined that have led to a change from an initially undisturbed to a disturbed rock mass. Here, tectonic and salt-tectonic processes (including exclusively halokinetic-processes) play an important role. Since their impacts depend on the rock type both regarding the phenomena and the determinability, they have to be examined separately.

In most cases, the mere tectonic impact (fault and fold tectonics, except salt tectonics) has negative effects on the characterisability of the geological structure.

This impairs the determinability of the spatial distribution of the characteristic properties.

As a consequence, the determinability for tectonically altered rock formations is assessed by means of the following criterion:

Criterion: The geological structure should show as little tectonic imprinting as possible. Its extent is derived from the structural situation with consideration of fault and fold tectonics.

Weighing: Tectonic imprinting:

Tectonic imprinting	Mainly unfaulted (fault spacing > 3 km); low inclination of layers	Sparsely faulted (fault spacing 100 m to 3 km); flexures	Intensely faulted (fault spacing < 100 m); intensely folded
Assessment group	favourable	relatively favourable	less favourable

However, in the case of salt, in particular rock salt, salt-tectonic activity may occur: The accumulation of rock salt in salt structures (in particular salt domes) due to halokinetic flow may be connected with small-scale folding and break-up of the original stratification of the salt formation which consists of rock formations with different rock-mechanic and hydraulic properties (above all rock salt, potash salt, anhydrite rock, claystone). On the other hand, however, this may also lead to the formation of large rock bodies with largely uniform rock parameters. Therefore, the effects of salt-tectonic alteration of the original rock formation in salt structures have to be differentially assessed.

In this assessment it has to be considered that salt structures have an individual internal structure, which can only be clarified in detail at a later stage within the framework of the selection procedure. Experience gained from salt- and cavern mining show that there is a certain relationship between the shape and size of a salt structure and the folding intensity of the various layers involved. To enable an early consideration of the consequences of salt-tectonic overprint on the determinability of the properties of the isolating rock zone searched for in the procedure, in the case of salt structures, the following indicator is proposed:

Indicator: Shape and size of salt structures

The following criterion is derived for the assessment of the potential impacts of salt-tectonic overprint of salt structures on the determinability of the properties looked for:

Criterion: Salt rock structures should show large-scale folding of strata with different mechanical and hydraulic properties.

Weighing: Salt-tectonic folding

Salt-tectonic folding	Large oval salt structures	Small round or narrow elongated salt structures
Assessment group	favourable	less favourable

Transferability

Subject matter

Transferability primarily concerns the interpolation and extrapolation of site-specific local information. Their reliability depends on the extent of rock areas with uniform properties and the structure of the geological unit that includes the isolating rock zone.

The following criterion serves to check whether, on the basis of site-specific local information, reliable statements on the existence of sufficiently extended areas of the considered rock type with its characteristic properties in the isolating rock zone can be made:

Criterion: Areas are favourable where the rocks of the isolating rock zone are uniform or very similar across an extensive area.

Weighing: With regard to the spatial uniformity of the rock structure, there are significant differences between the various genetic rocks (sedimentary rock, magmatic rock and metamorphic rock). Thus, a detailed assessment requires different assessment parameters. Their final specification is only possible when the rock type of the isolating rock zone or the host rock is known. For sedimentary rock and metamorphic rock, the following preliminary assessment groups are derived on the basis of the term "facies":

Rock shape	Facies regionally uniform	Facies variation with known pattern	Facies variation with unknown pattern
Assessment group	favourable	relatively favourable	less favourable

Regarding the assessment of the structure of the geological unit the corresponding criterion is applicable to the determinability.

4.1.4.5 Predictability of the long-term conditions

Subject matter

When assessing partial areas, the determination of the geological conditions and the spatial characterisation are not sufficient. The identification and assessment of safety-relevant long-term variations also require reliable predictions on their future development. Thus, the requirement of good predictability is an essential prerequisite for the proof of long-term stability of the geological conditions.

The selection procedure for a repository site aims at a favourable overall geological setting. The requirement of good predictability is also targeted at the entire geological structure. Thus, the requirement is not only effective with regard to the individual criteria but rather covers the entirety of the geoscientific criteria.

Predictions covering the required isolation period of an order of magnitude of one million years require a retrospective consideration of far more than one million years. Only then, can future developments of the geological conditions be analysed and assessed. Thus, partial areas are searched for where geological history can be traced back over long periods of time and where the safety-relevant features "thickness", "extent" and "field hydraulic conductivity" of the isolating rock zone have not changed essentially.

Criterion: The features "thickness", "extent" and "field hydraulic conductivity" of the isolating rock zone should not have changed essentially for several million years.

Weighing: Changes of the features "thickness", "extent" and "field hydraulic conductivity" of the isolating rock zone:

Change of the features of the isolating rock zone	No significant change of the considered features over a period > 10 million years	No significant change of the considered features over the period 1 to 10 million years	No significant change of the considered features over a period < 1 million years
Assessment group	favourable	relatively favourable	less favourable

4.1.4.6 Favourable rock-mechanic conditions

From a geotechnical or rock-mechanic point of view, the objective connected with the requirement *favourable rock-mechanic conditions* is to be able to construct stable infrastructural workings and repository cavities in the host rock for the envisaged period of operation without lasting damage of the surrounding rock (cracking) and a minimum of technical stabilising measures (no supporting structures). Moreover, no mechanical, thermal or hydraulic processes caused by anthropogenic impacts should be induced during the operating period as well as in the post-operational phase that could impair the barrier integrity (e. g. mechanically or thermally induced cracking, fluid flows). In particular, the future constructability and sound functional condition of the barriers, such as drift dams and shaft sealing structures, should not be impaired in such a way that the ensurance of long-term safety according to the respective decommissioning concept is impaired. Therefore, a geomechanical situation should be identified where the consequences induced by anthropogenic impacts on the rock with damage and weakening of the rock mass as well as the formation of secondary permeabilities during the period of construction and operation are as low as possible and furthermore, are reduced in the vicinity of geotechnical barriers in the longer term after decommissioning and finally eliminated in the case of the continuous retention of the barrier integrity.

Derivation of conditions/properties

Principally, conditions/properties have to be formulated for the rock in question according to the requirements, which characterise a situation favourable for a repository and which then are referred to for the identification of those rock conditions that comply with the requirement of favourable rock-mechanic prerequisites.

For the formulation of a preliminary orientating catalogue of conditions, it seems plausible to postulate the following conditions:

- Condition 1: Apart from near-face consolidation coupled with the load bearing capacity of the rock, no supporting structures should be required in order to maintain stable mines.
- Condition 2: No secondary permeabilities should be generated in the geological barriers that impair long-term safety.
- Condition 3: The functional effectiveness of the geotechnical barriers (seals) should not be reduced by a near-face excavation damage zone beyond an unavoidable degree.

Derivation of condition-related indicators

Against the background of this orientating condition catalogue, two indicators can be formulated for the existence of favourable geomechanical settings without explicitly assigning conditions:

Indicator 1:

Geomechanically, the rock mass is the main load-bearing element

Subject matter

The host rock is regarded as the main load-bearing element, if the load from excavation and operation can be borne without planned supporting structures with tolerable deformations (apart from near-face consolidation, e. g. rock bolts - wire netting).

The rock is supposed to have an adequate load capacity, if the loads resulting from impacts (load and temperature changes from rock and waste) do not exceed its load bearing capacity. This capacity is reached if there is a lasting need for concern about rock fall. The load capacity of the roof support is considered implicitly. Rock areas where the limits of load capacities are reached are called pseudoplastic zones.

The terms “sturdiness” and “stability”, which are common and necessary in the field of rock engineering within the framework of supporting structures planning/proof of stability, are deliberately not used, since no proof is furnished regarding the site selection and these general considerations do not include safety reserves.

Indicator 2:

No mechanically induced secondary permeability outside a (unavoidable) contour-near damaged zone.

Subject matter

Secondary permeabilities result from dilatant rock deformations due to a load exceeding the dilatancy strength. Here, existing fissures open up and new fissures may be formed and interconnected. Secondary permeabilities outside the contour-near border zone cannot be detected without substantial interference with the rock and therefore lead to additional uncertainties in the safety analyses, which principally can be avoided by careful planning. This reduces the predictability of the geohydraulic situation of the barrier rocks in the isolating rock zone.

Regarding the planned limitation of rock mass deconsolidation and disturbances to a minimal excavation damaged zone, the intact geological barrier in its spatial extension can at least be characterised clearly regarding the actual conditions (calculations) and proven with examples (field studies).

Further, rock damage and weakening that extend beyond the excavation damaged zone and that are not sufficiently quantifiable cause an additional reduction of the postulated hydraulic effectiveness of geotechnical barriers, such as drift dams or shaft sealing structures. A near-face deconsolidation-/excavation-disturbed zone is given and acceptable if the transgression of the dilatancy strength is to be regarded as moderate and if the zone remains limited, to different extents depending on the rock type, but is generally not more than a few metres from the face.

Weighing procedure

On behalf of the Commission, a two-part study was prepared for the demonstration and analysis of the general load behaviour of different rock types in the case of repository-relevant effects [LUX 2002b and 2002c]. This study includes an exemplary assessment of the load behaviour at a representative repository mine (drift near to the emplacement area).

The main results of this study are as follows:

(a) For a rock type-related postulation of an admissible

- extension of the near-face fracture zone (pseudoplastic zone),
- extension of the near-face excavation-disturbed zone, and
- rock deformation (strain, displacement).

there is a systemisable relationship between the potential depth of a mine and the rock strength, when observing the specified mechanic limit values.

(b) With regard to the uniformity of the load-bearing behaviour, distinction is to be made between

- rocks with elastic-brittle and marginal elastic and plastic creep behaviour, on the one hand, and

- rocks with distinctive creep behaviour, on the other hand.

The study showed that from a rock-mechanics point of view, the two indicators and thus the criteria can be summarised according to the results under one superior criterion. The reason for this is the fact that with a sufficient load capacity of the rock (= main load-bearing element), near-face damage and weakening are only to be expected to a limited degree so that if supporting structures are not used sufficient stability on the one hand and the limited formation of dilatant rock areas (and thus secondary flow paths) on the other hand are closely interrelated with regard to the load-bearing properties of the rock.

By conservative aggregation of the calculation data compared to the specified mechanical limit values, the requirement can be simplistically operationalised into one general criterion in the form of the relationship *representative rock's compressive mass strength – maximum admissible depth*. However, depending on the material type and the observation of the specified condition-related limit values, there are different characteristic relations according to the above differentiation under (b) between representative rock strength and potential repository depth. Thus, the identification of rock-mechanic favourable conditions is possible by means of a general criterion alone, despite the geomechanical aspects of the requirement on the one hand and geohydraulic aspects on the other. This criterion can be formulated as follows:

Criterion: There should be low tendency to mechanically induced secondary permeability outside a contour-near deconsolidated border zone around the repository excavations.

As an auxiliary for weighing in practical application, two diagrams (see Fig. 4.9 and 4.10) have been developed for the following differentiation according to material properties:

a) Host-/barrier rocks with no or marginal creep (ductile) behaviour, and

b) Host-/barrier rocks with distinctive creep behaviour, which then, again in dependence on the depth of the relevant mine and the representative rock mass' compressive strength, allows a criteria-related weighing. Thus, the objective of a quantitatively based weighing using the diagrams and the basis of the assessment within the framework of a three-stage assessment scale is to answer the question of whether a tendency towards mechanically induced secondary permeability outside a contour-near deconsolidated border zone is given to an acceptable or unacceptable degree. The answer to this question is transformed to the question of whether, in dependence on the rock strength, a specified depth is not exceeded, only moderately exceeded or unacceptably exceeded.

Weighing: Admissible depth in dependence on the representative rock mass' compressive strength

Weighing a): Solid rocks with no or marginal creep (ductile) behaviour (see Fig. 4.9).

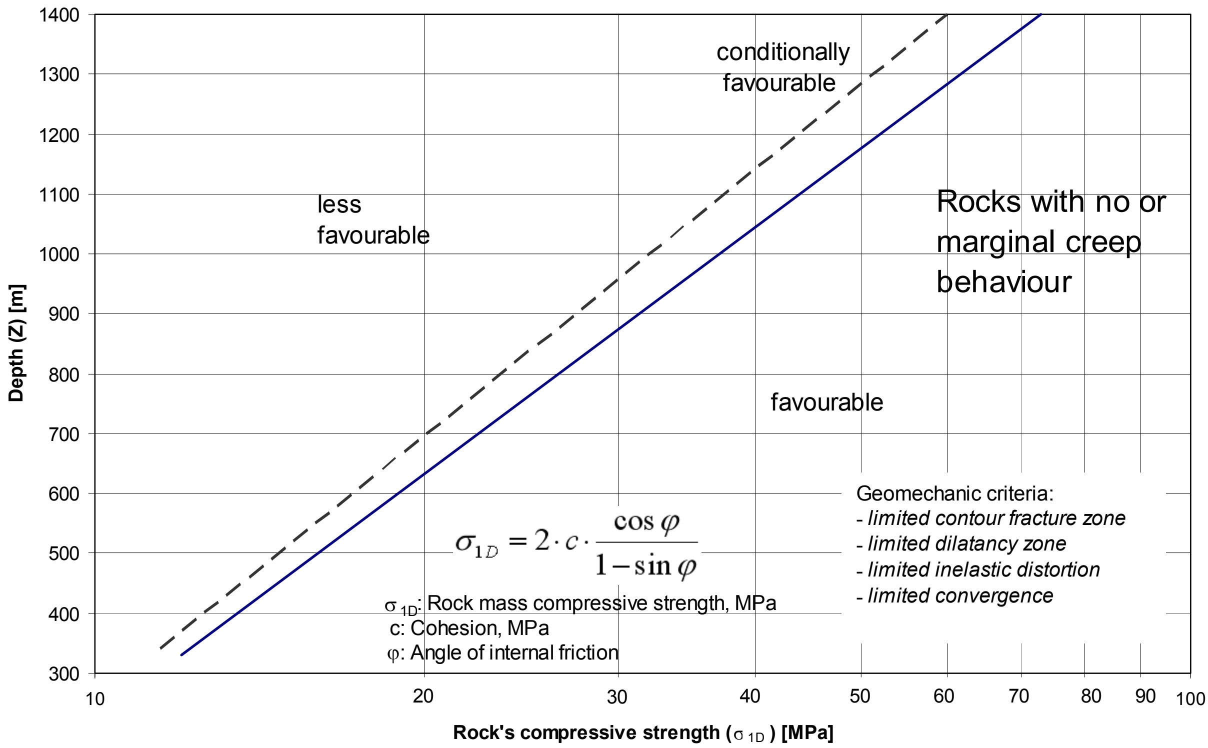

Fig. 4.9: Maximum possible repository depth in dependence of the rock mass' compressive strength for consolidated rock with no or marginal creep (ductile) behaviour from [LUX 2002b]

Admissible depth (Fig. 4.9)	The depth under evaluation lies beneath the graph of the maximum admissible depth, which is dependent on the rock mass' compressive strength (continuous line)	The depth under evaluation lies moderately above (< 10 %) the graph of the maximum admissible depth, which is dependent on the rock mass' compressive strength (dashed line)	The depth under evaluation lies clearly above (> 10 %) the graph of the maximum admissible depth, which is dependent on the rock mass' compressive strength
Assessment group	favourable	relatively favourable	less favourable

Weighing b): Solid rocks with distinctive creep (ductile) behaviour (see Fig. 4.10).

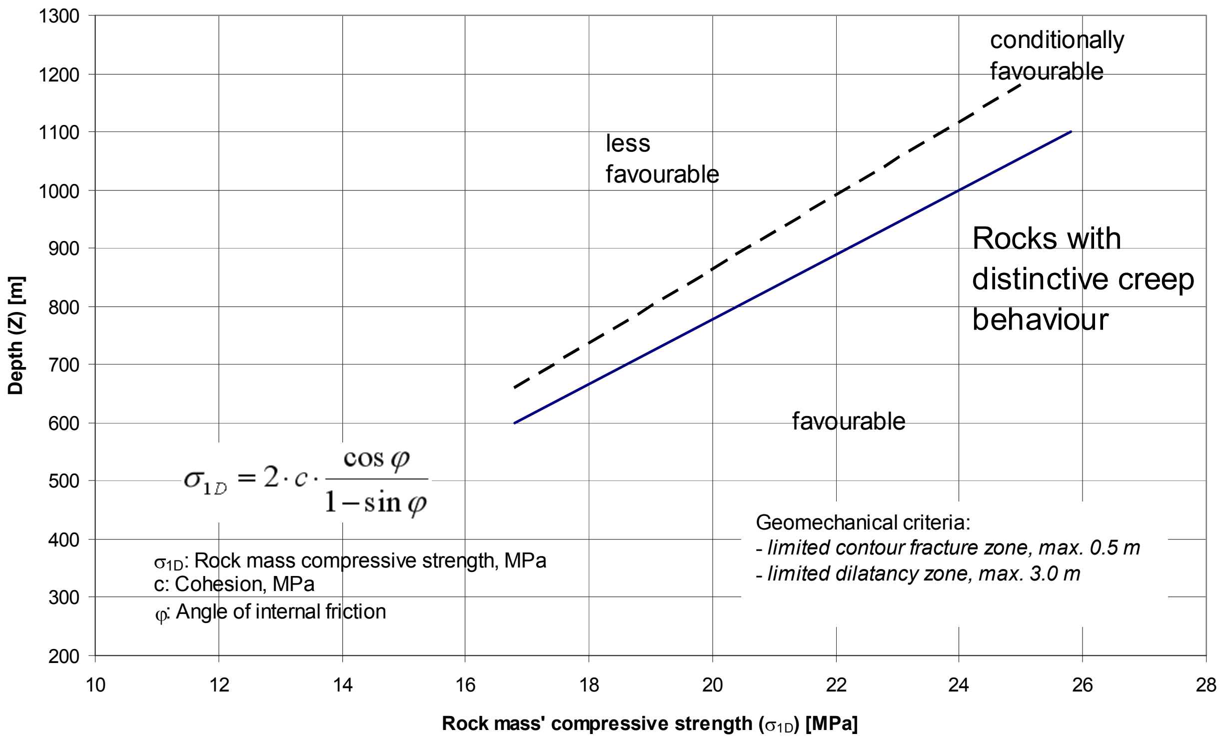

Fig. 4.10: *Maximum possible repository depth in dependence of the rock mass' compressive strength for consolidated rock with distinctive creep (ductile) behaviour from [LUX 2002c]*

Admissible depth (Fig. 4.10)	The depth under evaluation lies beneath the graph of the maximum admissible depth, which is dependent on the rock mass' compressive strength (continuous line)	The depth under evaluation lies moderately above (< 10 %) the graph of the maximum admissible depth, which is dependent on the rock mass' compressive strength (dashed line)	The depth under evaluation lies clearly above (> 10 %) the graph of the maximum admissible depth, which is dependent on the rock mass' compressive strength
Assessment group	favourable	relatively favourable	less favourable

4.1.4.7 Tendency of the formation of water flow paths

The requirement *low tendency of the formation of flow paths* is based on the approach that releases of hazardous substances from deep underground into the biosphere can take place via the migration of fluid phases, namely

- via primary flow paths already existing in the rock formation,
- via secondary flow paths due to anthropogenic activities (construction and operation of the repository), or
- via flow paths induced by future geogenic impact.

Therefore, a favourable overall geological setting seems to be given if, amongst other things, the isolating rock zone generally exhibits a low tendency for the formation of flow paths. Here, flow paths are defined as networks of pores and fracture cavities in the rock of any size and shape from the micro to macro scales that are accessible to fluids. Potential mechanisms for the formation of flow paths are

(1) structural damage due to thermomechanical loads (fissure propagation, formation of fissures), and

(2) selective dissolution of rock due to the impact of soluble water (geochemically reactive environment in the fissure area).

As the mechanism under (2) resulting from anthropogenic impacts requires, besides soluble rocks and a large-scale groundwater-near hydraulic potential gradient, the formation of first flow paths, which allow the intrusion of soluble fluids into this rock, but here only rock types with a low tendency for the formation of fissures are to be preferred, the development of criteria is limited to the mechanism stated under (1) – mechanically induced fissure propagation/formation of fissures.

For further specification of this requirement it seems plausible to assume that both basic rock properties and the relation between damage-free load capacity of the rock formation and existing or expected rock load have to be taken into consideration.

Derivation of conditions/properties

A central prerequisite for the suitability of a rock formation as geological barrier is the impermeability or sufficiently low permeability of the rock system, i. e. solid rocks with low to nearly no matrix permeability are the basis and starting point for further considerations. These are based on the approach that additional cracking also may occur in rock formations with low to no permeability at present if, under the influence of future geogenic or anthropogenic loads

- the rocks do not have an adequate load capacity to bear the loads without exceeding the tensile strength limit and the dilatancy or breaking strength limit,
- the rocks do not have an adequate stress relaxation capacity to bear the external loads without fractures by a stress transfer process accompanied by deformation and with stress relaxation,
- the rocks are subject to deformation-induced grain boundary separation and strain softening despite of a distinctive plastic-viscous behaviour.

In all of these cases, the rocks react to the external loads with the formation of new or further development of already existing fissures (micro- to macrofractures). In the case of sufficient connectivity, these secondary fissures lead to a possibly unacceptably large secondary permeability even if the conductivity of the rock is low or if it is impermeable.

Since there is no qualitative and quantitative criterion directly derivable for the requirement “low tendency to cracking” available for the weighing process, properties are first derived which cover the respective individual aspects of this central requirement and for which criteria can be formulated subsequently. Available general knowledge about rock and rock formation properties under geotectonic and repository-relevant loads suggests the theoretical formulation of the following conditions as properties for the specification of the general requirements:

(1) Rocks with distinctive ductility principally have a low tendency to cracking.

(2) Rocks with proven self-healing capacity under external load (without secondary mineralisation) generally are to be regarded as ductile and thus have only a low tendency to form stable fractures.

