Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste

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1. Objectives and scope of validity

These Safety Requirements set out the safety standards that a repository site for heat-generating radioactive waste in deep geological formations must demonstrably observe in order to comply with atomic energy legislation. These safety standards are not determined solely by the general protection targets and protection criteria that form an integral part of these Safety Requirements, but also via the implementation, in their entirety, of the requirements outlined below. These Safety Requirements assume a final disposal concept in which the radioactive waste is stored in a deep geological formation with a high containment capacity.

These Safety Requirements apply exclusively to a final repository that is to be built for heat-generating radioactive waste, and in this regard shall replace the Safety Criteria for the Final Disposal of Radioactive Waste in Mines published on 5 January 1983 in the Bundesanzeiger (Federal Gazette).

These Safety Requirements shall apply to the site at which the Federal Government, being responsible for the establishment of facilities for the final disposal of radioactive waste, has opted to conduct a plan approval procedure, to the final repository to be built, operated and decommissioned at that site, as well as to the organisations involved in the construction, operation, licensing and supervision of this final repository. As such these Safety Requirements shall apply to the planning, further exploration, construction, emplacement operations and decommissioning of such a final repository, and shall also address the required monitoring and evidence preservation measures following its decommissioning.

In particular, the Safety Requirements regulate the following points:

- The protection objectives pursued by the final disposal of radioactive waste
- The safety principles to be observed
- A step-by-step approach and optimisation with regards to radiation prevention, operational safety and reliability of the safe, long-term containment of waste, with due regard for feasibility
- Protection from damage caused by ionising radiation
- Requirements governing safety analyses and the evaluation thereof for operation and long-term safety
- Design requirements governing the safety concept for the final repository during the operating and post-closure phases
- Safety management for construction and operation of the final repository
- Documentation of the final repository

Where expedient, the Safety Requirements may be concretised by guidelines.

This document does not include a definition of the legal procedures for selecting the final repository site and for licensing a repository site for heat-generating radioactive waste, nor does it contain any specifications on the requirements resulting from § 7, para. (2), no. 5 of the Act on the Peaceful Utilisation of Atomic Energy and the Protection Against its Hazards (Atomic Energy Act, AtG) on the measures to be taken to protect against disruptive actions and other interference by third parties and from the international monitoring of nuclear materials or other areas of the law.
If, on the basis of alternative considerations, radioactive waste with negligible heat generation is also to be emplaced in this final repository, observation of these Safety Requirements shall be extended to include such waste, with the exception of the requirements applicable to waste containers pursuant to section 8.6.

2. Definitions and explanations of terms

Waste, heat-generating radioactive
Heat-generating radioactive waste is characterised by high levels of activity concentration, and associated with this, a high thermal output during decay. Such waste places particular requirements on a repository site (final disposal in deep geological formations, use of shielded in-facility transport containers, use of special emplacement techniques, thermal design of the repository mine). In particular, heat-generating radioactive waste includes waste in the form of spent fuel rods and vitrified fission product concentrates (possibly vitrified together with feed sludge), compacted fuel cladding and structural parts from the reprocessing of spent fuel rods. In accordance with § 3, para. 2, no. 1a of the Radiological Protection Ordinance (StrlSchV), these are radioactive substances as defined in § 2, paragraph (1) of the Atomic Energy Act (AtG), which, according to § 9a of the Atomic Energy Act, are to be disposed of in a regulated manner as radioactive waste.

Backfilling
Backfilling refers to the incorporation of backfill material into the mine structure to reduce the remaining volume of hollow space.

Barrier
A barrier is a natural or technical component of the repository system. Examples of barriers include waste matrices, waste containers, cavern and shaft sealing structures, isolating rock zones (IRZ), and the geological strata surrounding or overlying the IRZ.

A barrier may perform a variety of safety functions. The safety function of a barrier may be a physical or chemical property or a physical or chemical process. For example, preventing or inhibiting the ingress of liquids to the waste, or protecting the isolating rock zone from erosion, may be classed as safety functions. Elements of the final repository system which merely serve to distribute or dilute the substances released from the waste are not classed as barriers.

Containment
Containment refers to a safety function of the repository system which is characterised by the fact that the radioactive waste is contained inside a defined rock zone in such a way that it essentially remains at the site of emplacement, and at best, minimal defined quantities of material are able to leave that rock zone.

Criticality
Criticality refers to the point at which a chain reaction is self-sustaining, i.e. the neutron production rate is equal to or greater than the rate of neutron leakage.