(3) Tectogenetic rock formations prestressed deviatorically in different ways, which, from experience, presently have a low permeability, only have a low tendency for the formation of flow paths.

(4) If formations with deviatory prestresses and a minor self-healing capacity recently had a low permeability, and are thus free of fracture networks, then the previous load in situ was below the dilatancy limit of the rock and no tensile stresses exceeding the tensile strength exist or have existed.

(5) Distinctly brittle and high-strength rocks in general have a tendency to crack and only a low fissure-healing capacity. Generally fracture networks have to be expected. In the case of a previous geogenic load which has not resulted in an excess load, and an undisturbed tectonic sedimentation, for which no lasting change of the geogenic load is to be expected in future, it cannot be precluded that potential unavoidable anthropogenically induced and contour-near fissures/fissure systems can be permanently healed by (geo)technical measures in a hydraulically effective manner to the required extent.

Derivation of indicators

The above-mentioned properties for the further specification of the requirement shall be summarised in two main indicators with their respective conditions:

- **Indicator I1:**
- Changeability of the existing field hydraulic conductivity

  Condition: In the isolating rock zone, the changeability of the existing field hydraulic conductivity should be low under the expected anthropogenic and future geogenic loads.

- **Indicator I2:** Healing of anthropogenically/geogenically induced fissures/fissure systems

  Condition: In the isolating rock zone, a self-healing capacity, based on rock properties, should generally be present for anthropogenically/geogenically induced fissures/fissure systems.

Derivation of indicator-related criteria

On the basis of the properties postulated in theses-form for the specification of the requirement and the assignment of the derived indicators, criteria are developed in the following. These criteria are of such a nature that they transform the formulated indicators into qualitative/quantitative values, which thus can be evaluated. The essential facts on this issue are presented in [LUX 2002a]. As a result, it was possible to assign the following criteria to the two indicators:

Criteria for Indicator I1:

Criterion 1:

Assessment criterion:

Ratio of field hydraulic conductivity and matrix hydraulic conductivity

Criterion: The representative field hydraulic conductivity should be the same as the representative matrix hydraulic conductivity.

Subject matter

The conductivity/permeability of the rock is closely related to the rock-specific properties (→ matrix porosity/matrix permeability) on the one hand, and on the other to the tendency of the rock formation to a ruptural reaction to geotectonic loading leading to fissures (→ rock porosity/rock permeability – structure of separation surfaces). It can be concluded that rock masses whose large-scale permeability in general is equal to the permeability of the associated rock (specimen) have a low tendency towards the formation of fractures. This is especially true in the case of disturbed stratification, which indicates a considerable tectonic load. Furthermore, corresponding data for relevant rock types with low matrix porosity/matrix permeability is available from laboratory investigations of samples (drilling cores) and from field surveys. In [APPEL & HABLER 2001 und 2002], a current compilation and evaluation of measurement data from field surveys are presented.

Criterion 2:

Assessment criterion:

Experience of the barrier effectiveness of the rock formation

Criterion: The barrier effectiveness of the rock mass against the migration of liquids or gases (under geogenic and in part also under anthropogenic impacts) should be derivable from geoscientific, geotechnical or mining experience.

Subject matter

From experience it is known that the behaviour of rock formations towards groundwater movement differs. From the hydrogeological point of view, distinction is made between

- aquifer, and
- aquitard.

Further, it is also known from mining experience that in some rock formations, mines are exposed to considerable inflow, whereas in other rock formations mines are dry. In the field of salt mining it is of vital importance for the operation of the mine to prevent inflows from water-bearing layers at the top, bottom or laterally by the configuration of so-called hydrogeological protective layers and correspondingly adapting the direction of mining.

The property of some rock formations, to be slightly permeable or impermeable to fluids, is taken advantage of when storing liquid or gaseous media (hydrocarbons) in cavities and mines without containers and for the underground disposal of chemotoxic waste.

From the point of view of geosciences, mining and geotechnics, the following experience areas mentioned under "Weighing I2" can be regarded as geogenic (natural) or also anthropogenic indicators for the existence of rock formations with low to no conductivity.

Criterion 3:

Assessment criterion:

Ductility of the rock (qualitative or quantitative configuration according to available data).

Criterion: Under in-situ conditions, the rock should naturally show a plastic-viscous deformation ability without dilatancy.

Subject matter

A deformation capacity phenomenologically characterised as ductile is considered as one property of rocks with a low tendency for the formation of fissures. Under external loading, this form of deformation capacity partly leads to plastic-viscous deformation. In the case of linear-elastic material behaviour, this results in stress redistribution in extremely strained parts of the supporting structures at the time of loading or soon after. This stress redistribution has the effect that extreme loads, predicted by analysis based on a linear-elastic material model, will not arise or will be reduced, and simultaneously leads to larger deformations. However, this rather momentary and also extremely time-dependent stress redistribution is not free of (micro)fissures in the rock structure, which are generally referred to as structurally damaging. However, with an increasing ductility of the deformation capacity of the material, the deformations are decreasingly accompanied by structural damages. Phenomenologically, these structural damages involve structural deconsolidation and structural decompaction leading to an increase/extension of the rock volume, which is referred to as dilatancy. The dilatancy limit is defined as that load level which initiates (integrally referred to a test specimen) dilatant deformations of the rock. This does not exclude the previous formation of shear surfaces with reduced strength, however without volume increase (= closed latent separation surface, e. g. cleavage surfaces). Ductility and also the dilatancy limit of a material depend on the minimum stress and the temperature, but also, e. g. on the load rate. Thus, two mechanisms become apparent regarding the concern about fissure formation in the rock structure: on the one hand, the deformation-related stress redistribution with load reduction without fissure formation and, on the other hand, the dilatancy-related deformation in the case of an excessive overall load level.

From a mechanical point of view, the creep capacity is of special importance with regard to the long-term load behaviour. Here, with reference to a repository, distinction is to be made between brittle rock with negligible creep behaviour, such as granite rock and also clay marlstone, as well as plastic-ductile rocks, such as claystone with a rather low creep capacity on the one hand, and saliferous rock with a distinctive creep behaviour on the other hand.

The formulation of indicator-related assessment parameters seems to be possible, according to the respective state of knowledge, at different analysis levels:

(a) Qualitative analysis level (no site-specific exploration; application of general experiences):

- Specification of the rock type as indicator for the mineral grain inventory,
- the mineral grain inventory (monomineral, polymineral) is the basis for the assignment to the general material type (brittle, ductile), and to
- the basic type of deformation (elastic/brittle, elastic-pseudoplastic with tendency to momentary deconsolidation, elastic-viscoplastic/ductile with tendency to gradual deconsolidation, elastoviscous/ductile)

(b) Quantitative analysis level (site-specific laboratory investigations):

- Determination of dilatancy strength (→ parameter for load intensity without microfissures),
- determination of the dilatancy angle (→ parameter for intensity of fissure formation = structural decompaction),
- determination of the extent of inelastic deformation compared to the extent of elastic deformation at the dilatancy limit (→ parameter for structural change without fissures):
    - $\varepsilon^{ie} > \varepsilon^{el}$ for exist $\eta > \eta_{Dil}$

Criteria for Indicator I2:

Criterion 1:

Assessment criterion:

Fissure closure

Criterion: Upon stress inversion (increasing isotropic stress and decreasing deviatory stress), fissures/fissure systems in the rock should be closed in a geohydraulically effective manner.

Subject matter

Regarding the capacity to close fissures thus leading to a reduction of the secondary permeability, a distinction has to be made regarding the following rock types:

- *Polycrystalline and also fine clastic rock with elastic-brittle material behaviour* and no or negligible creep properties, as e. g. granite rock, but tendentiously also clay marlstone

- *Fine clastic* rock with viscoplastic-ductile material behaviour, as e. g. clays or some clay stones

- *Polycrystalline rock with viscoplastic material behaviour and distinctive creep capacity,* as e. g. (chloridic) rock salts

The formulation of an indicator-related assessment parameter can be based on the following:

- Qualitatively on the principle capacity of the rock for fissure closure, i. e. on the properties of the rock due to its mineral structure

- Quantitatively on exploration results, as e. g. on the degeneration intensity of secondary permeabilities after a realistic compaction pressure has built up

Criterion 2:

Assessment criterion:

Fissure healing

Criterion: Following fissure closure, fissures/fissure systems in the rock should be healed in a geomechanically effective manner.

Subject matter

Fissure healing takes place via geochemically dominated recrystallisation processes in the fissure with or without foreign minerals in dependence on the existing pressure and temperature conditions. Here, atomic bonding forces are reactivated in the former fissure areas that, phenomenologically, lead to the recovery of cohesion.

Different healing mechanisms are known for different rock types:

- Elastic-brittle polycrystalline rocks with no or marginal creep properties, e. g. granite, only heal through secondary mineralisation. Fracture healing through secondary mineralisation only takes place in the presence of a solvent, a concentration and temperature gradient as well as ions in solution (solutes).

- Marginal plastic-ductile fine clastic rocks, e. g. claystone, only heal through secondary mineralisation. However, this process does not have to occur regularly and thus cannot be predicted with the necessary reliability. The process of swelling has not been taken into consideration, since it actually does not represent a healing process but rather a fissure closure.

- Viscoplastic-ductile polycrystalline rocks with distinctive creep behaviour, e. g. chloridic rock salt, heal after mechanical fissure closure and geochemically dominated recrystallisation processes under the influence of temperature, moisture content (brine) and pressure with the new formation of mineral grains in the fissure area. An extreme example known from mining and at the same time in-situ evidence is the recompaction of fine salt (salt muck) which can, under the influencing factors of time, pressure, temperature, and moisture content, lead to the formation of a consolidated rock with almost natural properties.

The following indicator-related assessment parameter can be included in the formulation:

- Qualitatively, the existence of the mechanisms recrystallisation and secondary mineralisation together with the general existence of the conditions for activation and realisation of the respective rock-dependent healing processes

- Quantitatively, the recovery degree of the cohesion under the respective in-situ conditions (e. g. pressure, temperature, moisture content)

Weighing procedure

For the assessment of the requirement, two criteria with five indicators were derived. In accordance with the individual criteria, an assessment parameter was developed, being qualitative or quantitative according to the conditions. The conditions are compiled in [LUX 2002a], and general aspects of these conditions have been outlined above. On the basis of these conditions, the assessment parameters have been developed to enable, apart from one exception, a three stage criteria-based assessment of the respective results.

After the performance of the weighing process for each indicator, the results are aggregated to a total weighing.

In the following, the criteria and the weighing are presented in summary:

Changeability of the field hydraulic conductivity

Indicator I1: Changeability of the existing field hydraulic conductivity

Condition: The changeability of the field hydraulic conductivity of the isolating rock zone should be low regarding the expected additional anthropogenic and future geogenic impacts.

Criterion 1 for I1: The representative field hydraulic conductivity should be the same as the representative matrix hydraulic conductivity.

Weighing 1 for I1: Ratio of field hydraulic conductivity/matrix hydraulic conductivity:

Ratio of field hydraulic conductivity/ matrix hydraulic conductivity	$K_{field}/K_{matrix} < 10$	$K_{field}/K_{matrix} \leq 100$	$K_{field}/K_{matrix} > 100$
Assessment group	favourable	relatively favourable	less favourable

Criterion 2 for I1: The barrier effectiveness of the rock mass against the migration of liquids or gases (under geogenic and in part also under anthropogenic impacts) should be derivable from geoscientific, geotechnical or mining experience.

Weighing 2 for I1: Consideration of the following experience areas with regard to the rock formations:

- Recent existence as water-soluble rock
- Fossil fluid inclusions
- Underlying water-soluble rocks
- Underlying reservoirs of liquid or gaseous hydrocarbons
- Use as hydrogeological protective layer in extraction mines
- Maintenance of the sealing function even under dynamic load
- Use of cavities for the storage of gaseous and liquid media without containers

Experiences of the barrier effectiveness of the rock formation	On the basis of single or multiple fields of experience, the rock formation/rock type is directly/indirectly identified as impermeable or poorly permeable even under geogenic/technogenic strain.	The rock formation/rock type cannot directly/indirectly be identified as impermeable or poorly permeable due to lack of experience.	The rock formation/rock type is directly/indirectly identified as not sufficiently impermeable due to experience from a single field.
Assessment group	favourable	relatively favourable	less favourable

Criterion 3 ad I1: Under in-situ conditions, the rock should naturally show a plastic-viscous deformation ability without dilatancy.

Weighing 3 ad I1:

Ductility of the rock	Ductile / plastic-viscous behaviour	Brittle-ductile to slightly elasto-visco-plastic	Brittle, linear-elastic
Assessment group	favourable	relatively favourable	less favourable

Self-healing capacity of fissures

Indicator I2: Healing of anthropogenically/geogenically induced fissures/fissure systems

Condition: In the isolating rock zone, a self-healing capacity based on rock properties should generally be present for anthropogenically/ geogenically induced fissures/fissure systems.

Criterion 1 ad I2: Upon stress inversion (increasing isotropic stress and decreasing deviatory stress), fissures/fissure systems in the rock should be closed in a geohydraulically effective manner.

Weighing 1 ad I2:

Self-healing capacity of fissures	In principle, total closure of fissures with adaptation of surface roughness due to ductile behaviour of the rock.	Fissures are closed mechanically in connection with secondary processes, e. g. deformation due to swelling.	Incomplete closure of fissures (e. g. brittle failure; roughness of fissure surfaces; asperity contacts).
Assessment group	favourable	relatively favourable	less favourable

Criterion 2 ad I2: Following fissure closure, fissures/fissure systems in the rock should be healed in a geomechanically effective manner.

Weighing 2 ad I2:

Self-healing capacity of fissures	Healing of fissures due to geochemically dominated processes, thereby reactivation of atomic bonding forces between fissure surfaces.		Healing of fissures only due to crystallisation of secondary mineral phases (mineralised fluids in pore and fracture spaces; secondary □ineralization).
Assessment group	favourable	relatively favourable	less favourable

Summary weighing I1 - II2:

The evaluation of the individual weighing processes is followed by the summary weighing for the requirement “low tendency of the formation of water flow paths” by means of the following assessment scheme:

Sum of the individual indicators	Assessment mainly “favourable“	Assessment mainly “relatively favourable“	Assessment mainly „less favourable“
	No or marginal tendency of formation of water flow paths	Marginal tendency of formation of permanent water flow paths	Formation of permanent secondary water flow paths has to be expected
Assessment group	favourable	relatively favourable	less favourable

4.1.4.8 Gas compatibility

Subject matter

Disposed radioactive waste can generate gases by corrosion and radiolysis when coming into contact with water or solutions. Other sources of gas generation are organic components in the waste packages themselves or their microbial degradation. For the assessment of the effects of gas generation on the safety of a repository, the maximum possible gas volume that can be generated from the waste under repository conditions is of importance, as well as the gas generation rate (volume per year). The gas volume mainly depends on the waste type and the substances contained, the moisture content of the waste packages, as well as on the groundwater or solution supply to the packages. The gas generation rate depends on the temperature, the moisture content and the chemical environment at the emplacement area or in the package, respectively.

The contact of waste packages with groundwater or external solutions, i. e. solutions entering from outside, leads to the generation of corrosion gases. In addition, radiolysis gases may be generated if the radiation intensity of the waste packages is high enough. Both generation types are referred to as external gas generation.

Low- and medium-active waste (LAW/MAW), however also release gases without external intervention. These releases are due to internal processes, such as microbial degradation of organic waste components or to the humidity content of the waste packages (internal gas generation).

For the volume of LAW/MAW waste predicted to accumulate until the year 2040 of about 300,000 m^3, a gas volume of about 50 million standard cubic metres from internal and external gas generation is estimated, if external solutions are present, with about one third resulting from internal gas generation.

Safety relevance of gas generation

The gas generation of radioactive waste in the post-operational phase of a repository may lead to pressure build-up in the repository in the case of high gas generation rates and large gas volumes. The safety relevance of the pressure build-up resulting from gas generation is given by the potential impairment of the barrier integrity. Moreover, an accelerated transport of the radionuclides by gases cannot be excluded.

Countermeasures

A scientifically substantiated analysis of the effects of gas generation can only be made with site-specific data in a repository concept. For this reason, countermeasures are discussed and assessed in the following.

In order to limit the pressure build-up due to gas generation to admissible values, the repository concept and the properties of the isolating rock zone have to be aligned in such a way that the barrier integrity and effectiveness are not endangered. The following measures can principally be taken to counteract an admissibly high pressure build-up:

- Limitation of gas generation or gas volume, respectively, and the gas generation rate,
- limitation of pressure build-up by conceptional measures.

A limitation of internal gas generation regarding LAW/MAW waste can only be achieved by a different conditioning of the raw waste or the reconditioning of already conditioned waste. For already conditioned waste with a volume of about 60,000 m^3, reconditioning would be necessary to limit internal gas generation.

A prevention or limitation of external gas generation can be achieved by the emplacement of the waste packages in watertight, dry or almost dry barrier rocks of the isolating rock zone. Such a rock situation is most likely to be found in rock types with a field hydraulic conductivity of less than 10^{-19} m^2. When emplacing LAW/MAW waste in such a barrier rock, gas storage cavities are required, due to internal gas generation, to limit pressure build-up.

In the case of a host rock with adequate permeability and spatial extension, the pressure build-up can be counteracted both by the natural storage capacity of the host rock and by groundwater displacement processes. Here, internal and external gas generation has to be assumed. For LAW/MAW waste, a gas generation of about 50 million standard cubic metres has to be expected. On behalf of the Committee, case studies were performed for different geological situations and types of gas generation [JAVERI & BALTES 2001]. These show, e. g., that a host rock with a hydraulic conductivity of more than 10^{-10} m/s and an extension of several hundred metres would be able to limit the pressure increase to 20 % of the hydrostatic pressure in the repository.

Assessment of the countermeasures

For LAW/MAW waste, there is no efficient method available for reconditioning already conditioned waste with regard to the reduction of gas generation. Therefore, internal gas generation has to be taken into account regarding the disposal of this type of waste.

When providing gas storage cavities, their functional efficiency has to be ensured over long periods of time. In addition, the risk has to be assessed that water intrudes that is not in balance with the formation in which the gas storage cavities are emplaced. This may have a negative effect on the repository system that cannot be calculated. The future development of such a repository system can only be predicted under certain conditions and the proof of long-term safety can only be made with difficulty. Further, effects of unintentional human intrusion into the repository system cannot be controlled or, at least, only with great difficulty. For this reason, the inflow of water has to be excluded with a high probability for this concept.

When emplacing LAW/MAW waste in a host rock with a higher permeability, there is a conflict of objectives between the requirement of rock types with low permeability and isolation of the waste. The fulfilment of both requirements “limitation of pressure build-up” and “isolation of the waste” requires configurations of the isolating rock zone which have a host rock with a higher permeability and adequate spatial extension embedded in a barrier rock.

Formation waters entering the repository cavities do not only present a risk regarding the release of harmful substances from the LAW/MAW waste, but also for HAW waste if both waste flows were not emplaced in hydraulically separated areas with an adequate distance between them. However, connecting passages within a repository are always a risk regarding the propagation of water. In the case of disposal of both waste flows in one repository a site should be selected that enables the emplacement of HAW/BE waste in the barrier rock and the emplacement of LAW/MAW waste in a permeable host rock.

Conclusions

The following conclusions are to be drawn for the selection of sites:

- To limit external gas generation due to the inflow of water or solutions from outside, it is required in the selection procedure to search for a favourable overall geological setting with the largest possible confinement and with the lowest possible water supply.
- For the emplacement of LAW/MAW in watertight barrier rock, the provision of gas storage cavities is indispensable. For reasons of the long-term safety of this project, the probability of excluding an inflow of formation waters must be high.
- The targeted search for configurations of isolating rock zones with a host rock showing sufficient permeability and size being enclosed by a barrier rock, places high demands on the geological database and the geoscientific knowledge required for the implementation of the selection procedure.
- In the selection procedure, it has to be considered that the concept of storing LAW/MAW waste with gas storage cavities increases the area /volume demand for the isolating rock zone considerably. Moreover, it has to be taken into account that the storage of heat-generating HAW/BE waste and non-heat-generating LAW/MAW waste in one common repository requires adequate spatial separation of the two waste flows in order to minimise the influence on the gas generation by temperature increase at the LAW/MAW waste.

For the two waste flows, different geological conditions are to be regarded as particularly favourable. Under consideration of the mentioned items it is therefore reasonable or indispensable, respectively, with regard to the problem of gas generation, to dispose of the HAW/BE waste and the LAW/MAW waste at two adequate sites or at one site in adequate host rocks under the aspects of safety and the demonstration thereof.

Derivation of a criterion

Criterion: Gas generation of the waste under disposal conditions should be as low as possible.

Indicator: Availability of water in the host rock

Weighing: Water content and, where necessary, field hydraulic conductivity as indicator for the availability of water:

Availability of water in the host rock	dry	wet and impermeable (field hydraulic conductivity $< 10^{-11}$ m/s)	wet
Assessment group	favourable	relatively favourable	less favourable

If the availability of water in the rocks provides enough moisture for corrosion, the situation is classified “wet” or if not “dry”.

Criterion: The pressure build-up due to the expected gas generation of the waste should be low.

Indicator: Host-rock type

Weighing: Characteristic field hydraulic conductivity of the host-rock type (m/s):

Field hydraulic conductivity in m/s	$> 10^{-9}$	10^{-9} - 10^{-10}	$< 10^{-10}$
Assessment group	favourable	relatively favourable	less favourable

4.1.4.9 Temperature compatibility

Subject matter

The assessment of the rock with regard to thermal stresses is closely related to the formation of water flow paths in the barrier rock and thus the integrity of the repository. Although some knowledge exists on this matter (in particular on salt as a host rock), new numerical studies were performed on thermal expansion and thus on the build-up of local thermal stresses on behalf of the Committee [JENTZSCH 2002]. These model calculations allow estimations on the spatial and time-dependent distribution of stresses with regard to heat sources with different spatial extensions. The consideration of material properties, such as tensile strength, allows the determination of areas around a heat source where fractures are to be expected. In turn, requirements on the rock can be derived under the general condition of the predefined heat input that have to be fulfilled if the fracture zone shall be limited to the direct surrounding area of the repository to avoid an impairment of the barrier.

Derivation of criteria

With regard to the derivation of criteria, two aspects have to be taken into account:

a) Temperature-dependent changes of rock properties (*mineralogical aspects*),

b) Thermomechanical stresses leading to fractures, thus opening water flow paths (*thermomechanical aspects*).

The mineralogical aspect is of importance for claystone, but also for granite, as here a material is used, when backfilling with bentonite as an additional technical barrier, which has properties similar to those of claystone. Thus, the advantage of better temperature compatibility of granite compared to claystone, to be expected from a mineralogical point of view, cannot be made use of. Besides, model calculations show that high thermal stresses may occur under which granite remains unfractured only if its tensile strength exceeds certain strength limits.

The analysis of the temperature compatibility of the rocks shows that high and isotropic heat conductivity, high heat capacity and a low thermal expansion coefficient as well as a high tensile strength and a high relaxation capacity of the rocks are favourable properties. The requirement that the favourable overall geological setting searched for has to be sufficiently large ensures that an average heat production in the repository area of 0.1 W/m³ and a temperature of 100 °C at the face of the repository cavities will not be exceeded.

Criterion ad a): In the rock immediately surrounding the emplacement cavities, no mineral changes that would exert an inadmissible influence on the barrier effect of the isolating rock zone must occur if temperatures lie below 100 °C.

Weighing: The geochemical stability of the rock immediately surrounding the waste cavities with regard to thermally induced mineral changes that will not exert an inadmissible influence on the barrier effect of the isolating rock zone is ensured in the temperature range:

Temperature in °C	> 120	100 - 120	< 100
Assessment group	favourable	relatively favourable	less favourable

Criterion ad b): The tendency to thermomechanically induced secondary permeability outside a contour-near deconsolidated border zone should be as much spatially restricted as possible.

Weighing 1: Extension of the thermomechanically disturbed rock zone around the emplacement cavities [m] where thermally induced excesses of tensile - and dilatancy strengths may occur:

Thermo-mechanically disturbed surrounding area in m	< 10	10 - 50	> 50
Assessment group	favourable	relatively favourable	less favourable

Weighing 2: Tensile strength [MPa] in the near field (about 10 m to 50 m) of the repository at a contact temperature of 100°C for the rock types granite claystone and rock salt:

Granite	> 13	≥ 8	< 8
Claystone	> 8	≥ 4	< 4
Rock salt	> 2	1 - 2	< 1
Assessment group	favourable	relatively favourable	less favourable

4.1.4.10 Radionuclide retention capacity of the rocks

Subject matter

The ionic strength, or the concentrations of complexing agents and colloids, respectively, (e. g. carbonate or humic colloids) in deep water and the mineral inventory of the rock are decisive for a retardation of radionuclides in the geosphere. Further retarding properties of a formation are a high matrix diffusion (and sorption onto matrix particles) and the filter effect with regard to colloids.

Sorption

The extent of sorption depends both on the mineralogical composition of the percolated rocks and on the hydrochemical environment of the deep water. Clay minerals, manganese-, iron- and aluminium-oxides, -hydroxides and -oxihydrates, as well as organic substances (e. g. coal, peat) are good sorbents at least under special environmental conditions, whereas, for example, quartzose, low clay-content rocks, such as sandstone, granite or gneiss, generally have a low sorption capacity. The sorption mechanisms of the different mineral phases are not identical. So, e. g., sorption onto clay minerals can be described with ion exchange models, whereas the sorption of solutes onto manganese-, iron- and aluminium-oxides, -hydroxides and -oxihydrates can rather be explained by surface complexation models. However, these different mechanisms react differently to changes in the hydrochemical environment regarding their sorption intensity.

Regarding the hydrochemical environment, the factors pH-value, Eh-value, occurrence of competitive ions, ionic strength, speciation, concentration and charge of the dissolved ions, as well as temperature determine the sorption capacity. In general, neutral to slightly alkaline pH-values, low ionic strength and low concentration of competitive ions support the sorption capacity. Complexation processes (e. g. generation of carbonate complexes), however, reduce the sorption capacity.

The multitude of the above-mentioned influencing factors shows that there is a complex correlation between nuclide-, rock- and environment-specific factors, which do not allow the derivation of a generally applicable quantitative criterion, but only of the above-mentioned general trends (see Chapter 4.1.4.11). In fact, favourable geochemical conditions for sorption processes have to be assessed within the framework of a complex rock-, nuclide- and environment-specific case study.

Criterion: The sorption capacity of the rocks should be as high as possible.

Discussion:

A scientifically substantiated check of the criterion is only possible with the site-specific data in a repository concept; i. e. a generally applicable quantitative criterion for favourable geochemical conditions with regard to sorption processes cannot be derived without difficulty (see Chapter 4.1.4.11). However, trends can be presented with regard to favourable rock compositions and hydrochemical conditions. Rocks containing clay minerals or manganese-, iron- and aluminium-hydroxides or -oxide compounds, that are thus good sorbents under special environmental conditions, have to be assessed more positively than those poor in these minerals (e. g. sandstone, granites, gneisses), and thus having the disadvantage of a generally lower sorption capacity. However, it is questionable whether the above-mentioned hydroxide- and oxide-compounds exist in sufficient quantities at repository level in view of the reducing conditions to be assumed there.

In most cases, neutral to slightly alkaline pH-values, low ionic strengths and a low concentration of inorganic or organic complexing agents support the sorption capacity. For the most part, higher temperatures only have a positive effect with the presence of oxygen (generation of iron hydroxides).

The available data on sorption, however, are only applicable to experimental conditions (e. g. with regard to pH, ionic strength, general solution composition), for which they have been determined. It is not possible to apply the sorption data to other geochemical conditions.

Derivation of a criterion from safety-analytical considerations

Due to the above conditions, an estimation of the retention capacity of the rocks of the isolating rock zone in Step 2 of the procedure can only be made with restricted reliability. For this reason, this requirement can only be considered in Step 2 of the procedure as a safety reserve.

Indicators for the retention capacity of the rocks are their sorption capacity towards radionuclides and the presence of mineral phases with large reactive surfaces.

In safety analyses, the linear sorption coefficient Kd is referred to as parameter for the sorption capacity. A Kd-value of 0.001 m^3/kg means, in case of an absolute porosity of the rock of 0.15, that the transport of radionuclides in the groundwater is retarded by a factor of 10 to 20 compared to the field velocity.

In particular, rocks with a sorption capacity for long-lived radionuclides are regarded as favourable. Long-term safety analyses show that there are not relevant radiological risks emanating from radioactive waste with lower activity. This is supported by the values of the Radiological Protection Ordinance for the unrestricted clearance of radioactively contaminated building rubble (> 1.000 t/a). The analyses are based on a reference value of 0.01 mSv per year individual dose for the maximum admissible radiation exposure. Accordingly, waste with activities of about 10^8 Bq to 10^9 Bq of long-lived radionuclides (U-238, Np-237) can be cleared without restrictions in one year. On the basis of these considerations, the following criterion for retention can be derived:

Sorption capacity of the rocks in the isolating rock zone

Criterion: The sorption capacity of the rocks should be as high as possible. The Kd-value for the majority of the long-term-relevant radionuclides should be greater than or equal to 0.001 m³/kg.

Weighing: Number of elements of the long-term relevant radionuclides which can be well absorbed by the rocks of the isolating rock zone:

Elements	Uranium Protactinium Thorium Plutonium Neptunium Zirconium Technetium Palladium Iodine Caesium Chlorine	Uranium Plutonium Neptunium Zirconium Technetium Caesium
Assessment group	favourable	relatively favourable

Before implementation of the procedure, the list has to be adapted to the current estimations of the nuclide inventory (see Table 4.7).

Table 4.7: Long-term relevant radionuclides with total activities greater than 10^{10} Bq after 1 million years for a postulated inventory of about 10,000 spent DWR-fuel elements (0.534 Mg SM/BE)

Radionuclide	Estimated total activity after 1000 years [Bq]	Estimated total activity after 1 million years [Bq] [HERRMANN & RÖTHEMEIER 1998]
Ra 226	3.2×10^{12}	10^{14}
Ac 227		10^{12}
Th 229	1.5×10^{11}	10^{14}
Pa 231	2.6×10^{11}	10^{12}
U 233	3.7×10^{12}	10^{12}
U 234	2.2×10^{15}	10^{14}
U 235	1.2×10^{13}	10^{12}
U 236	2.9×10^{14}	10^{13}
U 238	2.6×10^{14}	10^{15}
Pu 242		10^{14}
Np 237	1.1×10^{15}	10^{14}
Zr 93	2.2×10^{15}	10^{14}
Tc 99	1.4×10^{16}	10^{14}
Pd 107	1.3×10^{14}	10^{13}
J 129		10^{13}
Cs 135	4.1×10^{14}	10^{14}
Cl 36	2.2×10^{15}	10^{11}

Mineral phases with large reactive surfaces

Criterion: The rocks of the isolating rock zone should have the highest possible contents of mineral phases with a large reactive surface

Filtering of colloids

Per definition, the colloid size is 1 µm to 1 nm (10^{-6} m to 10^{-9} m). Regarding the effective pore sizes (fracture apertures) of rocks, water is free and correspondingly advective from a distance of 5×10^{-7} m (0.5 µm) from the grain surface. Below this distance, the viscosity of the water constantly increases and the mobility decreases, respectively, due to electrostatic interactions. Thus, pore sizes (fracture apertures) smaller than twice this length, i. e. 1 µm (upper limit colloid size) theoretically cannot be flown through.

Pore sizes by which colloids are filtered are so small that even solutes (ideal tracers) cannot be transported in them. Such pore sizes or fracture apertures, respectively, do not allow groundwater flow, so that only diffusive transport can take place.

A criterion for the filtering of colloids is not derivable.

4.1.4.11 Hydrochemical conditions

Subject matter

Favourable hydrochemical conditions in a geological formation are characterised, among other things, by a reducing geochemical environment, low concentrations of complexing agents and colloids, as well as by neutral to slightly alkaline pH-conditions with low CO_2 partial pressure. Under such favourable hydrochemical conditions, low solubilities for radionuclides are to be expected.

The Eh-value, the existence of reduced solid phases, the content of organic substances and the absence of free oxygen in the groundwater and, in addition, the pH-value and the buffering by available carbonate rocks are regarded as potential indicators for the identification of favourable hydrochemical conditions. The concentrations of complexing agents and colloids (e. g. carbonate complexes or humic colloids) in deep groundwater and the existence of sorption areas onto mineral surfaces are decisive for a retardation of radionuclides. Another important indicator for favourable hydrochemical conditions is a geochemical equilibrium between deep groundwater and rock.

The Committee examined to which extent quantitative and qualitative criteria can be derived on the basis of the data accessible today for the above-mentioned indicators [LARUE et al. 2001]. In this respect, the step-wise approach to the site selection and the knowledge and data expected to be available for the respective procedure step have also been taken into account.

A scientifically based geochemical assessment of potential repository formations primarily considers the influence of the local/regional deep water and of the solid mineral phases on the solubility of the radionuclides, as well as their retention, e. g. by sorption and immobilisation.

Derivation of criteria

If there are no special indications in the first two procedure steps, criteria for the selection of repository formations suitable according to geochemical aspects can only be developed by means of existing and easily accessible knowledge on the mineral inventory, the deep water composition and knowledge of the behaviour of waste and radionuclides derived from laboratory experiments.

The existing data material on the chemistry of deep waters in Germany and the heterogeneous distribution of different water types in a small region does not allow wide ranging statements to be made on the identification of areas, regions and sites on the basis of hydrochemical criteria. In the case of deep groundwater, the current knowledge of its composition is too incomplete for a characterisation. In general, essential data is missing, e. g. on the redox potential and on the concentration of dissolved redox-sensitive components. Likewise, data on pH-values is incomplete. For this reason, reliable statements can only be made after a more detailed examination of regional and site-specific conditions.

An essential characteristic of a favourable overall geological setting is the presence of a chemical equilibrium between deep water and the solid bedrock. However, this condition cannot be examined directly in the first two procedure steps due to the generally insufficient database and is thus to be used subordinately to the hydraulic criterion “low groundwater movement”. In case of favourable hydraulic parameters of the host rock (e. g. hydraulic conductivity < 10^{-12} m/s) and a corresponding thickness of the rock formation, a chemical equilibrium can be assumed. The thermodynamic equilibrium is determined by means of geochemical model calculations.

Hydro- and geochemical parameters that have an influence on the solubility and transport behaviour of radionuclides are potential starting points for the derivation of further criteria. However, for the individual influencing factors of the geochemical environment, such as pH-value, redox condition, ionic strength, colloid formation and stability as well as complex formation with solutes, it is not possible to derive simple quantitative criteria. Advantageous are pH-values above 7 and low carbonate concentrations of the deep water. Due to the complex interactions, a generally applicable ranking of the influencing factors cannot be performed. The priority of the criteria rather has to be weighed up in dependence on the rock formation in each individual case on the basis of site-specific investigations and data.

Nevertheless, the influencing factors can be referred to as indicators. The desired ranges with regard to low solubility of radionuclides are stated as follows:

Indicator: pH-value

On the basis of the pH-dependency of the radionuclide solubility, a pH-value of deep water between 7 and 8 can be derived as positive criterion.

If there are dissolved carbonate species, an increase of the actinide concentrations in solution has to be expected for pH-values above 9 due to carbonate complexation. If there are only a few dissolved carbonate species, a higher pH-value (pH > 9) leads to lower actinide concentrations and is therefore to be classified as favourable.

Indicator: Redox conditions

Favourable redox conditions offer anoxic, reducing environments. Among other things, the presence of iron(II) minerals in the host rock indicates favourable redox conditions

Indicator: Ionic strength

The influence of the ionic strength on the radionuclide solubility is element-specific, and can therefore not be quantified in general. In addition, the ionic strength has an influence on the transport velocity, since high ionic strengths lead to a reduction of the transport velocity with regard to radionuclides. For this reason, a clear criterion regarding favourable or unfavourable conditions cannot be derived from the ionic strength alone. The deep waters in Germany generally have a high ionic strength at the depths envisaged for disposal.

Indicator: Colloid formation and colloid stability

The colloid formation and the content of natural colloids in deep water should be as low as possible. The hydrochemical environment should, if possible, not contribute to the stabilisation of the colloids. In general, high ionic strengths have a destabilising effect on colloids.

Indicator: Complex formation with groundwater solutes

The content of complexing agents in deep groundwater should be as low as possible. Since the complex formation depends on the geochemical environment of the deep water in many respects and on the interaction with the waste, the application of a simple quantitative criterion for this influencing factor is not possible. However, the carbonate concentration of the deep water should always be low.

Indicator: Sorption and precipitation

In general, rocks with mineral phases that show a highly reactive surface, e. g. clay minerals, Fe- and Mn-hydroxides and -oxihydrates, are desirable. Since, however, the charge of the adsorbing solid surfaces depends on the geochemical environment in a complex manner (in particular pH-value, ionic strength), this influencing factor is not suitable as generally applicable quantitative criterion.

In summary, it can be stated that site-specific information and data with regard to the repository conception have to be available for the quantitative determination of geochemical criteria. These, however, can be made available in the fourth procedure step at the earliest.

4.2 Socio-scientific criteria

The Committee holds the view that the political and public debate about the disposal of radioactive waste in Germany has shown that it will only be possible to realise a repository site with success if socio-scientific aspects are taken into account.

In a selection procedure, socio-scientific criteria shall range on the same level as scientific criteria. However, this must not lead to neglecting the safety regulations of a future repository. This conclusion is confirmed by the results of the representative surveys carried out in 2001 and 2002. At the same time this makes it quite clear that a safe repository and the societal interests do not exclude one another in the public eye.

4.2.1 Derivation of socio-scientific criteria

The socio-scientific criteria are based on two fundamental requirements (see Fig. 4.11): On the one hand, a repository should influence the development potential of a region positively to the largest possible degree, but in no case negatively. On the other hand, the willingness of the population to participate in the search for a repository site should be high.

Two sets of criteria are derived from the development potentials. One of them results from the legally protected potentials, such as nature reserves, water protection areas, protected monuments and protected ensembles (groups of individual objects that form one overall protected unity).

The legally protected development potentials lead to the planning-scientific criteria. Those areas which were legally determined as protected or those kept aside for a certain purpose are on principle classified as unsuitable or less suitable for a repository site.

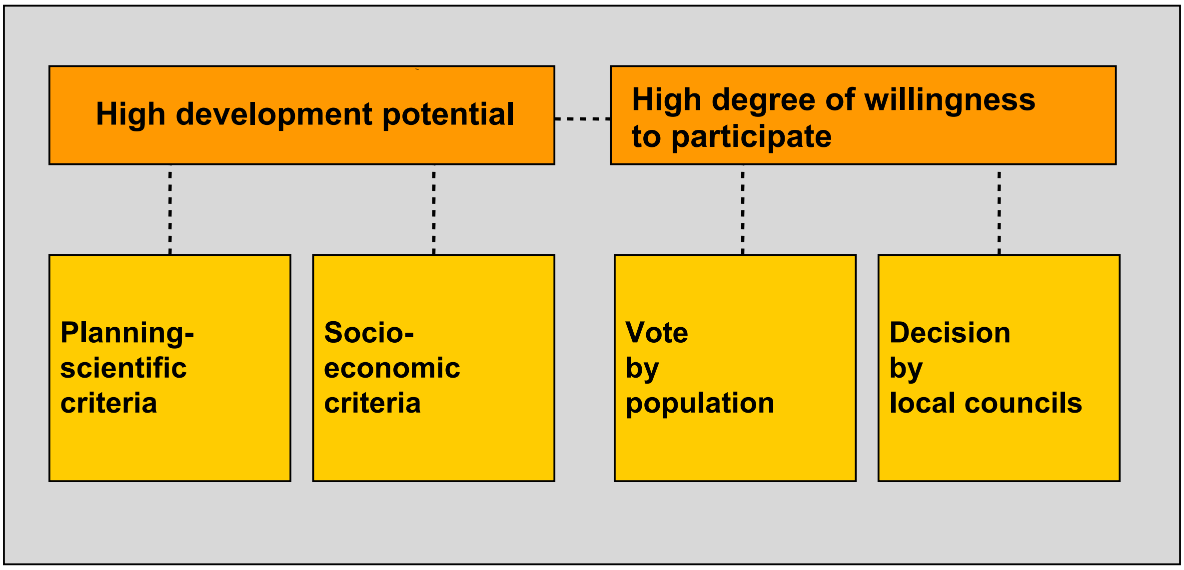

Fig. 4.11: Socio-scientific requirements and relevant criteria

The material justification of the legal protection is generally acknowledged. Depending on the degree of protection, a distinction is made between exclusion criteria and weighing criteria. Only in certain individual cases with special justification, a legal regulation may be questioned. This will subsequently have to be supported by experts' opinions before proceedings can be initiated for abandonment of legal protection.

The second set of criteria includes a multitude of development potentials that are not legally protected. These are cultural, social, economic and natural development potentials. They are considered to establish socio-economic criteria. These are partly region-specific criteria that concern special economic sectors in the respective region (e. g. tourism, smokestack industry) or generally applicable criteria (e. g. for the housing market).

For this reason, expert opinions are to be prepared for the determination of the socio-economic development potentials of the site regions in agreement with the population (potential analyses). These include assessments of the possible effects of a repository on regionally specific branches of industry (tourism, smokestack industries) or on the housing market. Socio-economic criteria are applied for the assessment of the development potential. They relate directly to the socio-economic structures and processes determining the development and quality of life of a region or location. If possible, a repository should have a positive effect on the region, but on no account must its influence be negative.

Criterion of the willingness to participate

Inspired by the concepts pursued in Sweden and Finland, the international community is discussing the principle of voluntary participation as a major element in the search for suitable sites. The Committee has decided to apply the concept of the willingness to participate. The willingness to participate is based on a broadly accepted obligation of society to establish a repository.

The enquiry about the willingness to participate offers the citizens the opportunity to declare whether or not they are willing to participate in the corresponding procedure steps as well as either to take an active part in the decisions involved in the search for a repository or to withdraw their participation in the procedure.

Should there be no willingness to participate in any of the potential site regions, or should the willingness to participate be withdrawn in all site regions after several attempts, the Committee recommends that the German *Bundestag* should regulate the further proceeding, preferably adhering to the fundamental approach of the selection procedure.

4.2.2 Planning-scientific criteria

With each wide-ranging measure – permanent disposal being one of them – it is highly likely that conflicts will arise with existing or planned areas designated for special land use or as protected areas. This potential conflict will normally be restricted to the areas considered for the surface installations of the repository since most of the areas for special land use or protected areas are thus designated with reference to the use of the surface area itself or of near-surface resources or protected targets, including surface water and groundwater. Therefore, the planning-scientific criteria relate to the areas which are subject to legal provisions due to their specified primary use or other special significance (e. g. as a resource or biotope) within the framework of regional planning and development. Thus, these areas, resources or objects of protection are more or less protected against competing uses and intervention.

The planning-scientific exclusion criteria which have to be considered according to the current legal situation are known. The basis for the formulation of the exclusion criteria is the degree of legal validity to which these areas have already been reserved for uses that are competing with permanent disposal or the protection status by which the resources or objects of protection are protected against interference. Depending on the degree of protection, planning-scientific exclusion and weighing criteria can be derived.

Once the implementation of the selection procedure has started, the planning-scientific criteria only have to be modified/supplemented in line with the legal provisions applicable at that point. The data required for the application of these criteria are available for all of Germany.