Decommissioning
Decommissioning comprises all measures implemented following the cessation of waste disposal operations, including sealing the final repository in order to create a maintenance-free state which guarantees the long-term safety of the repository. Decommissioning may include
measures carried out during the operational phase (e.g. sealing structures for filled emplacement chambers).

Developments of the repository system
Probable developments refer to normal developments forecasted for this site, and developments normally observed at comparable locations or similar geological situations. The forecasted normal development of properties should be used as a basis when considering the technical components of the final repository. If quantitative data on the probability of a certain development occurring is available, and the probability of it occurring in relation to the reference period is at least 10%, this shall be considered a probable development.

Less probable developments refer to developments which may occur for this site under unfavourable geological or climatic assumptions and which have rarely occurred in comparable locations or comparable geological situations. A consideration of the technical components of the final repository should be based on the normal forecasted development of their properties upon occurrence of the respective geological development. Any unfavourable developments in the properties of the technical components that deviate from normal development should also be investigated. Repercussions on the geological environment should be considered. Apart from such repercussions, anticipated geological developments should also be taken into account. Within such a development, the simultaneous occurrence of several unrelated faults should not be assumed. If it is possible to make a quantitative statement on the probability of a certain development or an unfavourable development in a technical component’s properties, this should be taken into account if the probability in relation to the reference period is at least 1%.

Improbable developments refer to developments which are not expected to occur at the site even under unfavourable assumptions, and which have not been observed in comparable locations or comparable geological situations. Statuses and developments for technical components which can be more or less excluded by taking certain action, as well as the simultaneous, independent failure of several components, are classed as improbable developments.

Integrity
Integrity refers to retention of the isolating rock zone’s containment capabilities in a repository site.

Isolating rock zone
The isolating rock zone is part of the repository system which, in conjunction with the technical seals (shaft seals, cavern sealing structures, dam structures, backfill, ... ) ensure containment of the waste.

Long-term safety
Long-term safety refers to the condition of the final repository for which related safety requirements are met following its decommissioning (see chapter 7.2).

Long-term safety analysis
A long-term safety analysis refers to an analysis of the long-term behaviour of the repository site after decommissioning. The central aspect is an analysis of the repository system’s containment capability and its reliability. For example, it includes the development of conceptual models, the development of scenarios, the analysis of consequences, the ...
analysis of uncertainties, and the comparison of the results with the prescribed safety principles, protection criteria and other evidence requirements. It is a pre-requisite for the long-term safety case.

**Overburden**
The geological strata overlying the isolating rock zone are known as the overburden.

**Phases of final geological disposal**
The operating phase begins with the emplacement of the waste in the repository and ends with the final sealing of the shafts and the removal of overground facilities within the framework of decommissioning. The post-closure phase begins following completion of the decommissioning work.

**Recovering radioactive waste**
Recovering is the retrieval of radioactive waste from a final repository as an emergency measure.

**Reference period**
Evidence of long-term safety must be provided for the reference period.

**Repository mine**
The repository mine is comprised of various components such as shafts, galleries, caverns containing the waste containers, backfill and seal elements.

**Repository system**
The repository system is comprised of the repository mine, the isolating rock zone, and the geological strata surrounding or overlying this rock zone up to surface level, insofar as these are relevant for safety purposes and must therefore be taken into account for the safety case.

**Robustness**
Robustness refers to the reliability, quality and hence insensitivity of the repository system’s safety functions and its barriers against internal and external influences and interference, as well as to the robustness of the results of the safety analysis against deviations from its underlying assumptions.

**Retrievability**
Retrievability is the planned technical option for removing emplaced radioactive waste containers from the repository mine.

**Safety**
Safety in a technical sense is guaranteed if the Safety Requirements have been met.

**Safety analysis**
The safety analysis is used to analyse the behaviour of the final repository system under a range of different load situations and with due regard for data uncertainties, malfunctions and possible future developments in relation to safety functions. It ends with an assessment of the reliability of the final repository’s compliance with the safety functions and hence also of its robustness (safety assessment).

**Safety case**
The safety case is based on a comprehensive safety analysis. It comprises the inspection and evaluation of data, measures, analyses and arguments indicating compliance with these Safety Requirements and hence the safety of the final repository. A comprehensive safety case includes a combination of all the evidence listed in these Safety Requirements, and may be updated in suitable depth for the various phases of final disposal according to the latest state of the art. In particular, a distinction is made between safety cases for the operating phase and for the post-closure phase of the final repository.

Safety function
A safety function is a property or process occurring in the final repository system which guarantees compliance with safety-related requirements in a safety-related system or sub-system or individual component. The combined action of all such functions ensures compliance with all safety requirements, both during the operating phase and the post-closure phase of the final repository.

Safety management
The safety management system shall define a strategy and processes to achieve reliable implementation of the safety requirements and continuous improvement in the safety standards of the final repository. This shall also include monitoring the achieved status and initiating concrete processes for improvement.

Safety management comprises the entirety of activities for the proper planning, organisation, management and control of individuals and work, including the necessary processes for advance planning and supply of the necessary personnel, organisational and financial resources, an adequate infrastructure, and a work environment that promotes safety, as well as for regulated cooperation with external organisations.

Scenario
A scenario refers to a post-decommissioning development of the final repository system and its safety-related properties, with a greater or lesser degree of probability, based on the current site conditions and on the basis of geoscientific and other considerations. This development is determined by the starting situation as well as by future events and processes. Several developments may also be combined into one scenario.

Seal
A seal refers both to the sealing of the emplacement zones by flush mount backfilling of selected galleries and underworkings, as well as to the sealing of the shafts in the repository mine. The seal includes all technical structures incorporated into the repository mine in order to safeguard the integrity of the isolating rock zone and protect against ionising radiation.

3. Purpose and general protection objectives

The aim of these Safety Requirements is to outline the purpose, basic principles and requirements for preventive and protective measures governing the final disposal of heat-generating radioactive waste in deep geological formations in order to protect man and the environment from the harmful effects of ionising radiation. Final disposal has two main general protection objectives:

3.1 To permanently protect man and the environment from ionising radiation and other harmful effects of such waste
3.2 To avoid unreasonable burdens and obligations for future generations

The Safety Requirements have been worded in such a way that the requirements for evidence of the permanent protection of man and the environment from the other harmful effects of such waste have also been met. The evidence itself must be kept in accordance with water regulations.

4. Safety principles

The permanent protection of man and the environment must be achieved with due regard for the following safety principles:

4.1 The radioactive and other pollutants in the waste must be concentrated and contained in the isolating rock zone, and thus kept away from the biosphere for as long as possible.

4.2 Final disposal must ensure that in the long term, any release of radioactive substances from the final repository only negligibly increases the risks associated with natural radiation exposure.

4.3 Final disposal must not endanger species diversity. Provided man as an individual is protected from ionising radiation, it is assumed that terrestrial ecosystems and other species are also protected.

4.4 Other uses of natural resources must not be unnecessarily restricted.

4.5 The effects of final disposal on man and the environment beyond Germany’s borders must not be greater than its effects within Germany.

In order to avoid unreasonable burdens and obligations for future generations, the following safety principles must be observed:

4.6 The final repository shall be constructed and operated in such a way that no intervention or maintenance work is required during the post-closure phase to ensure the reliable long-term containment of the radioactive waste in the isolating rock zone.

4.7 Construction of the final repository must be achieved as quickly as possible.

4.8 The necessary financing must be promptly in place for the construction and operation, including decommissioning, of the final repository.

5. Step-by-step procedure and optimisation

The measures involved in final geological disposal, from identification of the final repository site through to the completion of decommissioning, will cover a period of several decades.
For this reason, allowance must be made for advancements in the state of the art and increasing levels of knowledge. The concept and design of the final repository shall be developed on a step-by-step basis, having weighed up the optimisation targets listed below. Additionally, while operational, the final repository shall be continuously optimised in accordance with the principles of radiation protection and from a safety management viewpoint.

5.1 Before making any major decisions regarding the subsequent approach, optimisation shall be performed on the basis of safety analyses and safety assessments in accordance with chapter 7, including an analysis of possible alternatives. The depth of such investigations shall be based on the safety relevance of the respective decision.

This optimisation shall be carried out with due regard for all the circumstances of the individual case, and ensuring a balance between the following optimisation targets:

- Radiation protection for the operating phase
- Long-term safety
- Operational safety of the final repository
- Reliability and quality of long-term waste containment
- Safety management
- Technical and financial feasibility

A robust barrier system in which the safety functions of the final repository system and its barriers are insensitive to internal and external influences and disturbances, the behaviour of the isolating rock zone is very predictable, and the results of the safety analysis are insensitive to deviations from the underlying assumptions, is pivotal to the reliability of safe, long-term containment.