Planning-scientific exclusion criteria

The planning-scientific exclusion criteria refer to areas, resources or objects of protection that are protected by legal provisions in such a way that any competing utilisation or intervention is forbidden on principle. They are therefore out of the question as sites for a repository and are excluded from the procedure by means of the exclusion criteria (exclusion areas). That is to say that in principle the planning-scientific exclusion criteria have the same relevance in the procedure as the geo-scientific exclusion criteria. However, exceptions may be made under certain specified circumstances (see below).

The planning-scientific exclusion criteria mainly relate to nature reserves, national parks, special biotopes, natural monuments and water protection areas (see Table 4.8).

The planning-scientific exclusion criteria are applied at the beginning of the third procedure step to all partial areas with particularly favourable geological conditions (see Chapter 3.2), which passed the second procedure step. Those areas that are not considered as potential repository sites for planning-scientific reasons are thus "cut out" from the partial areas.

Table 4.8: Planning-scientific exclusion criteria

Field of assessment	Criterion	Legal basis	Notes
Nature and countryside protection	Nature reserves	§ 23 BNatschG	
	National parks	§ 24 BNatschG	case-by-case assessment
	Biosphere reserves	§ 25 BNatschG	case-by-case assessment
	Natural monuments	§ 28 BNatschG	
	Protected landscape parts	§ 29 BNatschG	case-by-case assessment
	Legally protected biotopes	§ 30 BNatschG	case-by-case assessment
	European network "Natura 2000"	§§ 32 - 38 BNatschG	case-by-case assessment
Farming and forestry	Protective forests, natural forest reserves	Forestry laws of the *Länder*, e. g. § 22 Hessian Forestry Law	*Länder*-specific regulations, case-by-case assessment
Water use	Fixed, provisionally secured and planned drinking water reserves and spas	§ 19 para. 2 WHG, water laws of the *Länder*	at least Protection Zones I and II
Flood areas	Fixed, provisionally secured and planned flood areas	§ 32 para. 2 WHG, water laws of the *Länder*	

BNatschG: Federal Nature Conservation Act

WHG: Federal Water Act

Case-by-case assessment means to examine if (and if yes, which) parts of the respective areas are so strictly protected that they have to be excluded.

The exclusion may then be overruled - thus allowing an interference with the protected area, the resource or the object of protection - if compelling reasons with regard to the public interest predominate and if no equally safe alternative sites are available. For the site selection, this would be the case if a site, compared to all other sites, was of the highest quality with regard to safety but would impair a protected area or if a site suitable for safety reasons could only be found in a protected area.

Planning-scientific weighing criteria

The planning-scientific weighing criteria relate to areas where legal protection is not very strict so that all other uses or interventions would be forbidden or could not be compensated for. They are therefore areas which preferably should not be used as a site for a repository (weighing areas).

The planning-scientific weighing criteria relate, for example, to designated priority areas for special uses, areas of special relevance for certain uses, landscape protection areas and natural parks (see Table 4.9). For all planning-scientific weighing criteria that are based on the provisions of regional planning and development, it has to be pointed out that the possibility for a repository site could certainly not have been considered at the time when these criteria were established. This means that for the agreement on repository sites, regional planning and development will have to be revised correspondingly.

The planning-scientific weighing criteria help in the weighing processes which have to take place within the potential site regions in connection with the selection procedure. With their help, areas can be identified which compared to others are relatively free of conflict. With regard to the order of the procedure, the planning-scientific weighing criteria belong in Steps 3 and 4 of the selection procedure, as this is where sites are determined within the site region (see Chapter 3.2.2).

Table 4.9: Planning-scientific weighing criteria

Field of assessment	**Criterion**	**Legal basis**	**Notes**
Nature and countryside protection	Nature reserves	§ 26 BNatschG	
	Natural parks	§ 27 BNatschG	
	Biosphere reserves, protected landscape parts, legally protected biotopes	§§ 25, 29 and 30 BNatschG	if case-by-case assessment shows that they do not fall under the exclusion criteria
	Priority areas and precautionary natural and landscape areas	Provisions of regional planning and development	

Field of assessment	Criterion	Legal basis	Notes
Farming and forestry	Forest areas with special functions	Federal Forest Act, forestry laws of the *Länder*	if case-by-case assessment shows that they do not fall under the exclusion criteria
	Priority and precautionary areas for farming and forestry	Provisions of regional planning and development	
	Agriculturally valuable areas (e. g. special cultivations)	Provisions of regional planning and development	
Recreation	Priority and precautionary areas for recreation	Provisions of regional planning and development	
Architectural Conservation	Structural, cultural or archaeological monuments, natural monuments, movable monuments	Architectural conservation laws of the *Länder*	if case-by-case assessment shows that they do not fall under the exclusion criteria
Water use	Priority and precautionary areas for water extraction	Provisions of regional planning and development	
Exploitation of resources	Priority and precautionary areas for near-surface and deep resources	Provisions of regional planning and development	
Competing use of the underground	Priority areas for infrastructure, energy supply, waste disposal	Provisions of regional planning and development	
Infrastructure	Transport connections		
	Supply and disposal network		
	Priority sites for special uses (e. g. power generation, waste treatment)	Provisions of regional planning and development	
	Protected areas around airports, military installations and the like	Provisions of regional planning and development	
Housing and settlement	Distance to housing and settlement areas	e. g. North Rhine-Westphalian distance decree	

4.2.3 Socio-economic criteria

The socio-economic criteria are based on the consideration that the long-term development of a site region shall not be impaired by the establishment of a repository. The individual criteria refer to the potential development of the labour market, of the regional investments and of the housing market under the assumption that a repository will be established. A potential analysis will generate the necessary general and specific local data in order to determine deviations.

Basically, the development potential of a site region shall be understood as the result of mental and material determination factors. This means that a decreasing or increasing regional identity affects the potential development as a mental factor, and the development of the natural environment or of traffic infrastructure works as a material factor. These partly quantifiable and partly qualitative factors which determine the development potential have to be specified for the individual site regions by means of a potential analysis.

The basis is provided by expert opinions on the development, which are to be prepared by the relevant institutes. The potential analysis shall include a general part, standardised for all site regions in order to allow comparisons of the investigated site regions and to record the characteristics of each individual site region. Moreover, specific potentials shall be assessed for the individual site regions. These can be far-reaching historical developments forming mental structures, but they can also concern region-specific economic sectors, such as the brewing industry, or regional agricultural characteristics which are crucial for the further development. A potential concerning both mental and economic structures represents the image of a region influenced by a potential repository. With the involvement of the research institutes performing the potential analyses, it is necessary to come to an agreement between the implementer of the procedure and the local community concerned after discussion within the citizens' forum.

Wherever possible, the potential analysis should also include quantitative threshold values indicating positive or negative variations with regard to a previously determined comparable region. This comparison may refer, for example, to the average development of the administrative district to which the site region belongs, or also to the development of the *Land* or the whole country. In general, a region close to the site should be referred to for comparison, e. g. the administrative district. Sociological studies suggest the following threshold values for the degree of deviation:

- significant deviation (+/-10 %)
- relevant deviation (+/-15 %)
- serious deviation (+/-20 %)

The Committee recommends that these threshold values be applied.

In addition to the standardised potential analysis, the potentials that are specific to a site region also have to be assessed. The potential analysis should include the following issues:

- Description of the initial socio-economic situation
- Identification of site-specific development potentials
- Prognosis of the development of the site without a repository
- Presentation of the positive and negative factors which may arise due to the identification as disposal site and the construction of the repository
- Scenario of the possible development following the decision on a site for the construction of a repository
- Representative polls among citizens concerning their ideas about desirable regional development
- Results of a workshop on future developments held with citizens
- Results of a public discussion event on the results of the potential analysis

The potential analysis shall come to a qualitatively weighted and, wherever possible, quantitatively supported result indicating whether positive, negative or neutral chances of development can be expected from the implementation of a repository in the site region.

The results of the potential analysis shall be assessed by the citizens and the implementer of the procedure. Should these assessments deviate considerably, the Committee proposes the preparation of an additional expertise under the responsibility of the control committee to clarify the disputed questions.

In order to avoid an endless series of additional expert opinions, the implementer of the procedure as well as the citizens' forum and the local community should participate in the definition of the disputed questions and the selection of experts. If still no settlement is reached, the decision shall remain with the control committee.

The results of the potential analysis may give reason to the implementer of the procedure to discontinue the investigations of a site if - in spite of existing willingness to participate - a repository will have severe and long-term negative effects on the development chances of a region. In the reverse case, that site region of those with similar willingness to participate should be further investigated where the development potentials in case of construction of a repository are particularly positive (see Table 4.10).

In the course of the different steps, interlacing of the performance of a potential analysis and the determination of the willingness to participate as regards contents may occur. It would therefore be possible that the citizens of a site region want to take a vote on the exploration of the site not until by means of a potential analysis they have clearly identified the potential effects of a repository on the development of a region. In cases like these, the Committee recommends to stay flexible and, if applicable, to perform the potential analysis first.

Table 4.10: Standardised development potentials

Development area	Indicators	Method
Labour market	• Expected development of unemployment • Expected migration balance • Expected development of purchasing power	Analysis of the regional development potential
Investments	• Expected development of investments • Expected strengthening of structure or weakening due to the development of important lines of business	see above
Housing market	• Expected occupation of dwellings • Expected development of building land prices and lease prices	see above

4.3 Criteria for the safety proof

According to Section 9b of the Atomic Energy Act (AtG), the construction and operation of a repository requires the performance of a plan approval procedure. It has to be ensured that the repository guarantees the damage precautions required by the state of the art in science and technology. The safety criteria define the required safety principles and protection goals as well as the ensuing fundamental requirements for a repository. Thus, they represent a concretisation of damage precaution. The safety criteria for the disposal of radioactive waste in a mine are currently being revised and updated. Fig. 4.12 presents the system of legal regulations for a repository.

The selection of a site according to a qualified site selection procedure is one fundamental requirement that is to be contained in the updated safety criteria. The Committee has developed the geoscientific selection criteria and weighing processes for Steps 1 and 2 of the procedure in view of the long-term and highest possible safety of the repository site and therefore also of the most favourable conditions for the fulfilment of the safety criteria. During the course of Steps 4 and 5 of the procedure it has to be checked whether the safety criteria are actually fulfilled at the respective sites. This process is referred to as the geoscientific safety proof and is carried out by the implementer of the procedure with the participation of the control committee and the public. This has to be distinguished from the proof that has to be furnished for and examined by the licensing authority in the subsequent nuclear licensing procedure.

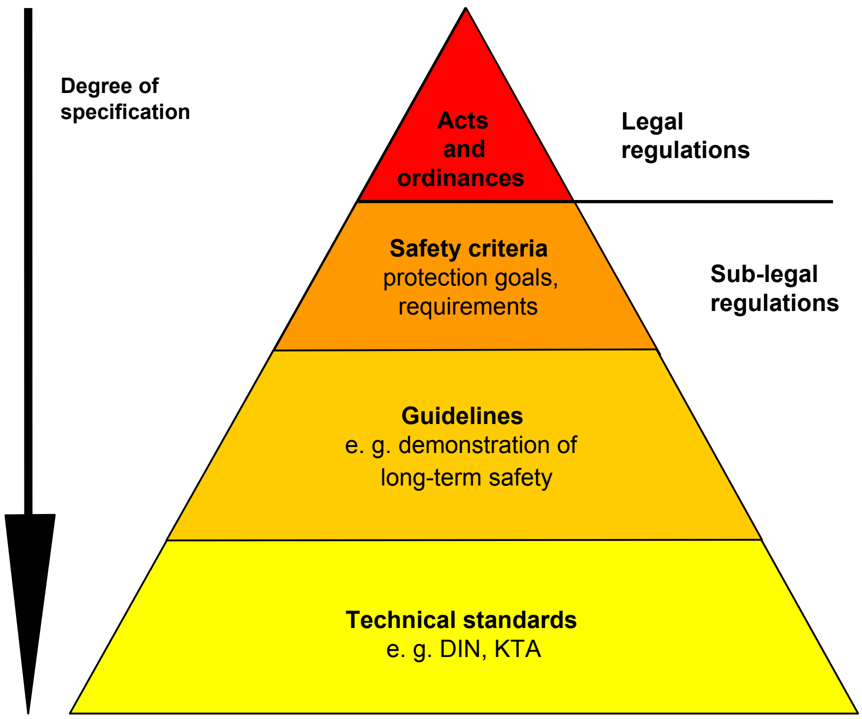

Fig. 4.12: Scheme of legal regulations for a repository

The safety proof is carried out by assessing the findings made in Steps 4 and 5. For this purpose, prior to the exploration from the surface in Step 4 and the underground exploration in Step 5, the implementer of the procedure sets forth the relevant arguments in favour of the choice or the statement of the qualification of the site. Together with the members of the population (centre of competence experts) and the control committee, he defines criteria for the assessment of the exploration results that have to be provided to confirm the arguments. In case the exploration results do not confirm the arguments, the implementer of the procedure has to take a step backwards in the procedure. The exploration from the surface in Step 4 therefore has to confirm the essential arguments that were applied for the selection of the particularly favourable partial areas at the end of Step 2 of the procedure. For the assessment of the underground exploration in Step 5, test criteria are derived from preceding steps that build on the results of orientating safety analyses. The test criteria have to be restricted to simple facts and data that can be reliably acquired with clear results and shall relate to the facts that are relevant with regard to long-term safety.

In addition, it has to be checked whether the precautions against damage as required by the Atomic Energy Act with regard to the operational and long-term safety of the repository can be demonstrated in a licensing procedure at a later stage.

The Committee defines the term “long-term safety” as that condition of the repository system that does not involve hazards to man and the environment emanating from radioactive waste, which is sustainable and maintenance free and does not impose undue burdens on future generations. To achieve this, the selection procedure shall serve to identify sites where,

- in the case of normal evolution, no harmful substances are released from the isolating rock zone within the isolation period of an order of magnitude of one million years, and furthermore, safety reserves are demonstrated with regard to the confinement of harmful substances, and
- in the case of extraordinary evolution, the standards applicable to man and the environment are complied with.

Normal evolution is given if the release-relevant conditions or processes endure or occur, respectively, with a high probability. These conditions or processes generally have to be easily describable. An extraordinary evolution is characterised by additional conditions and processes that have been derived specifically for the site and only have a low probability of occurrence.

The required safety cases for the remaining sites are prepared at the end of Step 5 of the procedure. These safety cases are to show the isolating capacity of the isolating rock zone in interaction with the technical and geotechnical barriers. For this purpose, normal evolution and extraordinary evolution (changes) of the components of the multi-barrier repository system as well as the consequences of unintentional anthropogenic impacts are taken into account in a long-term safety analysis. Here, the variation ranges of the release-relevant parameters have to be adequately taken into account. Concepts for the repository at the respective site have to be available both for the orientating safety assessment in Step 4 of the procedure and for the safety cases in Step 5. Only on this basis can the interaction of waste containers, backfilling of the cavities, shaft sealings and geological barriers be assessed (see Fig. 4.13).

Thus, the safety proof is based on the results of geoscientific studies that form the groundwork for the preparation of an exploration programme in Step 3, and on the results of safety analyses that form the groundwork for the orientating safety assessments in Step 4, and on the safety cases to be prepared in Step 5.

These studies and analyses are used, among other things, for

- the assessment of the isolating capacity of the repository system,
- the presentation of the importance of safety-determining properties and parameters of the repository system,
- the specification of the exploration programmes,
- the definition of assessment criteria and test criteria for exploration from the surface and underground exploration,
- the derivation of planning fundamentals for the repository, and
- the calculation and assessment of risks of a release of harmful substances from the repository (consequence analyses), which cannot be totally excluded.

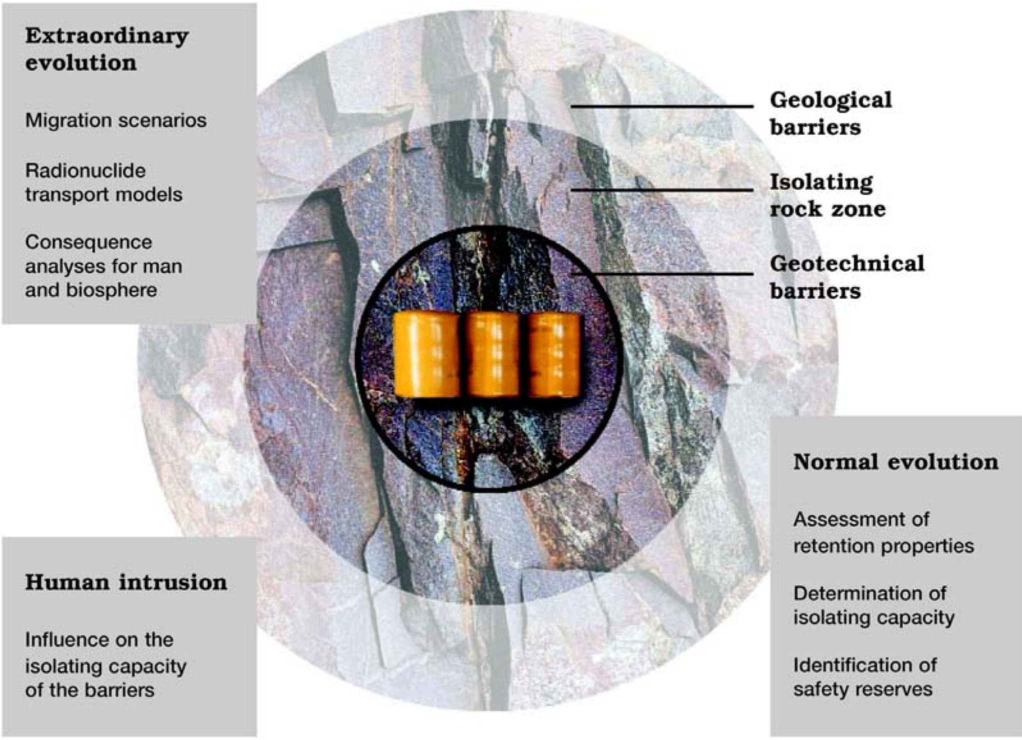

Fig. 4.13: Scheme of the long-term safety of the multi-barrier repository system

The geoscientific studies and safety analyses are prepared by the implementer of the procedure. The assessment is made both by the implementer of the procedure and the control committee. The publication of all criteria for the safety proof and their consequent application at the end of the selection procedure render the decision in favour of a particular site controllable and comprehensible for the decision maker as well as for the general public.

5 Public Participation in the selection procedure in Phase III

In democratic states, the realisation of large-scale projects calls for the intensive involvement of the general public prior to any formal planning. Since the UN Conference on Environment and Development in Rio de Janeiro in 1992, this idea has been accommodated in Agenda 21. The Aarhus Convention of 1998 specifies the right of the general public to be given access to information, to participate in decisions, and to take legal action in connection with intervention in the environment and related possible health effects. In the meantime, several forms of public participation have been established, especially in town, regional and landscape planning. Many countries that are searching for repository sites have declared that they will involve the general public. The Committee considers the active participation of the general public indispensable in each phase and each procedure step.

By order of the Federal Office for Radiation Protection, the Institute for Technology Assessment and Systems Analysis (ITAS) in Karlsruhe carried out two representative surveys in Germany in the years 2001 and 2002. These surveys focussed on the disposal of radioactive waste and on the trust of the public in the different institutions [STOLLE 2002]. The results of the surveys illustrate the initial conditions on which public participation is to be based (see Chapter 2.3).

During the development of the selection procedure (Phase I), the Committee continuously informed the public about the progress of its work. Interested sub-groups of the general public were given the opportunity to contribute their views on different occasions and in different ways. The results of these discussions were taken up by the Committee, assessed and – as far as the Committee could agree – adopted.

5.1 Assessment, control and decision in the selection procedure (Phase III)

In Phase III the implementation of the site selection procedure shall be applied on the basis of the criteria and procedure structure agreed upon in consensus during Phase II (see Chapter 7). In the end, the objective of the five procedure steps (see Chapter 3.2.2) is the decision on a site at which the repository is to be built. The year for this decision cannot be specified yet. In this respect, however, the declared intent of the Federal Government has to be taken into account to have a repository ready for operation by the year 2030 . To enable the realisation of this date, the Committee considers it indispensable to achieve the objective of Step 4 until 2010 which comprises the agreement on at least two sites for underground exploration.

A fundamental element of the selection procedure proposed by the Committee is the willingness of those involved to participate. In order to find a convincing solution for the national task of radioactive waste disposal in terms of civilian principles, it is necessary that suitable sites are identified and that the population at these sites are willing to participate in the solution. The selection procedure therefore strives for intensive efforts and incentives to achieve a sufficient level of willingness to participate.

The Committee is convinced that in addition to this, the selection procedure will only lead to a site for a repository if its performance and the assessment of the results of the procedure are carried out and the decisions about the further procedure taken independently and by separate competent entities.

In the following, the Committee deliberately chooses not to make a proposal by name which of the institutions existing today shall fulfil the roles of the three participants in the procedure proposed in the following.

- **Implementer of the procedure**

The implementer of the procedure is the institution that carries out the procedure and which is responsible for the efficient and economic performance of the procedure according to the rules stipulated in Phase II. The implementer performs his own safety assessment and involves the control committee from the start. A possible implementer of the procedure could be the future license applicant, because he bears the main responsibility for the implementation of the procedure and the safety of the repository.

- **Control committee**

The neutral control committee continuously monitors the work of the implementer of the procedure (see Chapter 5.2.1). It takes care that the selection procedure is carried out according to the rules. It also examines and assesses the results of the individual procedure steps and therefore has access to all documents. During and at the end of each step, the control committee reports to the decision maker. Continuously and on its own authority, it informs the citizens, and in particular those of the region concerned, and it is open to suggestions. The control committee is not responsible for the control of the financial aspects of the site selection procedure. This falls within the responsibility of the implementer of the procedure and the decision maker.

The members of the control committee shall possess distinguished scientific and technical competence and a good reputation in the public eye . They are nominated by a neutral scientific/technical institution and appointed by the Federal Government, the decision maker being excluded from this process. Several well-respected media representatives shall also participate in the control committee.

- **Decision maker**

The decision maker supervises the entire procedure and ensures the highest possible legitimation of the decisions. In this context, he considers the results produced by the implementer of the procedure as well as those of the control committee. He decides on his own responsibility whether and with which result a procedure step has been concluded and when the next step is to be taken.

When establishing and commissioning the implementer of the procedure, the control committee and the decision maker, the respective current legal basis must be observed. If the existing legal basis turns out to be inadequate, amendments have to be made or new laws have to be passed.

According to current law, Section 9b of the Atomic Energy Act (AtG) stipulates that the licensing procedure for the construction and operation of a repository is the plan approval procedure. Thus, the nuclear licensing authority will only be involved when the implementer of the procedure files an application for a plan approval procedure for a repository at a site that has already been selected. Furthermore, this nuclear licensing authority will be an authority of the *Land* in which the chosen repository site is located. The Committee, however, is of the opinion that it is reasonable and desirable that the scientific and technical notions of the licensing authority be integrated from the start in the site selection procedure in connection with the preparation of exploration programmes and the assessment of the results of the exploration. Also, the technical dialogue between the implementer of the procedure and the licensing authority has to be established. Therefore, the Committee recommends that the nuclear licensing authority should already be involved in Step 3 of the procedure. In order to bridge the currently existing temporal and legal gap between the establishment of the exploration programmes in the site selection procedure and the start of the licensing procedure, the Committee recommends

- to either supplement/modify the plan approval procedure and/or to commission a federal authority with the performance of the plan approval procedure,
- or to provide another option, e. g. a working committee of the *Länder*.

Regarding these proposals it is to be noted that the BMU currently (end of 2002) discusses a restructuring of the licensing procedure.

The responsibilities of other authorities for individual measures within Steps 3 to 5 of the procedure (e. g. for exploratory drillings) remain unaffected by this. By the year

2010, the sites which are to be explored underground for their suitability to host a repository shall have been clearly identified. By the year 2030 at the latest, a repository for all types of radioactive waste shall have been made operational. This scheduled target is supported by a *Bundestag* resolution of 12th December 2001. This resolution underlines the need for all those in charge to aim vigorously and with consciousness of the common responsibility at the establishment of a permanently safe repository for high active waste in Germany.

5.2 Forms of participation

The Committee is convinced that the controversial attitude of the society towards the issue of disposal can be dissolved if the citizens with all their complex interests are adequately involved in the solution. The Committee distinguishes between various different forms of participation that are to be applied in the corresponding procedure steps and which supplement each other. They are:

- participation through comprehensive information,
- participation in the supervision of the procedure,
- participation in the representation of regional interests, and
- participation in the decision-making process.

Participation through comprehensive information of the public is to explaining all procedure steps from the beginning to the population that is interested. Misunderstandings are to be avoided and rumours to be prevented. For this purpose, an independent information platform shall be set up which independently informs about the relevant topics, takes up queries and theses put forward by members of the public via different media; it also presents interesting national and international topics independently at public events.

For the public supervision of the procedure, a group of independent experts and personalities of public life is to be set up - the **control committee** - in Phase III. It shall monitor each step of the selection procedure and check that the specifications made in Phase II are duly kept. The control committee shall serve the public, issue on its own authority regular information about the progress of the procedure, and assess critical questions posed by the general public.

For the participation in the representation of regional interests and in the decision-making process a **citizens' forum** should be set up at each site which is supported by a **centre of competent experts** composed of experts of its own choice. At the citizens' forum, the citizens of a site region should be able to take an active part in the discussion of issues related to disposal in general and the regional interests regarding the willingness to participate in particular, and to make suggestions or voice demands to the local council or councils involved.

In addition, the chances ensuing for a region from the identification of a repository are to be discussed at a **round table on regional development** at which representatives from regional stakeholders, political parties, the local industry, trade unions, farming, environmental protection associations as well as other relevant societies and associations can take part.

Instruments of public participation

The organisational structure and the individual instruments of participation of the public in the selection procedure are presented in Fig. 5.1 and described in the following.

- Information platform

The implementer of the procedure, the control committee and the decision maker are obliged to inform the public about the progress of the work in a timely and comprehensive manner. For this purpose, the Committee proposes to set up an information platform which organises and collects independently and on its own all information available in Germany on the selection procedure and makes it accessible to the public in a suitable form. This concerns, above all, the results of the work of the implementer of the procedure, the control committee and the decision maker.

Furthermore, the information platform provides an opportunity to answer queries submitted by members of the public. In addition, interesting topics are edited in a suitable form and made accessible to the public. For this purpose, authorised experts and institutions may also be consulted. Moreover, the information platform shall promote and accompany public discussions. The information platform works independently and parallel to the public relations activities of the three institutions involved in the procedure.

- Citizens' forum

In the potential site communities, citizens' forums are established where all questions relating to the site exploration are discussed. The citizens' forum recommends to the local council or councils whether or not to participate in the procedure. At the citizens' forum, all questions regarding regional development are also discussed as far as they are related to the search for a repository (see Chapter 6). The citizens' forums shall be financed by the implementer of the procedure.

- Centre of competent experts

The citizens' forums are provided with financial means in order to obtain advice from experts in whom they have confidence (centre of competent experts). These authorised experts must be able to judge criteria related to natural sciences and to social sciences.

- Round table

Along with the citizens' forum, the local political parties and administrative bodies as well as relevant regional stakeholders, whose representatives constitute the round table, have to be involved in the regional development as well.

Impulses from the citizens' forum are to be recorded and elaborated further at the **round table**. The concepts worked out here shall in turn be discussed within the citizens' forum and then be passed on with recommendations, requests for modifications or concerns to the local council which is in charge of deciding on how to proceed further.

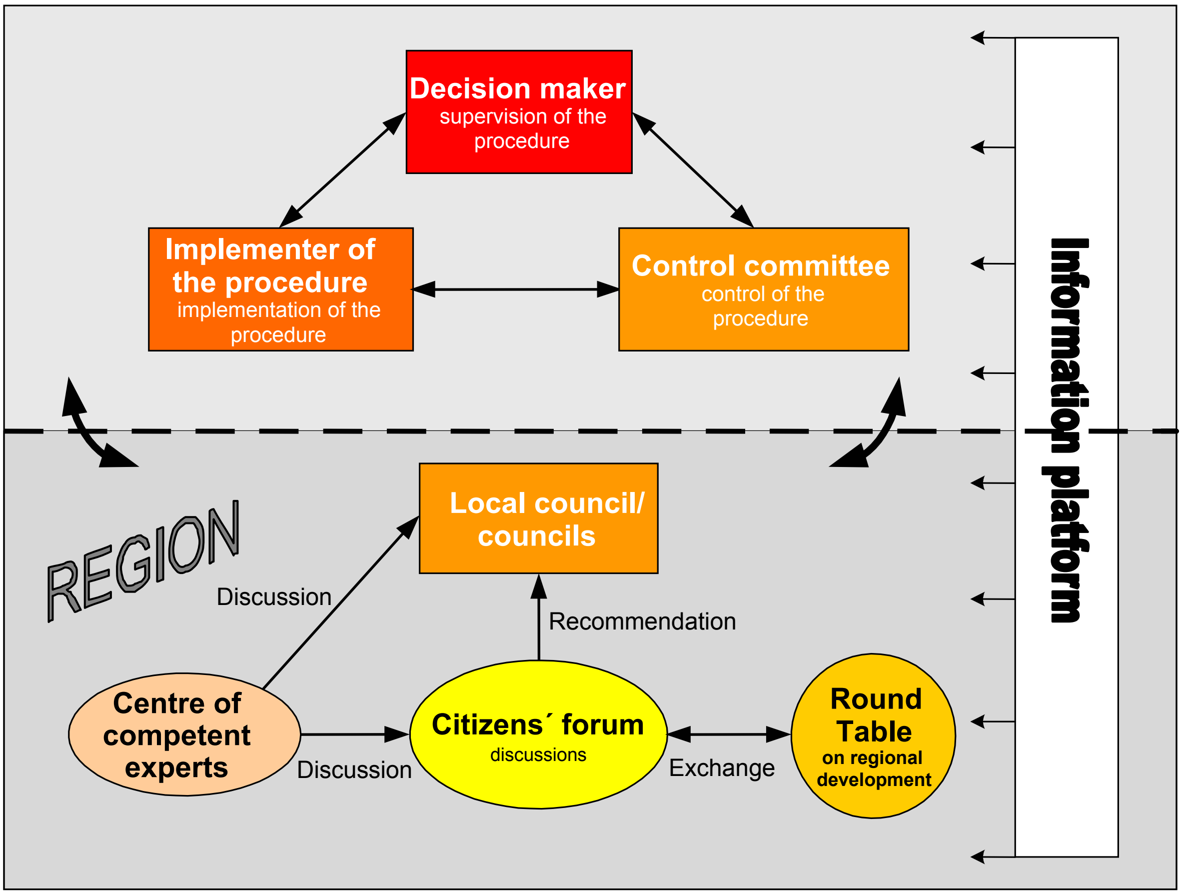

Fig. 5.1: *Organisational structure and instruments of participation of the public in the selection procedure*

5.3 Willingness to participate

The willingness to participate comprises many factors. They reach from specific regional experiences with technology and industry to the value systems and the collective historical experience of the population. The results of a specific regional potential analysis, in which the socio-economic factors of a region are analysed, may be quite important in connection with the willingness of the population to participate. One can easily imagine that the population of a particular region will base its decision of whether it will participate in any exploration from the surface dependent on the results of such a potential analysis. In such a case, the Committee suggests that the potential analysis should be carried out in advance if the public so wishes, even if this requires a large number of potential analyses. The willingness of the public to participate has a significant impact on the further implementation of the procedure.

5.3.1 Determination of the willingness to participate

Both an existing readiness and a lack of willingness to participate are results of difficult social decision processes. Therefore, the provision of information, discussions and clarifying statements are essential to achieve a willingness to participate. The Committee recommends that

- the public is informed extensively by the implementer of the procedure and the information platform, and
- discussion events are performed for the relevant groups of the population.

The citizens' willingness to participate is to be polled in a ballot (the option preferred by the Committee) or a representative survey, organised by the local council. On no account must public participation mean a step backwards compared to the already existing possibilities in the different *Länder*.

During the selection procedure, the willingness to participate is determined by two polls. In Step 3 of the procedure, the citizens are asked whether they would agree to exploration activities from the surface in the site region. Secondly, in Step 4, they are polled as to their consent to underground exploration. Here, the conditions which have to be fulfilled in order to maintain public participation are established in co-operation with the citizens (e. g. socio-economic criteria in Chapter 4.2 or test criteria in Chapter 4.3).

At the sites remaining in the selection procedure, each of these two queries of the willingness to participate is composed of two elements: a vote by the population and a vote by the local council or councils. The vote of the population on the willingness to participate is submitted as a recommendation to the local council or councils if the site region consists of several communities. In a public meeting, these shall come to a conclusion about the population's willingness to participate. Should the geographical area of a potential repository include several communities, this procedure has to be performed in each community. Only in case of concurrent decisions, the willingness to participate is deemed to be given. Regarding the citizens' vote, the simple majority of the votes cast shall apply. Should the site region extend beyond a regional or national border, the citizens of the neighbouring region or state have to be involved as well.

The willingness to participate shall be considered as given if the majority of the population and the local council or councils have voted in favour of further participation. In weighing up different site regions, the relative number of votes is taken as a basis for comparison. The same applies to the decision of the local council or the councils.

5.3.2 Orienting vote of the population at the end of Step 5

The selection procedure, which is composed of five procedure steps (see Chapter 3.2.2), stipulates the enquiry about the willingness to participate in the exploration from the surface in Step 3 and about the willingness to participate in the underground exploration in Step 4. These enquiries will have a guiding effect on the further implementation of the procedure, i. e. site regions where there is no majority in favour of a participation are put back in the selection procedure.

The enquiry of the willingness to participate in the exploration from the surface is preceded by the information that at the end of Step 5 a decision by the *Bundestag* in favour of one of the remaining sites is likely if the results of the underground exploration – measured on the previously specified test criteria – are positive.

The citizens' forum – supported by its centre of competent experts – will then continuously monitor the underground exploration and will form its own judgement of whether the results of the underground exploration fulfil the test criteria. Both assessments will then be submitted to the control committee, which in turn makes its own assessment.

At the end of Step 5, safety assessments will be available for two sites, each prepared separately by the implementer of the procedure, the citizens' forum and the control committee, as well as the assessments of the development potentials and the regional development concepts. On this basis, the population at the sites will be asked in a survey as to how they will vote on the construction of a repository at the respective site. This information will help the German *Bundestag* as a reference in its final decision on which site is going to be chosen.

To clarify its own position, the Committee has considered and assessed the following arguments against and in favour of a vote by the population at the end of Step 5 of the selection procedure:

The possibility that such a vote might be understood as a form of pseudo-participation and might therefore raise doubt in the credibility of the selection procedure is an argument against the final vote by the population. One must also fear that - provided the results of the underground exploration are positive – such a vote may be negatively influenced by irrelevant arguments and the whole procedure would be undermined. It also has to be taken into account that the underground exploration of two sites will generate costs going into billions of euros which cannot be simply written off if the positive results of the exploration are followed by a negative vote. This holds true especially because the general public has been involved in the specification of the test criteria for the assessment of the results of the underground exploration.

What would speak for a final vote at the end of Step 5 would be that the citizens would not only subjectively be exerting a decisive influence but that this influence would also be crucial in the sense of controlling the procedure. Moreover, by constantly monitoring the exploration activities, the citizens are kept informed about how the results are to be assessed under the aspect of safety. This in turn prevents the generation of misinformation or rumours, enhances the control of the procedure, and increases the trust among the population that the procedure is managed properly. All this needs a high degree of willingness among the citizens to participate. In order to maintain the motivation, and with regard to the extended duration of the underground exploration, the population should be asked once more for its opinion once the point has been reached where the conclusive and final question is raised. It is also conceivable that two sites may turn out equally suitable when compared with each other. In this case, the public vote may have a crucial function for the direction in which the procedure develops.

5.3.3 Proceeding if no willingness to participate is reached

It cannot be ruled out that no willingness of the public to participate may be achieved despite intensive efforts. It may also be possible that a willingness to participate once declared is withdrawn at a certain point in time by a new vote of the citizens. If willingness to participate cannot be raised in at least two potentially suitable regions, it would be a severe setback in the search for a site.

In this case, the Committee recommends that the German *Bundestag* should decide on the further procedure - maintaining, however, the remaining stipulations for the selection procedure in the further search for a potential site. Such a limitation can only be justified if all possibilities in the selection procedure have been exhausted.

However, the Committee expects that a local or regional willingness to participate can be achieved due to the comprehensive activities provided in the procedure, and that the identification and selection of a site can in general be carried out and concluded successfully.

6 Chances for the development of the site regions

Site regions being checked for their suitability regarding the construction of a repository, are living spaces and therefore unique worlds for the people living there. The living space comprises their everyday life and its meanings. The major part of the social network in which people live, the material basis of life, housing, the leisure activities - all this is regional to a high degree. Only a minority would be willing to move to another *Land* [STOLLE 2002]. More than half of the people live in the region where they grew up. The information about regional events and every day occurrences in the region are obtained via a daily newspaper. By doing so, more than 60 % feel well or even very well informed. Apart from the town district or village where people live, they also feel attached to the region. As an answer to the question what they define as “home”, the region was mentioned nearly as often as Germany (see Fig. 6.1).

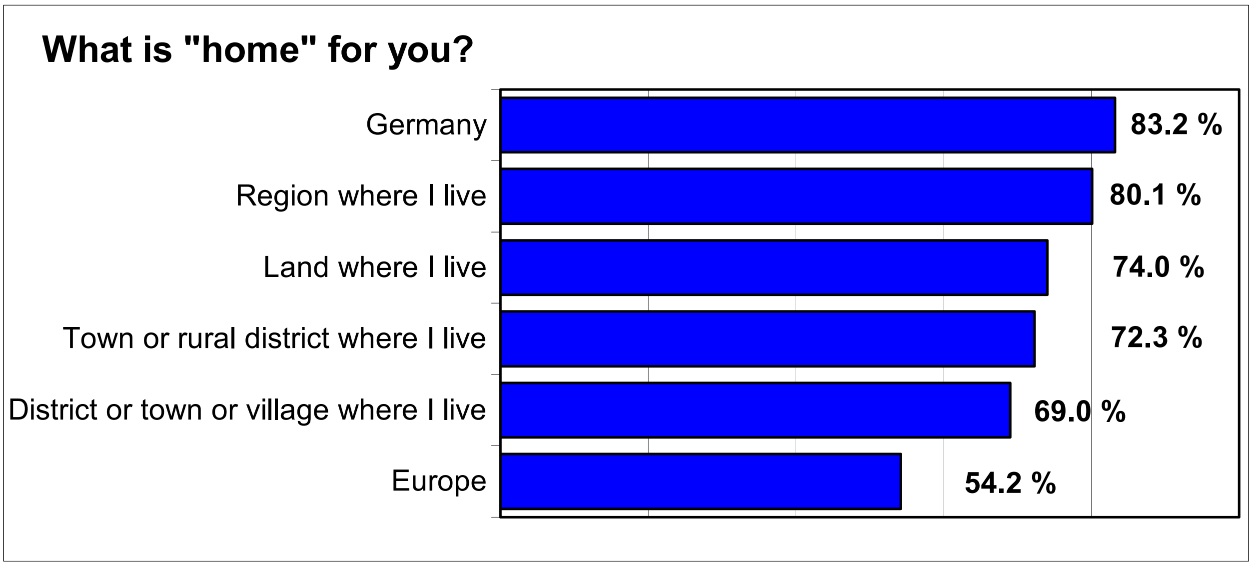

Fig. 6.1: The term “home”

From the citizens’ point of view, the most important task of regional policy is to promote local trade and industry, to stimulate the economy and to reduce unemployment. For this reason, the Committee recommends to offer regional development perspectives to the potential site regions and government assistance in its realisation. On no account must regional development be understood in this respect as compensation for the concerns and fears of the population.

Formation and delimitation of regions

A region is no administrative but a social, cultural and economic unit. This means that it has no clearly marked borders. It is rather a process than a defined area. People move, goods are transported, information flows, as well as water, energy and waste. A region is a system of flow variables with aggregations and changing boundary zones. For the issue of site selection, this means that a region is formed communicatively and "builds" both the core and the boundary. The dynamic character of the region is of great importance regarding the organisation of public participation[3] and the decision-making process. It is to be expected that the delimitations of the site regions will change in the course of the selection procedure.

Thus, the definition of regions is not only governed by geological and political (administrative) regional units but will also be influenced by the participants in the local communities in a dynamic and communicative process.

However, the development of a future perspective for a region in connection with the construction of a repository for radioactive waste presupposes that a group of communities capable of making its own decisions and acting on its own has formed in which the population is willing to get into the further selection procedure and possibly adopt the repository in its own neighbourhood. As regards the delimitation of the regions, functional regional interdependencies between the different communities play an important role, e. g. concerning the labour market, the transport of energy and goods, and the use of social infrastructure . This is another reason why the citizens in the region involved in the process have to be given the support of the existing administrative structures.

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[3] **Participation/involvement:** In general: the term for the participation of members of a group or an organisation in the realisation of objectives.. In regional planning: participation of the citizens in the planning process. Participation or involvement supplements the formal decision-making process but does not replace it.

6.1 Regional development

The potential site regions are to be offered a plan for a regional development perspective and government support in its implementation. This may not solve the conflict between the national task of establishing a repository for radioactive waste and the regional interests, but it may after all build a bridge between national and regional interests. The Committee suggests this form of perspective instead of short-term financial compensation. However, the funding for the long-term implementation of development perspectives must be secured.

The development of regional perspectives for the future is closely related to the socio-scientific weighing criteria and thus directly depends on the results of the potential analysis for the region (see Chapter 4.2). Further, the willingness to participate in the above-ground or underground exploration and to possibly accept the repository in its own neighbourhood will also be closely related to the development potentials and the development of regional perspectives for the future.

The Committee proposes, as explained in Chapter 4.2, to consider the development potential in the weighing process for the identification of site regions in Step 3 of the procedure, i. e. to enable that regions may be deferred in the further course of the procedure if the development potential to be expected is negative when establishing a repository. On the other hand, regions where neutral and positive development potentials are to be expected have to be shortlisted.

What such a development potential may look like can only be specified adequately for each region individually. This shall be worked out with the citizens in the citizens' forum. Under consideration of the work of the Institute for Organisational Communication (IFOK), the committee developed the following strategic objectives for the drafting of such a regional development, which are related to a potential repository [IFOK 2002]:

Integrating a repository into the region and enhancing employment effects

Regarding the employment effects and the economic interdependence with the region, it seems to be reasonable to pursue the strategic objective of using the potentials of a repository and its integration into the region in order to achieve an improvement of the employment and income situation in the region, and to contribute to a sustainable regional economic development. Above all, it is necessary to tie the new jobs created to the region and to create additional employment opportunities in connection with the identification of a repository in the region. In this respect it is necessary to create synergy effects and a creative environment as well as to extend the value-added chain[4].

Avoiding property depreciation, enhancing property values

Regarding the concerns about property depreciation, individual disadvantages should be avoided. A further objective could be the increase in property values by means of the regional development process. Options for compensation have to be found for potential individual strains.

Avoiding damages to the image, improving the image

For a region, it is of particular importance how its image changes with the establishment of a repository. In turn, this depends on the willingness of the population to accept a repository in its region. The image of a region has an influence on the migration movement of individuals and capital mobility. Regions with a positive image attract both . Regions with a negative image, however, lead to a migration from the respective region. This has an impact on the real estate prices, the employment market and the investments in a region. Therefore, it is no surprise that 76.5 % of the population in a region are personally affected by a change of image.