Regarding the technical design of the final repository, the following key specifications must be provided:

- Location and dimensions of the isolating rock zone with due regard for provisional planning of the containers, emplacement technique and emplacement geometry
- Positioning and technical design of the shafts, ramps and infrastructure galleries.
- Emplacement concept (e.g. logistics, arrangement, and handling and monitoring of the containers)
- Decommissioning, including sealing measures

5.2 Optimisation of the final repository with regard to reliable isolation of the radioactive materials in the final repository from future human activities shall be carried out as a secondary priority to the aforementioned optimisation targets. As future human activities cannot be forecasted, a variety of reference scenarios for unintentional human penetration of the final repository, based on common human activities at the present time, shall be analysed. Within the context of such optimisation, the aim shall also be to reduce the probability of occurrence and its radiological effects on the general public.
5.3 During emplacement operations, the operator shall review safety-relevant changes in the state of the art at ten-year intervals when assessing the safety of final repositories, and shall also review and confirm the safety cases. Feedback from operation of the final repository shall also be incorporated into this review and confirmation process. As well as ensuring that any changes in the statutory provisions, advancements in emplacement techniques and the evolving status of knowledge are taken into account when assessing plant safety during operation of the repository, the review and confirmation of safety cases during the operational phase should also ensure that emplacement operations are optimised and that all participants have up-to-date knowledge.

6. Protection from damage caused by ionising radiation

The relevant provisions of the Atomic Energy Act and related regulations shall apply to protection from damage caused by ionising radiation during emplacement operations and decommissioning of the final repository. The currently valid nuclear regulations shall apply analogously.

The Radiological Protection Ordinance does not contain any criteria for assessing the protection of future generations and the environment from ionising radiation. In the case of a planned, operated and decommissioned final repository observing these Safety Requirements, all essential measures are taken to protect future generations and the environment from ionising radiation, which means that as a rule further evidence is no longer necessary. Internationally there is agreement that calculated or estimated risks or doses in this phase may only be interpreted as indicators of the level of protection being striven for with the final disposal. The following assessment criteria apply for these indicators.

6.1 The integrity of the isolating rock zone is crucial for protection from damage caused by ionising radiation during the post-closure phase. The radioactive waste must be isolated in this rock zone in such a way that it remains in situ and, at best, only minimal quantities of substances are able to exit this rock zone. Additional radiation exposure should only be able to occur in a limited area so that as small a number of people in a generation as possible can be affected.

6.2 For the post-closure phase, evidence must be provided that for probable developments through the release of radionuclides from the emplaced radioactive waste, an additional effective dose in the range of only 10 microsieverts\(^1\) per year can occur for individuals. Individuals with today’s life expectancy and with a lifetime of exposure are to be taken considered.

6.3 For a less probable development in the post-closure phase, evidence must be provided that the additional effective dose caused by the release of radionuclides from the emplaced radioactive waste does not exceed 0.1

\(^1\) Based on ICRP 104 (trivial dose)
millisieverts per year\(^2\) for the individuals affected. Here too, individuals with today's life expectancy and with a lifetime of exposure are to be considered.

For these types of developments, higher releases of radioactive substances are admissible because the occurrence of such developments is less probable.

6.4 For improbable developments, reasonable risks or reasonable radiation exposure have not been quantified. However, where such developments may lead to high radiation exposure, it is necessary to investigate, within the context of optimisation, whether it is possible to reduce such effects with a reasonable input. However, this must not impair optimisation in relation to other developments.

6.5 For developments associated with unintentional penetration of the isolating rock zone, reasonable risks or reasonable radiation exposure have not been quantified.

7. Safety cases

7.1 One key prerequisite for licensing the final repository within the context of the plan approval procedure prescribed by § 9b of the Atomic Energy Act is that the necessary precautions against damage, in accordance with the state of the art, must have been taken in conjunction with the construction and operation of the final repository. The work and actions to be carried out are regulated by the provisions of the Radiological Protection Ordinance. Similarly, when constructing and operating a geological repository, the relevant provisions of the Federal Mining Act must also be observed. Operation of the final repository shall be measured against similar requirements as the operation of other nuclear facilities.

A comprehensive safety case shall be documented for all operating states of the final repository, including the surface facilities. In particular, facility-specific safety analyses shall be conducted for emplacement operation and decommissioning, with due regard for defined design basis accidents, which should verify the protection of operating personnel, the general population and the environment as required by the Radiological Protection Ordinance. This shall include an analysis and representation of the robustness of the final repository system. Furthermore, the respective probabilities of impacts, failures or deviations from the anticipated case (reference case) of safety-related systems, sub-systems or individual components should be calculated or assessed as far as possible, and their impacts on the corresponding safety function analysed. The relevance of such analysed failures to operational safety must be investigated using probabilistic methods.

7.2 Prior to any major decision pursuant to chapter 5.1, a comprehensive, site-specific safety analysis and safety assessment covering a period of one million years must be carried out to provide evidence of long-term safety. This shall comprise all information, analyses and arguments verifying the long-term safety of the final repository, and shall justify the reasons why this... 