Positive strategic objectives in the different subject areas as a whole automatically contribute to the objective of improving the image of the respective region. Furthermore, a positive signal should be sent, even beyond the region’s border, to

[4] **Value-added chain:** In general: the accumulation of value in companies, institutions and other economic entities. The value-added chain is a chain of such value accumulations in a company (purchase, production, sales) and between companies (e. g. producer and supplier of raw materials, fabricator, haulier, distributor).

avoid a loss of image or even to improve the image. The positive image to be built up should also be communicated supraregionally.

Avoiding hazards, support of the region in the fields of environmental and health issues

A large part of the population does not only associate a repository with the impacts during the construction phase and during operation, but also with health risks due to radioactivity (see Fig. 6.2). It is thus an understandable phenomenon that the population considers waste disposal an urgent problem that needs to be solved, but that at the same nobody wants a repository in their own region (see Fig. 6.3).

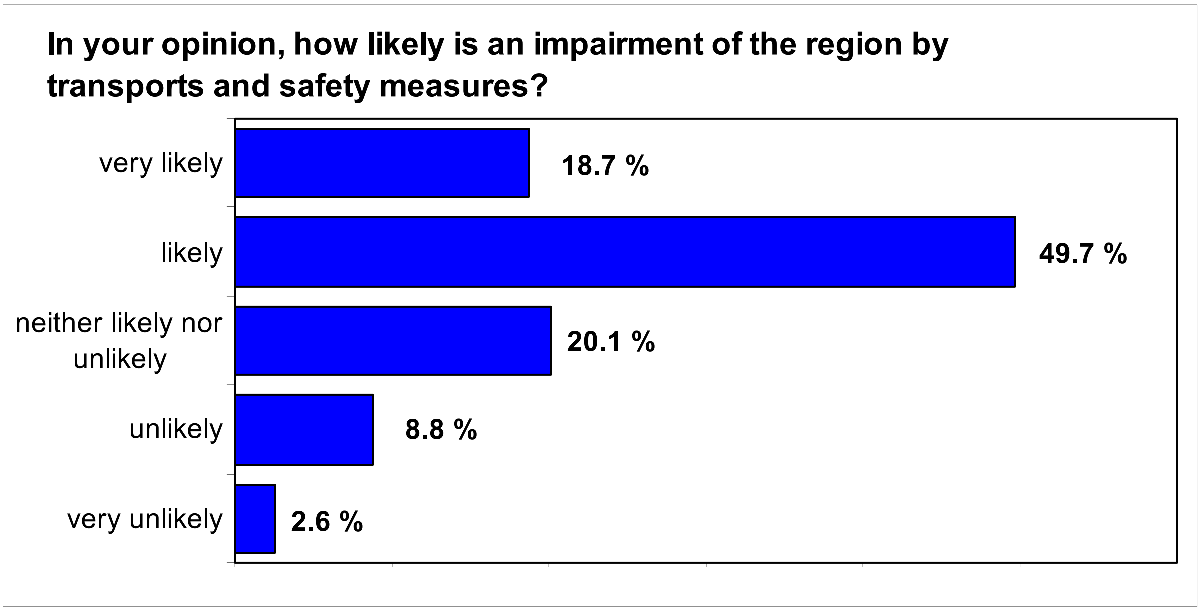
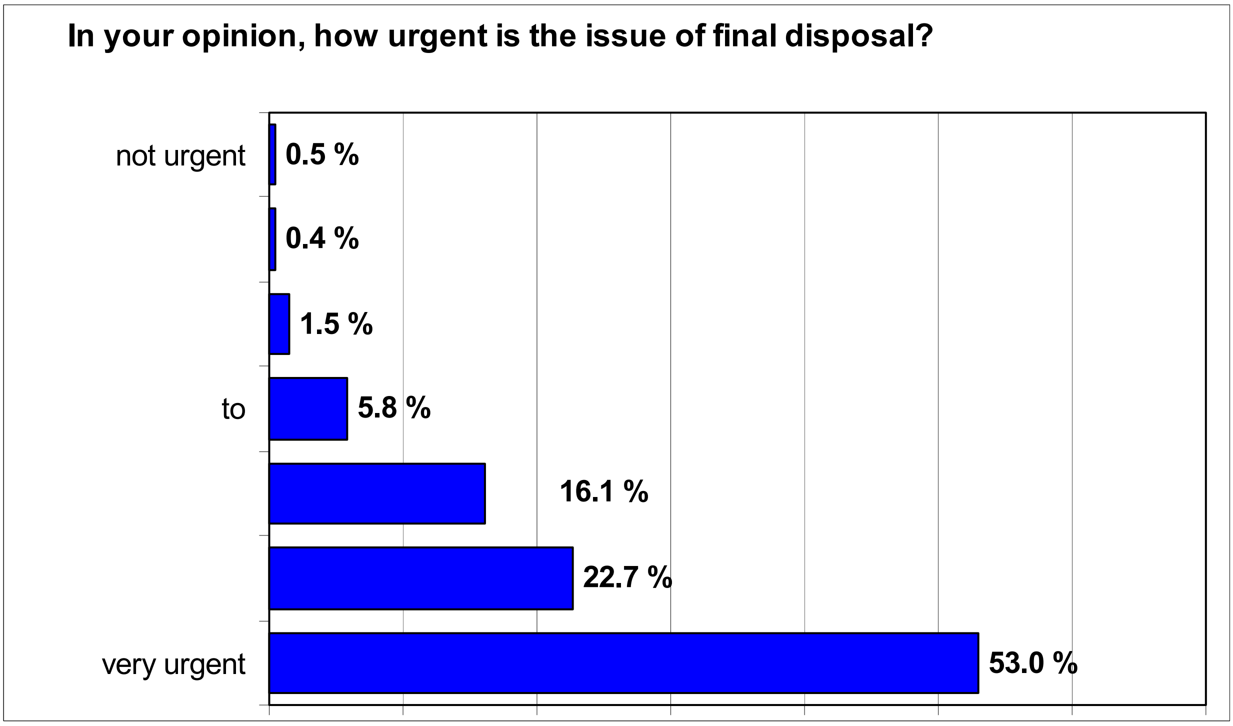


Fig. 6.2: Expected impairment of the region by a repository

In view of the environmental and health hazards presumed by the population, the objective must be to counteract these fears. Within the site selection procedure, the Committee gives highest priority to safety. Thus, the safety of the repository is the basic requirement of the development of a regional future perspective. Besides, a further objective is to provide the repository with the highest environmental quality standards. In addition, all political sectors in the region should pay more attention to environmental and health objectives (e. g. landscaping, recreational facilities).



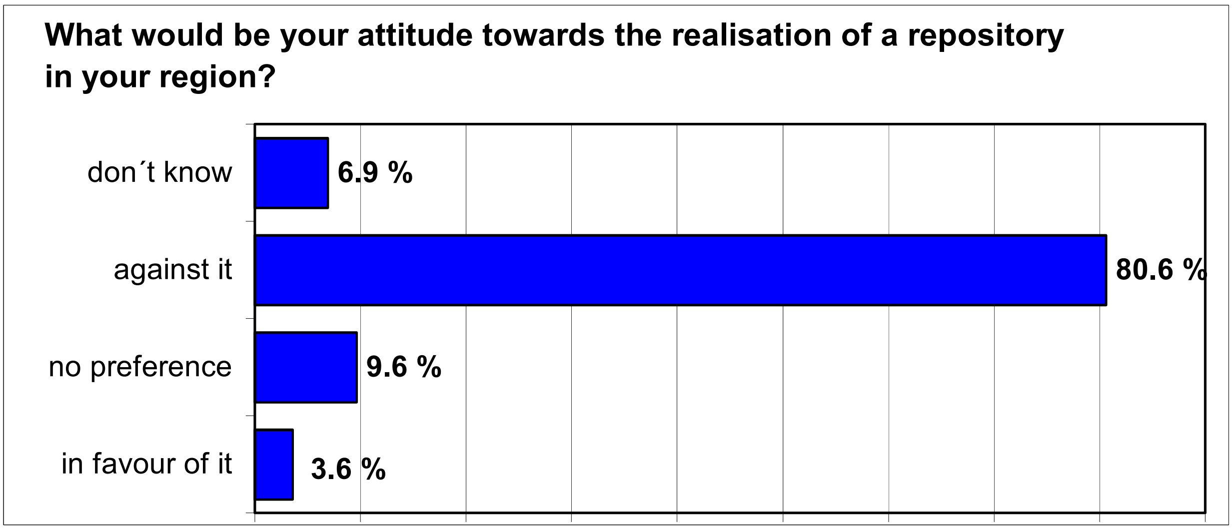


Fig. 6.3: Urgency of solving the issue of disposal / realisation of a repository in the own region

Avoiding polarisation and supporting co-operation

In order to avoid social tensions, one of many goals is to enable people to live together in peace and to create a climate of tolerance, to have an open and transparent discussion about the integration of the repository into the site region and to solve problems by way of communication. In this respect, a primary task has to be the development of a transparent site selection procedure. Consequently, the development of a regional future perspective generally has to correspond with the selection procedure.

6.2 Organisation of the regional development

When a regional development concept is elaborated and subsequent concrete plans for its implementation are drawn up, professional expertise and the citizens' needs have to be merged. The organisation must be interdisciplinary, which is to say it has to provide a technical and operative process of interaction in order to integrate the institutions in charge of planning and development. Furthermore, it has to consider the complex interests in a region and the concerns of neighbouring communities as well. The regional development is closely related to the future planning of the repository.

In this respect, it has to be ensured that the proceeding with regard to regional development is comparable in all potential site communities. It is important to the Committee that the performance of the site selection and the drafting of a regional development concept are not interdependent with regard to organisation, persons involved and funding.

Citizens take centre stage

A development concept can only be drawn up on a platform which is open enough to guarantee broad participation of the citizens but which is also able to work efficient.. The citizens' forum is to organise the active participation of the public. Here, all issues relating to the examination of the site and the regional development perspective are addressed. The citizens' forums are open to all citizens from the affected regions who want to take part. The citizens' forum may set up work groups to deal with tasks such as the regional future perspectives or with the risks/strains caused by the repository. It can also host conferences on the region's future. In this respect, it is essential that the citizens' forum informs those citizens who are not involved in the citizens' forum at events open to the public and gives them the possibility to speak up. This way, an isolation of the "citizens' specialists" can be avoided, thus enabling the consideration of the interests and concerns of all citizens living in the site region. Due to the close relationship between socio-scientific, in particular the socio-economic criteria and the development of a regional perspective for the future, the Committee suggests that both the aspects referring to the site selection and those referring to the regional development are discussed in the citizens' forum.

Finally, unambiguous recommendations have to be formulated. The citizens' forum has the right to make proposals, i. e. it makes recommendations to the local council, which is in charge of deciding on the further proceeding.

Support by a centre of competent experts

In order to be able to cope with these comprehensive technical and organisational tasks, the region needs to be supported in developing the corresponding competence. This concerns the technical competence, the knowledge about political institutions and legal regulations, as well as communicative competence. Here, the citizens' forum is to be assisted by a centre of competent experts. This centre is composed of experts in waste management but also in regional planning and development. The citizens' forum shall have the binding right of proposal on who should fill the positions in the centre of competent experts. The centre of competent experts plays an important role regarding the fairness of the procedure. Because they can rely on experts they trust, the citizens gain an equal position as the experts of the implementer of the procedure and those of other institutions involved.

A round table for regional development

Besides the citizens' forum, the local political parties and administrative bodies as well as the various stakeholders also have to be involved in the regional development at a round table (see Chapter 5.2.1). These include the Chamber of Commerce and Industry, the different trades, farming representatives, churches, trade unions and relevant associations. Besides, the mayors of the neighbouring communities also have a seat at the round table to represent their interests. The round table and the citizens' forum also deal with potential changes of the spatial delimitation of the site region and recommend possible enlargements and reductions. Should the round table and the citizens' forum not reach a solution by consensus, the district assembly will arbitrate between them, and, if required, on the basis of an expert's opinion.

Impulses from the citizens' forum are to be recorded and evaluated further at the round table. The concepts worked out here shall in turn be discussed within the citizens' forum and then be passed on with recommendations, requests for modifications or concerns to the local council which again is in charge of deciding on how to proceed further.

All institutional and political contacts shall be maintained directly via the local administration, which – together with the local council – is responsible for the harmonisation of all development concepts and plans with the existing institutions, planning requirements and public concerns.

Fig. 6.4 shows the organisation of the regional development based on participation, as proposed by the Committee.

It is possible that a site region includes or is adjacent to the area of several communities. In this case, all necessary decisions have to be taken in the different local councils by consensus. The citizens of all communities involved form a citizens' forum which gives its recommendations to the respective local councils.

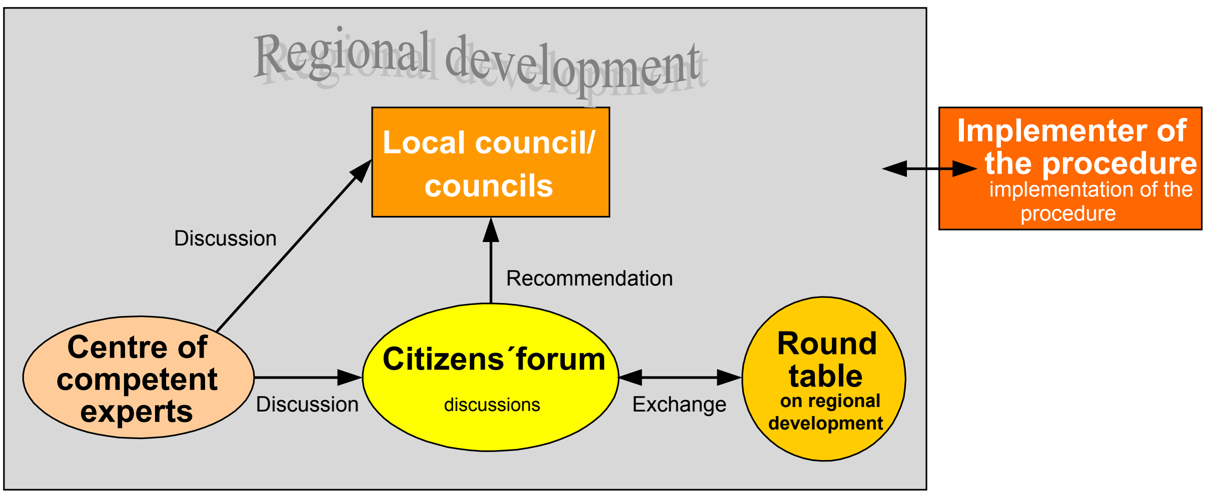


Fig. 6.4: Organisational structure and steps of the participation procedure

6.3 Principles of financing and realisation

Long-term chances instead of short-term profits

The elaboration of a regional development concept and the implementation of the corresponding proposed measures is to sound out the future chances associated and perceived in connection with a repository without communicating an impression of "political landscaping" or even "corruption". In order to prevent such an impression, funding of a regional development perspective has to be on a legally admissible basis. In this respect it has to be taken into account how the financing strategies may be perceived by the general public with regard to procedural ethics and their compatibility with democratic ideas.

Support to promote self-initiative

Any assistance – be it in the form of funds, services or human resources – shall only serve to support the self-initiative of companies, clubs and societies, associations and institutions. The regional development concept has to be drawn up from inside and be implemented by the initiative of the region. The funding is only to be understood as support of the self-initiative. By that token, any funding or other transfer payments are closely tied to the development concept and the site region.

All grants are temporary

The extent of financial support depends on the shaping of the regional development perspective, which is developed in dialogue with the region. It turns out that the extent of the costs depends in particular on the success of the measures (from when on do they pay for themselves?) and on the period of funding (for how long are funds provided?). Financing of the regional development concept shall only be maintained until the development impulse becomes self-sustaining.

Who will provide the support?

The Committee suggests that the generators of the waste provide funds to the regions for the elaboration and implementation of the regional development concepts. These means should be paid into a fund in order to ensure their flexible management. Co-financing of certain individual measures by the *Länder* cannot be ruled out.

Step-by-Step implementation of the regional development planning

The elaboration and step-by-step implementation of a regional development perspective are closely related to preparatory planning of a possible repository. Before the population is polled for its willingness to participate in Step 3 of the selection procedure, the actual development potential of the region has to be determined. While surface exploration is being performed, further concepts are to be worked out concerning the future development of those regions that have declared their willingness to participate. The Committee recommends that starter and pilot projects should be realised while underground exploration is underway in order to prepare the implementation of the regional development concept. Full implementation of the development concept should then take place at the same time as the construction of the repository.

6.4 Regional development scenarios

As previously mentioned, the development perspectives strongly depend on the concrete regional situations so that model-based or even transferable perspectives cannot be developed. In order to show that the establishment of a repository may open up positive development potentials, the Committee commissioned the Institute for Organisational Communication (IFOK) with the development of scenarios for three different types of regions [IFOK 2002]. Principally, there is a multitude of potential development scenarios. By means of the three scenarios for very different regions the largest possible spectrum of development paths shall be presented.

The scenarios shall demonstrate that a repository may lead to a positive development and give thought-provoking impulses for innovations. In this respect, the aim is not to draw up realistic and actually realisable development potentials.

Scenario A “Rural area”

Scenario A was developed for a rural area provided with potentials for tourism [IFOK 2002]. In particular, this scenario relates to the almost incomprehensible concept of time periods in connection with repositories and to the responsibility of today’s generations for future ones. In this context, various facilities in the fields of research, education, culture and sciences can be understood as chance for the development of the region.

The first component of the impulse consists of a repository information centre with a particularly attractive design which informs about nuclear energy and disposal of waste in an entertaining and impressive manner, e. g. by means of a walk-in model of a repository gallery. The second component represents an interdisciplinary centre for long-term responsibility which deals with the requirements and possibilities of potential solutions for future problems in its function as research facility, as an educational establishment, a meeting place and a place for reflection. Moreover, the way of communication of future generations should also be subject of research activities. This scenario is complemented by a theme park focusing on the interrelations between man, space and time in which instructive and interactive exhibits provide an insight into the past and the future of the earth and mankind. Here, humanities’ questions surrounding energy could be the focus of attention . The size of the facilities must be adapted to the population and infrastructure density of the region.

Scenario B "Industrial region"

Scenario B was developed for an industrial region with relatively high population density [IFOK 2002]. It includes the idea that competences in the field of use for new purposes and redevelopment of industrial derelict land and environmental technology are systematically developed or enhanced. Research and education can be integrated on a campus with several relevant faculties where research could be performed in different fields such as innovative ecological waste disposal technologies, dismantling of nuclear installations, as well as issues related to conversion and regional development .

As a second facility, an institute for safe disposal and underground storage sites is possible, which concentrates its research activities both on safe disposal and on underground storage sites. The demand for research results from the required long-term safety analyses for disposal and for underground storage sites. With regard to safety features and equipment, issues related to mining and geotechnologies as well as sealing concepts are to be dealt with. In addition, the question of retrievability of the waste could also be an important research subject of the institute. Further, its world-wide co-ordination could be realised by an international network[5] of a few highly qualified institutes for research on repository safety.

Finally, this approach also includes the realisation of an industrial and business park which establishes a technology and founder's centre as link between research, education and business. In addition, places for meetings and exhibitions shall be provided in form of a park designed for information, communication and innovation. Industry and business locations shall be established, above all, in the sector of waste and environmental technology.

[5] **Network:** This term is often used as a metaphor for a complex of relationships. A network is a number of combined units with relationships existing between them. The units may both be individuals or groups, organisations or whole societies. In many cases, a network functions as a platform for the exchange of experiences, as well as for co-operation or mutual assistance.

Scenario C "Conurbation"

The third Scenario concentrates on a fast growing conurbation that is strongly characterised by services, research and development as well as by cultural facilities [IFOK 2002]. It offers favourable site conditions for addressing such strongly interrelated topics as information society, risk assessment and problem solving as a central theme. From this viewpoint, a nationally acknowledged knowledge centre deals, as a branch of study, with the relationship between knowledge, society and technology with regard to the targeted use of knowledge as central innovation factor in society. The knowledge centre provides a link to sources from the past which have not been digitised or translated, but it also safeguards the preservation and understanding of the testimonies of social changes which are constantly accelerating. Among other fields of research, studies are performed on how society structures and archives its knowledge by the example of declining knowledge in the field of nuclear technology. The work of the respective chairs is increasingly interdisciplinary, and strong emphasis is placed on future research as well as knowledge transfer and organisation.

A second facility may be an institute for applied risk and conflict research, which deals with risks and societal conflict situations by example of a repository. A demand in risk research is particularly given in a long-term perspective and integral assessment in the sense of sustainable development. Conflict research relates to the communication of risks and enables the public and commercial application of the results from conflict management. The establishment of a knowledge database and a corresponding data research service are also integrated in the institute. In particular, the institute shall address the citizens in a discourse-oriented way[6] and render

[6] **Discourse:** Literally, conversation. Regarding content as well as formal criteria, defined communication system between individuals, groups or societies. The original philosophical idea of the discourse referred to the creation of systematic argument sequences and communication situations for the identification of the truth. In the present context, it refers to societal discourses which, compared to discourses at other levels, often are unstructured; they can be compared to debates.

advisory services in the fields of politics and business. A third component, the centre for culture and communication, supplements this discoursive approach. The centre shall be able to accommodate citizens' initiatives, clubs and associations, a citizens' office and educational institutions in order to provide an opportunity for exemplary communication between politics, economy, sciences and the citizens. In addition, cultural programmes are offered, such as theatre performances, concerts and exhibitions.

Overall, the development of a regional future perspective should be oriented towards the common interests as well as the cores of development and the economic clusters[7] in the region. Special concepts, especially innovative ideas and those relating to the established repository, should be developed as well. These ideas could then generate an impulse for developments of supraregional importance.

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[7] **Cluster formation:** Spatial concentration of enterprises with a specific specialisation profile and a high-density of business-to-business interactions (regional clusters).

7 Proposal for the agreement on the selection procedure in Phase II

The Committee presumes that prior to the actual implementation of the site selection procedure, a political and societal agreement has to be reached first. The site selection procedure and its criteria - if required with modified results of the Committee – has to be determined definitely. It is to be expected that without clear regulations before implementation of the site selection procedure, the population will inevitably have doubts concerning the objective implementation of the procedure. The resulting problems would endanger the acceptance of the result of the selection.

Due to the necessity to first define the rules of the procedure, the Committee agreed upon a proceeding that comprises the three phases leading up to the selection of a repository site:

- In Phase I, a proposal is developed for criteria and a site selection procedure. This phase will be concluded with the submission of the recommendations to the BMU and the present final report of the Committee.

- In Phase II, the political and societal agreement on the selection procedure takes place.

- In Phase III, the selection procedure determined will be implemented (see Chapters 3 and 5).

With this approach, new ground is broken internationally, since participation in those few countries, where it takes exists at all, only begins with the actual identification and examination of suitable sites.

In connection with the determination and implementation of the procedure, public participation goes beyond the transmission of information and the discussion of results. The Committee believes that public participation in the development of an informed opinion is indispensable. In Phase II, a fair, just and efficient procedure is to be established, involving relevant stakeholders and interested members of the public. A high degree of societal legitimation of the selection procedure for repository sites can only be achieved by means of an extensive dialogue between experts, stakeholders, politicians and the general public.

The proposed site selection procedure can generally be implemented within the current legal framework. In Phase II, however, consideration could be given to the question how far changes of the existing legal framework are reasonable and practicable.

In the opinion of the Committee, Phase II should consist of three steps to allow the necessary sovereign activity of constitutional bodies on the one hand and the inclusion of the discussion within society on the other hand (see Fig. 7.1):

- The political determination to implement the selection procedure is stipulated by an **institutional commencement**.
- As a second step, the public and stakeholders are involved according to the “dialogic field" model the centre piece of which is the **negotiation group**. This group has the task to examine the Committee’s proposals on a site selection procedure.
- At the **institutional end**, there is a political and legal decision on the site selection procedure under consideration of the results of the negotiation group.

With this structure, the necessary degree of commitment for the implementation of the selection procedure in Phase III is achieved.

Regarding the development of the following model, the Committee referred to an elaborate expert’s opinion of the auditing company WIBERA [LENNARTZ & MUSSEL 2002]. Chapter 4 of this expertise includes elaborate sociological and legal statements for a number of aspects.

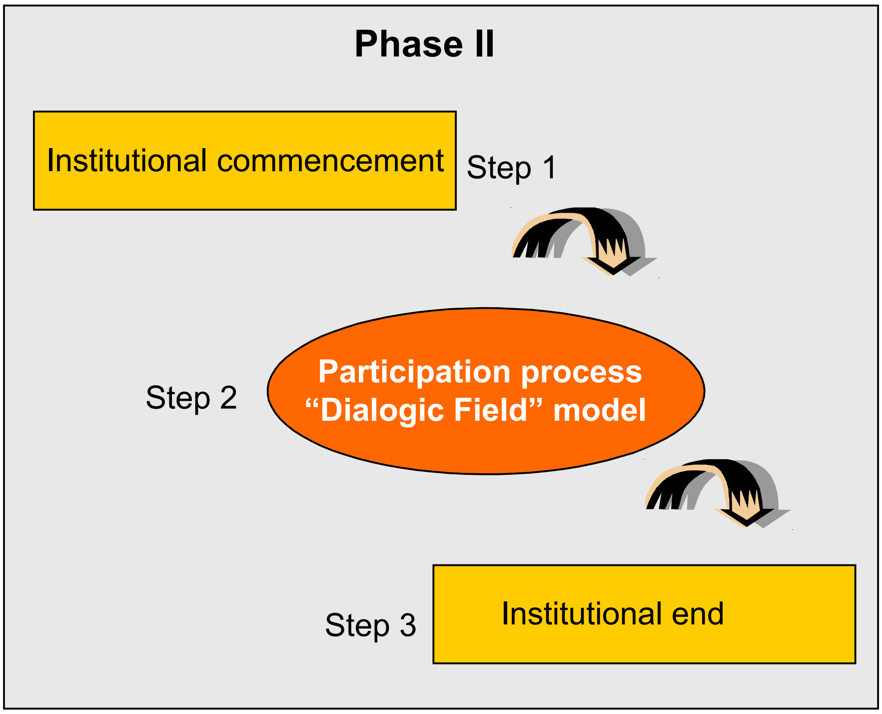

Fig. 7.1: *The three steps of Phase II*

The Committee furthermore suggests that, parallel to Phase II, an international group of experts should evaluate the procedure it proposes, e. g. by the OECD. This would ensure that the proposals comply with the requirements established internationally. The time frame for the international evaluation should be selected as to enable a consideration of the results in the decisions to be taken by the institutional end of Phase II.

7.1 First step in Phase II: Institutional commencement

The Committee takes the view that it is crucial to implement the institutional commencement and the institutional end of Phase II on the basis of the broadest possible political consensus. Otherwise, the different political participants will hardly support a site selection procedure. Since the subsequent site identification and agreement on a repository for radioactive waste has consequences for the *Länder,* they should be involved in the procedure in an adequate manner. An appropriate central democratically legitimated board should initiate and institutionalise the process of agreeing on a site. At the beginning of Phase II, this board could take the decision that the proposals of the Committee are to be examined. A negotiation group will then be commissioned to perform this examination, which in turn gives a report on the results to the democratically legitimated board. In the third step of Phase II, the institutional end of the procedure, the democratically legitimated board would accept and adopt this report, if required with corresponding modifications. This would legitimate the procedure and criteria applicable to the site selection in Phase III. The modifications to the legal framework are performed correspondingly.

Only a few boards can be considered as democratically legitimated for the institutional commencement. The most adequate solution would be a corresponding decision of the Federal Government and, where appropriate, in co-operation with other constitutional bodies. This co-operation with other constitutional bodies would in particular be required to reach a broad consensus and thereby keep party-political disputes limited. Other constitutional bodies involved could be the *Bundestag* and / or the heads of the *Länder* governments. The latter would follow the decision on the waste management provisions [BMI 1980] passed in1979.

From the Committee's point of view, the decision could comprise the following central components:

- Firstly, the political agreement on a process of site identification as proposed by the Committee or in a similar form, and
- the general conditions for the second step (discussion of the selection procedure with the public) and for the third step (institutional end) of Phase II.

Within the framework of the institutional commencement, the prerequisites for the second step have to be established as well. These steps include first and foremost the necessary decisions concerning staffing as well as technical, organisational and financial issues.

7.2 Second step in Phase II: Discussion of the selection procedure with the public

The Committee is of the opinion that it is required not only to perform the actual identification of suitable repository sites according to a democratic and participative proceeding, but that already the agreement on the procedure and the criteria should be organised in a participative way to enable the development of a sound procedure on the basis of a broad consensus. The participation of the public at an early stage shall increase the legitimacy of the selection procedure and the acceptance of the results. By doing so, the Committee hopes that the dialogue leads to a general approval and that in later steps of the site selection not every step has to be negotiated in court.

The second step of Phase II is determined by the discussion of the selection procedure in a public participation procedure (model of the “dialogic field”, Fig. 7.2). The participation procedure includes the dialogue with representatives of societal stakeholders (negotiation group), including representatives of the Federal Government and the *Länder,* and the participation of the public in this process.

7.2.1 Dialogic field

The new term “dialogic field” refers to two essential concepts which guided the development of the participation procedure. On the one hand, it is not the main intention of the Committee to reach the largest possible acceptance for its proposals, but to involve the public actively in the discussions and agreement on the procedure and criteria to be selected. The proposals on procedures and criteria of the Committee represent the basis of the dialogue, which is expected to induce a substantial or gradual modification and improvement of the proposed procedures for the criteria as well as of the actual search of a repository. Secondly, the field term indicates, both in social sciences and in natural sciences, the dynamic of the processes and, above all, the different influencing factors by which the field is formed and subjected to changes. The proposal of the "dialogic field" is therefore based on the Committee’s thesis that a more appropriate model for the search for a repository site, supported by the public, can be obtained through dialogues which can then be considered and in a final step adopted by the legislature.

Thus, the dialogue is supposed to allow a review of the procedure and the criteria and, on the other hand, lead to the broadest possible agreement in the form of a consensus within society in order to achieve a widely accepted basis for the implementation of the actual selection procedure. The procedure thus gains a high degree of legitimation because the citizens and their stakeholders are already involved during the final agreement on the procedure and its rules. This way, the requirements regarding representation, credibility, fairness, competence and transparency are also fulfilled.

The “dialogic field“ is characterised by four lines of activities: A negotiation group, virtual and regional forums and joint activities with the youth (see Fig. 7.2).

Task of the negotiation group

In the centre of the “dialogic field” there is the negotiation group which selects the topics to be negotiated on its own within the framework of the general specifications. As far as the content is concerned, the work of the negotiation group, and thus the communication within the dialogic field, could be subdivided according to three sets of topics:

- Basic ethical issues (what we are allowed to do)
- Scientific-technical criteria (what we can do)
- Socio-scientific and planning-scientific criteria (what we want to do)

The negotiation group organises and focuses the discussion and has the task to discuss the procedure in public, to modify it, if required, and to prepare decisions. At the end, a written recommendation is presented to the Parliament, the Federal Government and the heads of the *Länder* governments.

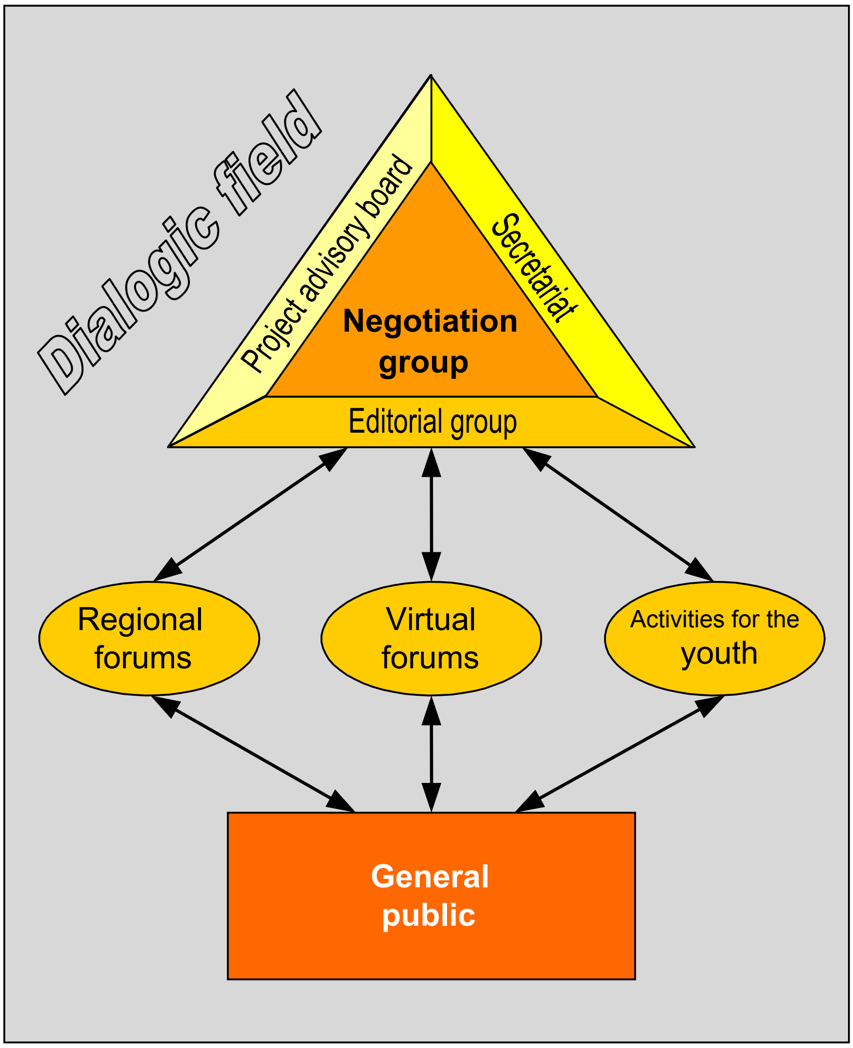

Fig. 7.2: *Dialogic field*

Composition of the negotiation group

The number of participants of the negotiation group has to be manageable so that the working ability is not impaired. Based on previous experience, a maximum of 25 to 30 members should not be exceeded.

The participants of the negotiation group (see Fig. 7.3) could be representatives from

- the political parties represented in the German *Bundestag*,
- environmental and nature conservation associations,
- the *Länder*,

- the electricity producers,
- BMU and BfS,
- the local communities,
- citizens' initiatives,
- the churches,
- youth associations,
- other associations and institutions, and
- the sciences.

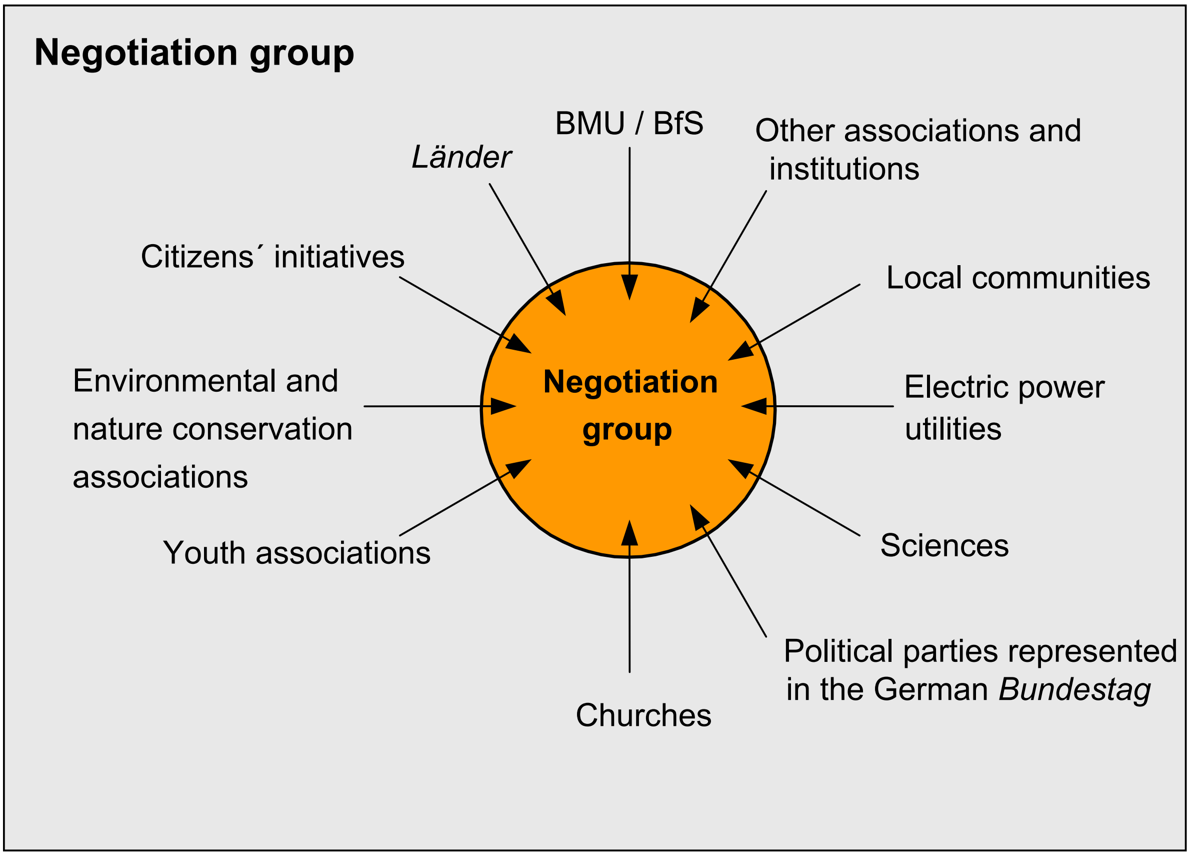

Fig. 7.3: Composition of the negotiation group

The composition of the negotiation group should be specified by the Federal Government, as democratically legitimated board which initiated the institutional commencement of Phase II. In this context, the Committee proposes that the Federal Government requests relevant organisations and institutions to participate in the negotiation group and that these select the individuals to be delegated as participants in the negotiation group.

Due to the current status of discussions within the different societal groups dealing with the issue of waste disposal, it is likely that all nominated groups will participate in the negotiation group. Should a group refuse to participate, this will not result in a major deficit, because it does not essentially impair the function of societal communication. The corresponding reasons are included in Chapter 4.5.2 of the WIBERA expertise [LENNARTZ & MUSSEL 2002].

Organisational structure of the negotiation group

The negotiation group will have its own organisational structure (see Fig. 7.4). It is reasonable to elect a chairperson and two representatives among the members of the negotiation group. Their tasks, among others, include the structuring of the work programme and of the meetings. The negotiation group is assisted by a team of presenters chairing the meetings, and by a business office that will provide the negotiation group with organisational and editorial support as well as help concerning dialogic planning methods.

If decisions on individual items cannot be taken in consensus, majority decisions will be taken. The option of minority votes is provided.

A project advisory board consisting of experts will be established for scientific support in Phase II. The participants shall be nominated by the business office and confirmed by the negotiation group. Further, structures have to be provided in Phase II which enable the involvement of the public regarding organisation and contents as described above.

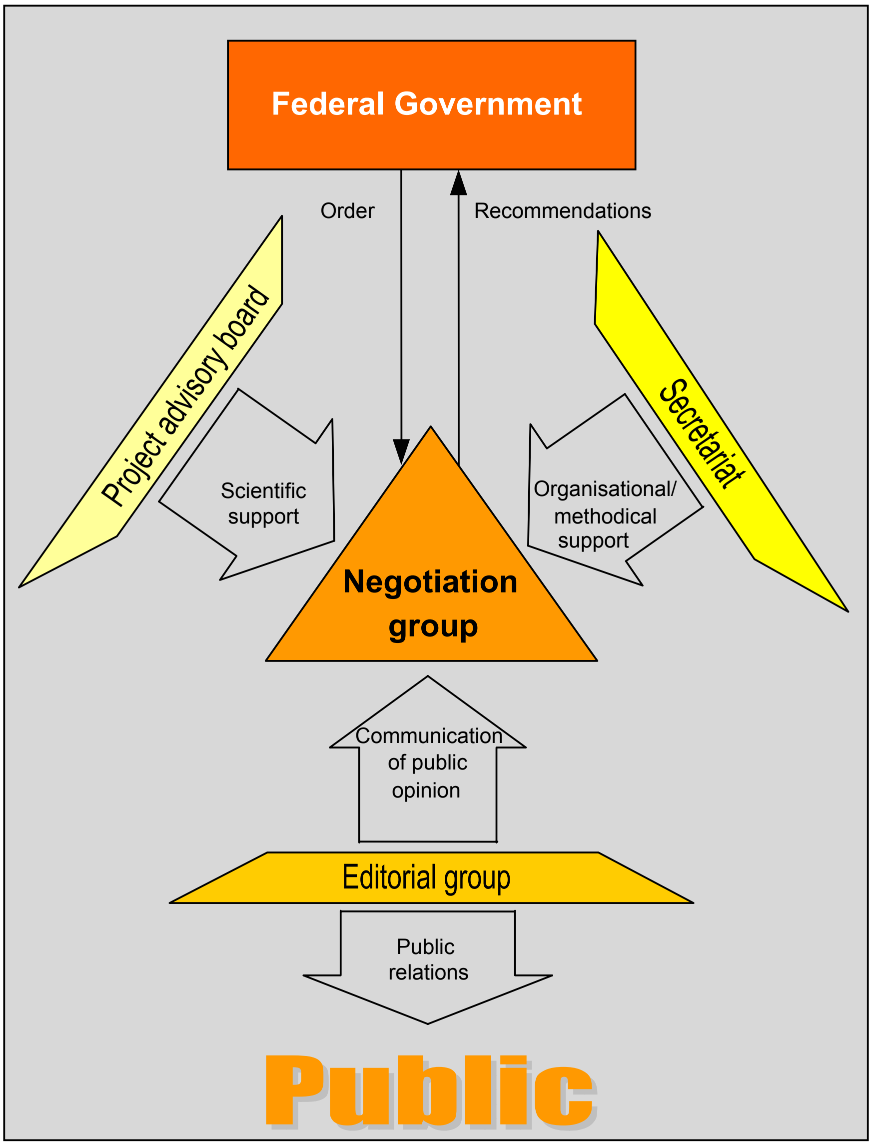

Fig. 7.4: *Organisation of the negotiation group*

Participation of the public in the negotiations

The public will be able to actively participate in the negotiation via the internet (chat room), but other forms of participation shall also be provided. In addition, the negotiation group shall meet regionally at public meetings, thus allowing further participation of the public, and shall provide further transparency by ensuring media coverage. The possibility of public access to the negotiations should be a part of the standing orders of the negotiation group.

The public is informed about the current status of discussions within the negotiation group via a virtual forum (see Fig. 7.2). The public can then react to it with supporting or critical arguments and actively exert influence on the negotiation group through proposals and requests. An editorial group consisting of journalists and experts compiles the contributions in the virtual forum and forwards the arguments to the negotiation group. The “virtual forums” are fixed items on the agendas of the negotiation group’s meetings, where these arguments are discussed. The results of the discussions are again published in the virtual forum. In this way, a binding dialogue can be established between the negotiation group and the public. In addition, it must also be possible to participate in this forum without a computer (circular letter and correspondence).

The regional forums have a similar function. At these public forums, the negotiation group holds its meetings coram publico on the basis of an invitation with a corresponding agenda. The discussion will occupy a considerable part of the meeting in the regional forums in order to get to know not only the arguments but also the atmosphere within the public through direct communication.