\(^2\) Based on ICRP 81 (smaller risk than 10-5/a)
assessment is to be trusted. In particular, this assessment and the documentation thereof should include the following points:

- The underlying final repository concept
- The quality-assured collation of data and information from site exploration, research and development
- The quality-assured implementability of requirements pertaining to technical barriers
- The identification, characterisation and modelling of safety-relevant processes, together with confidence-building in this regard and qualification of the models.
- The comprehensive identification and analysis of safety-relevant scenarios and their allocation to probability categories pursuant to chapter 6.
- The representation and implementation of a systematic strategy for the identification, evaluation and handling of uncertainties.

Moreover, this assessment of long-term safety must be based on the following findings as a minimum requirement:

7.2.1 **Long-term statement on the integrity of the isolating rock zone**: For probable developments, evidence must be provided on the basis of a long-term geoscientific prognosis verifying that the integrity of the isolating rock zone is guaranteed throughout the reference period of 1 million years. To this end, the applicant should provide a clear spatial and temporal definition of the isolating rock zone and should demonstrate that, with due regard for the emplaced waste and technical barriers,

- The formation of secondary water pathways within the isolating rock zone which could lead to the ingress or escape of potentially contaminated aqueous solutions can be excluded, and that
- Any pore water that may be present in the isolating rock zone does not participate in the hydrogeological cycle outside of the isolating rock zone as defined by water legislation. This requirement shall be considered to have been met if the dispersion of pollutants within the isolating rock zone by advective transport processes is at best comparable with dispersion by diffusive transport processes.

In rock salt and argillaceous rock, the integrity of the isolating rock zone should additionally be tested using the following criteria:

- The anticipated stresses should not exceed the dilatancy strength of the rock formations in the isolating rock zone outside of the disturbed rock zone.
• The anticipated fluid pressures must not exceed the fluid pressure capacity of the rock formations in the isolating rock zone in a manner that could lead to the increased ingress of groundwater into said isolating rock zone.
• The barrier effect of the isolating rock zone must not be inadmissibly influenced by temperature development.

7.2.2 Long-term radiological statement: For probable and less probable developments, evidence must be provided that the criteria cited in chapters 6.2 and 6.3 have been met. Provided sufficiently reliable statements can be made for the reference period of one million years regarding the effectiveness of the safety functions of the overburden and adjoining rock of the isolating rock zone, the long-term radiological statement may include this.

A simplified radiological long-term radiological statement without modeling the dispersion of substances in the overburden and adjoining rock is permissible if the radioactive substances released from the isolating rock zone lead to a maximum of 0.1 person-millisieverts per year for probable developments and a maximum of 1 person-millisievert for less probable developments. This ensures that only very low overall amounts of radioactive substances can be released. These person-millisieverts shall be calculated using a recognised generic exposure model for analyses of long-term safety, for which it should be assumed that:

• The reference group in question contains 10 persons that obtain their entire annual water requirement for nutritional purposes (including drinking water, animal watering, crop irrigation) from a well, and
• This well water contains all the radionuclides that have escaped from the isolating rock zone in the year in case. The dilution of well water to a mineral content which would permit it to be used as drinking water should be taken into account.

As it can practically be ruled out that all released radionuclides collect in exactly the same well and further distribution or retention in the overburden or adjoining rock can be assumed, this calculation model ensures that the requirements under 6.1 to 6.3 are met.

7.2.3 Proof of the robustness of the final repository system’s technical components: The long-term robustness of the technical components of the final repository system must be forecasted and described on the basis of theoretical considerations. If technical barriers perform significant safety functions with regard to long-term safety and are subject to special requirements, and if there are no recognised technical rules available in this regard, as a general rule, their manufacture, construction and function must have been tested. Testing must include quality assurance in accordance with the state of the art. The need for testing may be waived if the robustness of these structures, i.e. their insensitivity to internal and external influences and failures, can be proven by some other means, or if safety reserves exist to an extent that obviates the need for testing.

When providing proof of integrity and containment, allowance must be made for technically unavoidable barrier perforations (such as shafts) and backfilling of the final repository. It is necessary to demonstrate that the integrity required
of the geological barrier and its guaranteed containment are preserved even when technical sealing structures and the backfilling thereof are taken into account. Inter alia, this should be verified by analysing the stress conditions and properties of the construction materials that are decisive for proper functioning of the technical sealing structures. Adequate load capacity and durability of such construction materials must be proven for the same length of time as that for which proper functioning of the structures must be guaranteed. Where necessary, immediately effective barriers must ensure containment of the waste until such time as barriers with a long-term action have developed their full potential.

7.2.4 **Exclusion of criticality**: The exclusion of self-sustaining chain reactions for both probable and less probable developments must be proven.

7.3 For a numerical analysis of the final repository’s long-term behaviour with respect to

- Integrity of the isolating rock zone
- Radiological consequences
- Mobilisation of natural radionuclides
- Properties of containers and backfill
- Properties of the sealing structures,

deterministic calculations should be based on the most realistic modelling possible (e.g. median values as input parameters). The objectives of these calculations are:

- To demonstrate the anticipated system behaviour
- To derive (where necessary) time-dependent requirements applicable to the components of the repository system
- To optimise the repository system

Additionally, uncertainty and sensitivity analyses must be carried out in order to highlight the potential solution space and be able to estimate the influence of uncertainties. Model uncertainties must also be taken into account. Compliance with numerical criteria resulting or derived from these safety analyses must be assured with an adequate degree of reliability, with due regard for the uncertainties. Any numerical violations of these criteria resulting from the analyses should be evaluated for relevance.

Furthermore, where applicable, reference models (e.g. reference biospheres) shall be applied to periods with a high level of uncertainty regarding the input data and calculation models. Additionally, for such periods, qualitative arguments should also be consulted.

7.4 A monitoring and evidence preservation programme must be used during emplacement operations, decommissioning, and for a limited period following decommissioning, in order to verify that the input data, assumptions and statements of the safety analyses and safety cases performed for this phase have been observed. In particular, this measurement programme should record the impacts of the rock’s thermomechanical reactions on the heat-generating waste, technical measures and rock-mechanical operations.
Measurements should continue to include the initial status and development of activity concentration in spring water and groundwater, soil, water bodies and the air within the repository’s sphere of influence. Any significant deviations from such data, statements and assumptions in the cited safety cases should be evaluated with regard to their safety relevance. If necessary, counteractive measures should be carried out by the operator during emplacement or decommissioning in order to avoid any impairment to important safety functions. Where approval is needed for such counteractive measures, this should be obtained by applying to the competent authority. The competent authority shall also decide who will perform the measurement programme following decommissioning, and when this measurement programme may be discontinued.

7.5 Based on the properties of the radioactive waste incurred or still being incurred and appropriate conditioning techniques, the operator of the final repository shall derive the safety-relevant properties of the emplaced waste containers from the safety analyses, and transpose these into emplacement conditions.

7.6 The parties obliged to deliver their waste to the final repository are responsible for compliance with these emplacement conditions. Evidence of compliance with the emplacement conditions is subject to the following provisions:

- The parties obliged to deliver their waste to the final repository shall ensure that the waste containers exhibit the properties required by the emplacement conditions, and shall determine the waste data to be notified as per the emplacement conditions.

- The validity of these properties and waste data shall be verified by the operator of the final repository within the context of independent quality control checks (“product control”). For reasons of radiological protection and expediency, as a general principle, such inspections shall take place prior to emplacement and outside of the final repository.

- Within the context of incoming inspections, the operator of the final repository shall verify the identity of the waste containers and the relevant properties in relation to radiation protection and handling of the waste containers in the final repository.

7.7 During exploration, the applicant shall ascertain the principal site data relating to safety of the repository in an adequate level of detail as required for the safety cases. To this end, the accuracy / range of and any potential changes in such site data under emplacement conditions shall be ascertained. The applicant must prove the validity of such data to the licensing authority. Where data obtained from other sites is to be used, the transferability of such data must be justified.

7.9 It is necessary to investigate the extent to which radioactive or other groundwater- or soil-relevant substances occurring naturally in the repository system can be mobilised, and the extent to which groundwater flows could be modified on a safety-relevant scale. For example, this could be caused by the high thermal output of the emplaced waste or by modified geochemical conditions.
The long-term safety case should evaluate releases of radionuclides from naturally occurring materials (backfill and rock) separately from releases of radionuclides from the emplaced waste.

8. **Design of the final repository**

8.1 For the safety of the final repository in the operating phase including decommissioning, the reliability and robustness of safety functions within the final repository must be proven in accordance with the specifications of the nuclear legislation for comparable functions in other nuclear facilities. For the operating phase, moreover, a four-level safety concept should be planned analogous to that for nuclear power plants. A “defence in depth” concept should be implemented by allocating these four levels to plant statuses and by specifying the protection measures to be taken or provided for such plant statuses.