The young generation that will particularly be affected by the search for a repository and its construction and operation shall be involved through special events for young people. Here, emphasis shall not be placed on forums for discussions, but on subject-related activities, such as exhibitions and contests, the results of which can then be evaluated (see Fig. 7.2).

At the end of the participation procedure in Phase II, the discussion results of the negotiation group will be submitted to the ordering constitutional body in form of a report as the basis for a decision. With the submission of the report, the second step is completed (see Fig. 7.5).

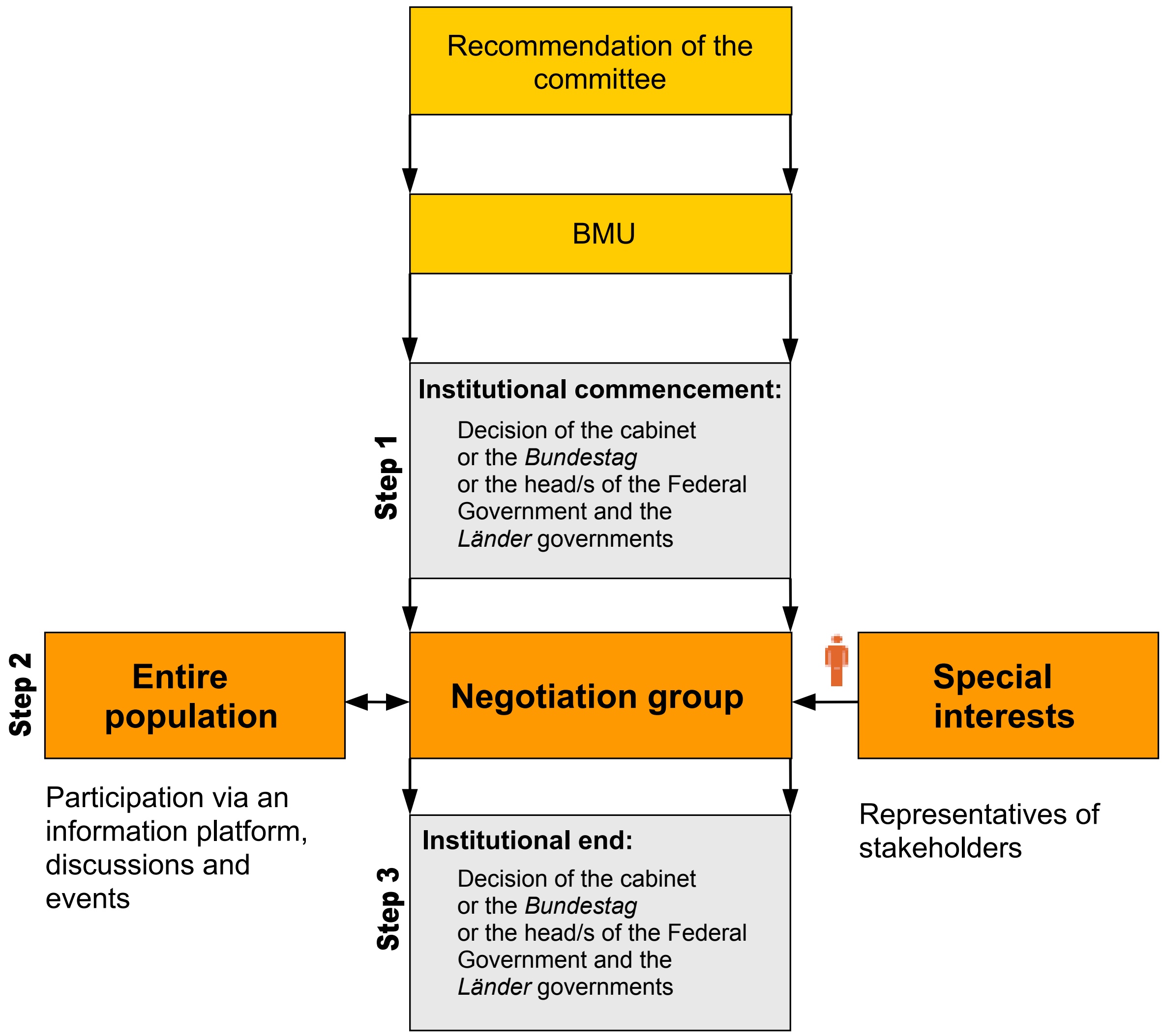

Fig. 7.5: Proceeding in Phase II

7.2.2 Timeframe for Step 2 of Phase II

A public discussion process cannot be performed over any desired periods of time with sufficient intensity. In order to be able to start the search for a repository site for radioactive waste as soon as possible, the duration of Phase II has to be limited. For the performance of Step 2 in the "dialogic field", the Committee estimates the required time at approximately one year. Altogether, the discussion on the procedure and the criteria, including the institutional commencement and end, should not take more than 24 months. Since this causes the time schedule to become very tight , the Committee suggests to start the preparatory work directly, such as the set-up of the virtual forums, addressing the youth, the search for a suitable location for the business office.

7.3 Third step in Phase II: Institutional end

The third step (institutional end) includes the political / legal agreement on the selection procedure by the Federal Government or the ordering constitutional bodies, respectively. The basis for this should be the report of the negotiation group, unless there are opposing legal or constitutional reasons.

The Committee is of the opinion that the following variants may be possible:

- Decision of the Federal Government and information of the German *Bundestag*

  The Federal Government makes a decision in which the results of the participation procedure are adopted directly or with modifications. In this case, the information of the German *Bundestag* is recommended.

- Decision of the *Bundestag* with the assistance of the *Bundesrat* (German Federal Council)

  The decision can be made, e. g., in form of a law in which the essential initial conditions for the subsequent site selection procedure (Phase III) are laid down. This may comprise, among others, the following items:

  - Rules of the procedure,
  - applicable criteria,
  - stipulations on consultative votes in different steps of Phase III,
  - stipulation that the *Bundestag* will define the selected site at the end of the procedure by law, and
  - issues related to financing and organisation.

Since, in any case, the planned law affects the concerns of the *Länder*, it has to be dealt with both in the *Bundestag* and in the *Bundesrat*. For the success of a planned law of this kind, respective discussions in both boards are already required in the preliminary stages (e. g. parallel in time to the second step).

- Common decision of the Conference of Minister-Presidents and the Federal Government

  Since the identification of suitable repository sites for radioactive waste in Phase III, on the basis of the results of Phase II, in Germany will take place simultaneously in one or more territories of the *Länder*, it seems to be appropriate to involve the *Länder* already in the preliminary stages of the concrete site selection and –decision, also with regard to an agreement reached on the basis of the broadest possible consensus. A common agreement or decision of the Federal Government and the Minister-Presidents of the *Länder* would not be opposed by the fact that the “Conference of Minister-Presidents” is not an organ according to the constitutional law. Besides, this proceeding would also comply with the “waste management principles” adopted in 1979.

However, since the decision on the appropriate path falls into the competence of the Federal Government itself, the Committee refrains from a prioritisation between these alternatives.

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A Appendix

A.1 Members of the Committee

Dr. Detlef Appel
PanGeo-Geowissenschaftliches Büro, Hannover

Year of birth: 1943

Detlef Appel studied geology in Hanover and Vienna. From 1971 to 1981 he was scientific assistant at the Hanover University, where he received his doctorate in 1979. Since 1981, he has been an independent consultant and surveyor in the field of environmental geosciences. His work focuses on conceptional and object-related groundwater and soil protection, environmental impact assessments, waste disposal sites, contaminated sites and disposal of radioactive waste.

Dr. Bruno Baltes
Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), Köln

Year of birth: 1944

Bruno Baltes studied reactor technology at the faculty of mechanical engineering at the Aachen University of Technology, where he received his doctorate in 1977. Since 1977, he has been employed at the Gesellschaft für Anlagen- und Reaktorsicherheit where his work concentrates on the safety - and especially the long-term safety - of repositories for radioactive waste. He is head of the Final Storage Department in the technical division of waste management at GRS.

Dr. Volkmar Bräuer
Federal Institute for Geosciences and Natural Resources (BGR), Hanover

Year of birth: 1953

Volkmar Bräuer studied geology at the Technical University of Karlsruhe and received his doctorate in this field of study at the Hanover University. Since 1983, he has been working for the Federal Institute for Geosciences and Natural Resources (BGR) in Hanover. His work focuses on the development of selection and suitability criteria regarding the selection of repository sites. He was project leader for the activities of the BGR at the Swiss rock laboratory Grimsel and conducted the investigations on the identification of repository sites in crystalline rocks in Germany. Since 1997, he has been co-ordinating the Gorleben project for the disposal of radioactive waste. From 1995 to 1997, Volkmar Bräuer was delegated to the Federal Ministry of Economics in Bonn and engaged as expert for nuclear waste management in the preparation of the consensus talks between the Federal Government and the opposition held at that time.

Prof. Dr. Wernt Brewitz
Gesellschaft für Anlagen- und Reaktorsicherheit (GRS), Braunschweig

Year of birth: 1940

Wernt Brewitz studied geology at the Technical University of Clausthal with the main courses in mining geology and mineral deposits. From 1969 to 1977, he was working as exploration and mining geologist in South Africa. During this time he received his doctorate at the TU Clausthal. After this, he joined the Gesellschaft für Strahlen- und Umweltforschung mbH (GSF) as scientific employee and was project leader of the feasibility study for the Konrad mine as repository for radioactive waste with negligible heat, performed on behalf of the Federal Ministry for Research and Technology.
From 1988 to 1995, Wernt Brewitz was director of the joint management of the GSF-Institute for Disposal of Wastes in Deep Geological Formations (IfT). Since 1995, he has been head of the scientific-technical division "Final Repository Safety Research" of the Gesellschaft für Anlagen- und Reaktorsicherheit. He participates in different international committees as expert, i. a. at the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development. Further, he is directly involved in the experimental research in foreign underground laboratories in granite and claystone.

Prof. Dr. Klaus Duphorn
Kiel University, Professor (ret.)

Year of birth: 1934

Klaus Duphorn studied geology/paleontology in Jena - until the diploma - and Würzburg, where he received his doctorate in 1962. From 1962 to 1974, he worked

as quaternary geologist for the Lower Saxonian State Office for Soil Research (NLfB) and as economic geologist for the Federal Institute for Geosciences and Natural Resources (BGR). After that, he was appointed to a professorship at the Kiel University. In 1998 he was given emeritus status.
Klaus Duphorn led two working groups on the investigation of the Gorleben repository site and furnished several safety-related geological expert opinions on this site - so in 1983 for the Physikalisch-Technische Bundesanstalt, in 1988 for the SPD of Lower Saxony and in 1993 for the Ministry of Environment of Lower Saxony. As expert for repository geology, he participated in several political hearings in the committee on environmental issues of the State Parliament of Lower Saxony, in the committee on internal affairs and in the committee on environment, nature conservation and nuclear safety of the German Federal Parliament.

Rainer Gömmel
GSF-National Research Center for Environment and Health, Asse Research Mine, Remlingen

Year of birth: 1951

Rainer Gömmel studied mathematics and physics at the Friedrich-Alexander-University Erlangen/Nürnberg and passed the state examination for teaching at Grammar School there. After teacher traineeship, pedagogical examination and some years of teaching, he was responsible for the public relations of the GSF-Institute for Disposal of Wastes in Deep Geological Formations from 1985 to 1995, which was succeeded by the GSF-Asse Research Mine. In addition to public relations for this service institution, documentation and information have been focal points of his activities since then.

Heinz-Jörg Haury
GSF-National Research Center for Environment and Health, Neuherberg

Year of birth: 1945

From 1965 to 1967, Heinz-Jörg Haury was employee at the department of radiochemistry at the University of Munich. In 1972, he graduated as engineer of industrial sciences, and in the same year became head of the Department of Public Affairs at the GSF-National Research Center for Environment and Health in Neuherberg, Germany. He was member of various national and international

committees.
During this time, he was also a free-lance journalist (Bild der Wissenschaft, several daily papers) and is engaged in adult education.

Prof. Dr. Detlev Ipsen
University of Kassel

Year of birth: 1945

Study of sociology, psychology and ethnology in Munich, Vienna and Mannheim. Study of statistics and methods of the empirical social research in Ann Arbor (USA) and Colchester (GB). Doctorate and assistant researcher in Mannheim. Since 1979 he has been professor for urban and regional sociology at the Department of Urban Planning and Landscape Planning at the University of Kassel (GhK).

Prof. Dr. Klaus Kühn
Technical University of Clausthal, Clausthal-Zellerfeld

Year of birth: 1938

Klaus Kühn studied mining engineering at the Technical University of Clausthal, where he received his doctorate in 1968. Since 1965, he has been working in the field of disposal of radioactive waste at the GSF- National Research Center for Environment and Health. From 1973 to 1995, he was head of the GSF-Institute for Underground Disposal of Wastes. During this time, he laid the foundation for joint German-American projects in the field of disposal of radioactive waste. Since 1995, he has been working more intensively in research and training at TU Clausthal, where he was appointed honorary professor in 1989.
From 1983 to 1998, Klaus Kühn was member of the Reactor Safety Commission (RSK) for issues related to radioactive waste management. Further, he was member of numerous international boards, so, among others, in commissions and committees of the International Atomic Energy Agency (IAEA), the Nuclear Energy Agency (NEA) of the Organisation for Economic Co-operation and Development (OECD) and the Commission of the European Communities (CEC).

Prof. Dr. Gerhard Jentzsch
Friedrich-Schiller-University, Jena

Year of birth: 1946

Gerhard Jentzsch is geophysicist. He studied and received his doctorate at the Technical University of Clausthal. After this, he attended the Free University of Berlin for ten years, where he qualified as a university lecturer on geophysics. In 1987, he was appointed to a professorship for applied geophysics at the University of Bonn, changed to TU Clausthal in 1990, and to the Friedrich-Schiller-University Jena in the year 1996. The scientific interests are diversified, but generally concentrate on environmental research with regard to earthquakes, volcanism, gravity field, climate, but also to studies on contaminated sites.
Gerhard Jentzsch participated in the committee on disposal of the advisory board for issues related to the nuclear phase out of the Ministry of Environment of Lower Saxony and was repeatedly consulted as expert in connection with earthquake hazard assessments for nuclear installations in Germany.

Jürgen Kreusch
Gruppe Ökologie e. V., Hannover

Year of birth: 1952

Jürgen Kreusch studied geology with focus on engineering geology and hydrogeology as well as geophysics in Marburg and Hanover, where he did his diploma in 1982. Since 1980, he has been working for the Gruppe Ökologie e. V. in Hanover. Jürgen Kreusch furnishes expert opinions and has an advisory role. His work concentrates on the disposal of chemico-toxic and radioactive waste, the treatment of contaminated sites, issues related to hydrogeology and water resources management, as well as environmental impact assessments for major infrastructural measures.

Prof. Dr. Karl-Heinz Lux

Technical University of Clausthal, Clausthal-Zellerfeld

Year of birth: 1948

Karl-Heinz Lux studied civil engineering at the University of Hanover, where he received his doctorate for a work on tunnelling in loose rock in 1977. In 1983, he qualified as a university lecturer with a work on salt cavern construction and became lecturer on geomechanics. In 1986, he was offered a professorship at the Technical University of Clausthal.
In teaching and research, Karl-Heinz Lux represented the special fields of "rock mechanics" and "geotechnics in mining, tunneling and landfill technology" at the Institute of mining at the Technical University of Clausthal and the Department of Waste Management and Landfill Technology at the CUTEC Institute in Clausthal. In 1992, he was offered a professorship for rock mechanics/rock engineering at the Technical University and Mining Academy of Freiberg, which he refused. In 1993, he was appointed to the committee on final storage of the Ministry of Environment of Lower Saxony. In 1995, he was offered a professorship for landfill technology at the Technical University of Clausthal. Since 1997, he has been holding the professorship for landfill technology and geomechanics at the Institute of Mineral and Waste Processing and Dumping Technology of the Technical University of Clausthal.

Michael Sailer

Öko-Institut e.V (Institute for Applied Ecology), Darmstadt

Year of birth: 1953

Michael Sailer studied technical chemistry at the Technical University of Darmstadt, where he graduated in 1982. Since 1975, he has been dealing with different issues related to nuclear energy and has been working at the Institute for Applied Ecology in Darmstadt since 1980. There, he established the Nuclear Engineering and Plant Safety Division, where he currently acts as division co-ordinator.
Since 1980, Michael Sailer has mainly been working as expert and consultant in the nuclear field. His activities concentrate on issues related to waste management and disposal, the safety of nuclear installations, proliferation and safeguards as well as on issues related to nuclear installations in the neighbouring countries and Eastern Europe. He is Deputy Director of the Institute for Applied Ecology. Since 2001, Michael Sailer has been chairman of the Reactor Safety Commission (RSK) of the

Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU).

Dr. Bruno Thomauske
Federal Office for Radiation Protection (BfS), Salzgitter

Year of birth: 1949

Bruno Thomauske studied physics and received his doctorate 1983 with a thesis on a topic in the field of high energy physics. From 1978 to 1980 he worked at the European Organisation for Nuclear Research CERN (formerly: Conseil Européenne pour la Recherche Nucléaire), Geneva, Switzerland. Since 1983 he has been working in the field of waste management, first at the Physikalisch-Technische Bundesanstalt and then at the Federal Office for Radiation Protection (BfS). He started in the field of radiation protection. In 1988 he became head of the Gorleben repository project. From 1991 to 1997 he was head of the division "Project Management for Repository Projects". In 1997, Bruno Thomauske became head of the department and in 1999 head of the division "Repository Projects, Operation" at BfS.

Former members are

Prof. Dr. Albert-Günther Hermann (until July 2000),

Dr. Reiner Papp (until September 2000)

Dr. Klaus-Detlef Closs (until April 2002)

Dr. Helmut Röthemeyer (until August 2002)

A.2 Round of talks and information visits of the Committee

Round of talks	Date
Round of talks with members of the *Landtag* of Schleswig-Holstein	19.09.02
Round of talks in Salzgitter	28.08.02
Round of talks with members of the *Landtag* of North Rhine-Westphalia	23.04.02
Round of talks with members of the *Bundestag* and the *Landtag* of Thuringia	18.03.02
Second round of talks with representatives of the energy industry	05.03.02
Round of talks with members of the *Landtag* of Baden-Wuerttemberg	14.01.02
Round of talks at schools	13.11.01
Round of talks with the Nuclear Waste Technical Review Board of USA	16.07.01
Round of talks with representatives of the communities with interim storage facilities	16.07.01
Information visit to Sweden	18. - 19.06.01
Round of talks with environmental associations	10.05.01
Round of talks with representatives of trade unions and churches	04.07.00

Round of talks	Date
Round of talks with industry associations using nuclear energy	16.05.00
Information visit to Switzerland	26. - 29.03.01
Round of talks with environmental associations	21.03.00
Round of talks with members of the *Landtag* of Lower Saxony	25.01.00
Round of talks with the citizens' initiative of Lüchow-Dannenberg	31.08.99

A.3 List of abbreviations

AkEnd	Arbeitskreis Auswahlverfahren Endlagerstandorte - *the Committee*
AtG	Atomgesetz - *Atomic Energy Act*
AVR	Atomversuchsreaktor - *experimental reactor*
BE	Brennelemente - *fuel elements (FE)*
BfS	Bundesamt für Strahlenschutz - *Federal Office for Radiation Protection*
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe - *Federal Institute for Geosciences and Natural Resources*
BKG	Bundesamt für Kartographie und Geodäsie - *Federal Agency for Cartography and Geodesy*
BMU	Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit - *Federal Ministry for the Environment, Nature Conservation and Nuclear Safety*
BMWA	Bundesministerium für Wirtschaft und Arbeit - *Federal Ministry of Economics and Labour*
BNatschG	Bundesnaturschutzgesetz - *Federal Nature Conservation Act*
BSK 3	Brennstabkanister 3 - *fuel rod canister 3*
CASTOR ®	Cask for storage and transport of radioactive material
DIN	Deutsches Institut für Normung e. V. - *German Institute for Standardisation*
DWR	Druckwasserreaktor - *pressurised water reactor*
EG	einschlusswirksamer Gebirgsbereich - *isolating rock zone*
EL	Einlagerungsbereich - *emplacement area*
EU	Europäische Union - *European Union*
GWL	Grundwasserleiter mit Kontakt zur Biosphäre - *aquifer with contact to biosphere*
FRM-II	Forschungsreaktor München II - *Munich Research Reactor II*
HAW	hochradioaktiver Abfall - *high active waste*
IAEA	International Atomic Energy Agency
ICRP	Internationale Strahlenschutzkommission - *International Commission on Radiological Protection*
IFOK	Institut für Organisationskommunikation - *Institute for Organisational Communication*
ITAS	Institut für Technikfolgenabschätzung und Systemanalyse - *Institute for Technology Assessment and Systems Analysis*

LAW	schwachradioaktiver Abfall - *low active waste*
LWR	Leichtwasserreaktor - *light water reactor*
MAW	mittelradioaktiver Abfall - *medium active waste*
NEA	Nuclear Energy Agency (organisation of the OECD)
NRC	US Nuclear Regulatory Commission
OECD	Organisation für wirtschaftliche Zusammenarbeit und Entwicklung - *Organisation for Economic Co-operation and Development*
RFR	Rossendorfer Forschungsreaktor - *Rossendorf Research Reactor*
SKB	Svensk Kärnbränslehantering AB - *Swedish Nuclear Fuel and Waste Management Co*
StrlSchV	Strahlenschutzverordnung - *Radiological Protection Ordinance*
SWR	Siedewasserreaktor - *boiling water reactor*
THTR	Thorium-Hochtemperaturreaktor - *Thorium high-temperature reactor*
VKTA	Verein für Kernverfahrenstechnik und Analytik Rossendorf e. V. - *Nuclear Engineering and Analytics Rossendorf Inc.*
WG	Wirtsgesteinskörper - *host rock body*
WHG	Wasserhaushaltsgesetz - *Federal Water Act*