The following four safety levels should be taken into account:

- Normal operation          - Measures prevent the occurrence of operational failures
- Anomalous operation       - Measures prevent the occurrence of design basis accidents
- Design basis accidents    - Measures control design basis accidents
- Beyond design basis       - Measures reduce probability or limit environmental impacts accidents/incidents

The safety concept should outline and justify the potential operational failures and accidents that could occur in the final repository. Decisions regarding which events are to be classified as design basis accidents as defined in § 49 of the Radiological Protection Ordinance (StrlSchV) should be based in particular on the results of the safety analysis and the effects in the vicinity of the repository. This should include an account of which accidents the repository is designed to withstand. Allowance should be made for human error when analysing potential accidents.

Events which cannot be classified as design basis accidents due to their low frequency of occurrence should be evaluated and, where necessary, measures proposed to reduce their likelihood of occurrence and impacts.

8.2 Every effort must be made to minimise the number of holes in the isolating rock zone caused by shafts, galleries and boreholes. Boreholes, shafts and other galleries should be executed in a manner designed to cause minimum damage to the rock, and if they are no longer required, should be sealed prior to emplacement operation in a way which preserves the barrier properties of the isolating rock zone and other safety-relevant barriers.

8.3 When specifying the limits of the isolating rock zone with the driven waste emplacement drifts and emplacement caverns or boreholes, it is essential to maintain both an adequate depth and an adequate distance from geological faults. The depth and distance should be derived from the safety analyses and safety assessments carried out.

...
8.4 Wherever possible, the handling of waste containers should be completely separate from the mining work required e.g. for the maintenance, driving and backfilling of tunnels.

8.5 The final repository should be divided into emplacement drifts with individual emplacement zones. The number of open emplacement zones should be kept to a minimum. These should be promptly loaded, then backfilled and reliably sealed from the mine building.

8.6 Waste containers must fulfil the following safety functions, with due regard for the waste products packaged therein and the backfill surrounding them:

- For probable developments, handleability of the waste containers must be guaranteed for a period of 500 years in case of recovery from the decommissioned and sealed final repository. Care should be taken to avoid the release of radioactive aerosols.
- During the operating phase up until sealing of the shafts or ramps, retrieval of the waste containers must be possible.

Measures taken to secure the options of recovering or retrieval must not impair the passive safety barriers and thus the long-term safety.

8.7 The containment capacity of the final repository must be based on a range of different barriers with varying safety functions. With regard to the reliability of containment, the interactions must be optimised between these barriers in terms of redundancy and diversity. Allowance must be made for the hazard potential of the waste and the varying actions of the barriers in the different time zones. The safety of the final repository after decommissioning must therefore be ensured by means of a robust, graduated barrier system that fulfils its functions in a passive, maintenance-free manner and which continues to ensure adequate functionality even if individual barriers fail to develop their full effect.

8.8 A practicable, tested decommissioning concept must be available before the repository can be commissioned. It is important to ensure that the staffing, financial and technical conditions facilitate short-term implementation of the decommissioning concept, should it become necessary at any time. The decommissioning concept should be reviewed in line with the state of the art as part of the ten-yearly safety reviews, and updated where necessary. The period within which sealing is possible must be specified.

9. Safety management

9.1 The following overarching aspects of safety management must be observed:

- Guaranteed operational safety throughout all process steps and permanent passive safety of the final repository system after sealing as the paramount safety objective
- The continuity of all processes, structures and resources required for successful implementation of the final repository project spanning several
generations, even under changing organisational, national and international framework conditions
- The unequivocally and clarity of competencies and regulated responsibilities, both internally and between the parties involved
- The creation and maintenance of a suitable environment for obtaining, pursuing, evaluating and implementing scientific findings and assessments that are relevant to the final repository project
- Guaranteed financing and organisation even for periods when the waste originators have ceased to exist
- The prompt heeding of possible influences which could cause delays in the final repository project (e.g. unplanned evidence requirements, new technical developments, modified safety requirements).

9.2 The applicant/operator shall set up a safety management system which is maintained throughout all phases of the final repository project until decommissioning is complete. He shall make it a top priority to guarantee and continuously improve safety over other management targets, and shall support the development and maintenance of a vigilant safety culture.

Safety management must be designed to ensure high levels of trust in the quality of the organisation and in the observance of all safety requirements and existing limits, guidelines and criteria. It must ensure that the operator organisation’s safety standards can be continuously assessed by all parties involved in the light of advancing information.

Responsibility for the implementation, performance and promotion of safety management lies with the management of the operator organisation. The various management levels within the organisation must promote and support safety management.

9.3 A safety management system must be set up to achieve safety management. This system must include all specifications, regulations and organisational tools for the handling of safety-relevant activities and processes. All its elements must be derived and justified in an accountable fashion. Interactions, interfaces and delimitations between different processes shall be designed and described in a logical fashion.

The safety management system is an integral component of the overall management system. It must reflect the state of the art as well as the relevant regulations. This integrated safety management system and the processes implemented must be documented in a verifiable format.

Safety management must be designed as a learning system. Checks should be undertaken at regular intervals, including in particular
- Independent internal and external reviews of the management system
- Systematic comparisons with other facilities and operators, including those in other fields.

9.4 The organisational structure of the applicant/operator must be geared to the safety objectives. It must
Specify clear responsibilities for content and processes
- Promote the gradual optimisation of the project with due regard for continuous advancements in information and findings
- Support the internal and external, disciplinary and interdisciplinary exchange of information
- Adopt a transparent approach to obtaining, processing and documenting data and results, and
- Promote self-critical conduct and a critically inquisitive attitude among all employees, as well as relationships based on trust throughout all areas of the organisation.

For each of these objectives, records should be kept outlining how they are to be encouraged, and the criteria against which success is to be measured. The processes implemented to this end must be documented.

9.5 With regard to personnel, the safety management system must ensure that:

- Persons are only entrusted with tasks for which they are trained and competent. This applies to all levels of responsibility. To this end, clear requirement profiles must be prepared for all activities with safety relevance, including the criteria against which the respective competencies are to be assessed. This must include documentation of how the specific incumbents of the positions fulfil these requirement profiles.
- For every safety-relevant task, an adequate number of suitable individuals must be deployed. What constitutes an adequate number shall be ascertained and documented in each case.
- For every safety-relevant task, suitable individuals must be readily available to replace any personnel that leave (fluctuation, retirement). To this end, forecasted analyses should be prepared periodically, and on the basis of this, suitable measures derived and implemented. Particular attention should be devoted to optimum handovers, e.g. with regard to the transfer of knowledge.
- All persons must maintain and develop their knowledge and qualifications by means of suitable advanced training measures. To this end, advanced training programmes should be prepared in accordance with the specific requirements of the relevant tasks. All advanced training carried out must be duly documented.

9.6 As a general rule, the requirements pertaining to safety management also apply to external organisations operating as third-party companies, suppliers or contractors on behalf of the applicant/operator, in accordance with the respective nature of their activity on behalf of the applicant/operator. The contractual provisions between the applicant/operator and external companies, suppliers and contractors commissioned by the former must include appropriate specifications on safety management and the review thereof by the client.

The applicant/operator shall periodically ensure that the organisations commissioned by him comply with the corresponding safety management requirements and supply the agreed services, activities and products in the requisite quality.
Internally, the applicant/operator shall at all times make the necessary capacity of suitable personnel available who are capable of expertly assessing and controlling the services, activities and products of external organisations acting on behalf of the applicant/operator from a safety management viewpoint.

9.7 Following decommissioning of the final repository, evidence preservation and control measures must be carried out. Prior to the completion of sealing work, it is necessary to determine which measures are to be carried out, which organisation shall perform them, and which resources will be made available for this purpose.

For the period after sealing, administrative precautions should be implemented to ensure, as effectively as practically possible, that no human activities which could endanger the permanent containment of the waste are carried out in the vicinity of the final repository. Furthermore, these measures should be designed in such a way that they remain effective for as long as possible in the future.

10. Documentation

10.1. All data and documents relevant for the safety statements and for future assessments and decisions must be documented prior to completion of decommissioning. In particular, this shall include:

- The mine survey data for the final repository, including its historical development
- All relevant information regarding the individual waste stored, including its safety-relevant properties
- Planned and executed technical measures during the construction, emplacement operations and decommissioning of the final repository
- The results of all measurement programmes
- All forecasts made regarding developments in the repository mine and its environment
- All records kept regarding operational safety and long-term safety.

All partial documentation shall, as a minimum requirement, include the relevant events, data and results, the underlying assumptions and framework conditions, documentation of the calculation programs used, and a description of how the results were obtained.

The documentation shall be updated at regular intervals, whereby out-of-date partial documents shall be left in a suitable format as part of the document set.

Regarding the manner and location of storage, care shall be taken to ensure that all document sets are readily accessible at all times using the currently available technology. The principle of diversity must be observed.

10.2. For the period after sealing the final repository, prior to decommissioning, regulations shall be adopted concerning the scope, preservation and accessibility of the documentation to be held on file by the Federal Government by arrangement with the licensing authority. The documentation to
be held on file after sealing the final repository must contain all data and
documents from the documentation updated during the operating phase which
could contain relevant information for future generations. In particular, this
should include information regarding the area surrounding the repository mine
that must be protected from human intervention in the deep subsoil, and which
types of intervention must be subject to special conditions.

Complete sets of documents must be stored in at least two different suitable
locations.