Note:
This is a translation of the ESK recommendation entitled “Anforderungen an Endlagergebinde zur Endlagerung Wärme entwickelnder radioaktiver Abfälle”.
In case of discrepancies between the English translation and the German original, the original shall prevail.

E S K

RECOMMENDATION of the Nuclear Waste Management Commission (ESK)

Requirements for packages for the disposal of heat generating radioactive waste

CONTENTS

0 Preamble

The NUCLEAR WASTE MANAGEMENT COMMISSION (ESK) considers it necessary to define in more detail the regulatory requirements relating to waste containers for the disposal of heat-generating radioactive waste set out in the Safety Requirements of the BMU of 2010 [1]. Although essential parts of the container requirements depend on the site of the disposal facility, the host rock and the disposal concept, basic requirements for disposal packages can be specified such that they can be developed iteratively. The ESK considers this recommendation to present basic aspects for the future development of a more specific “container guideline”. Annex A1 provides a definition of terms, Annex A2 lists the various regulatory requirements, and Annex A3 gives examples of the requirements for waste packages from disposal projects in crystalline rock (Finland), in clay (Switzerland) and in salt (Germany).

1 Role of the disposal packages for heat-generating radioactive waste as an engineered barrier in the disposal system

According to the Safety Requirements of the BMU [1], the objectives of disposal are

- the safe containment of the waste,
- the prevention or hindrance of radionuclide releases and the retardation of significant radionuclide migrations, respectively,
- ensuring that in the long term unavoidable radionuclide releases will not lead to an increased risk for man and the environment, and
- taking precautions against the possibility of inadvertent human intrusion to the emplaced waste and the related impacts.

According to [1], heat-generating radioactive waste should be disposed of safely in deep geological formations with a high containment capacity. “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” ([1] Section 8.7). To implement this safety requirement, safety concepts are developed which take into account the site conditions, in particular the host rock properties, as well as the properties of the radioactive waste to be disposed of.

The disposal concepts currently developed in the various disposal programmes for heat-generating radioactive waste are based on the principle of the multi-barrier system (defence in depth). All disposal concepts for heat-generating radioactive waste intend to use the disposal package as a barrier of the disposal system. In order to meet the above-defined objectives of disposal both in the operating phase (including the closure phase) and in the post-closure phase, this barrier has to fulfil specific requirements, depending on the host rock and the disposal concept. Regarding the backfill, a distinction is to be drawn for the post-closure phase between a transitional phase and a stationary long-term phase. In the transitional phase, the geotechnical barriers develop their barrier effectiveness, and the long-term phase begins when hydraulically reaching full effectiveness of the backfill, such as crushed salt or bentonite, as well as of the closure systems.

Two basic safety concepts have to be distinguished whose impacts on the disposal concept and, in particular, on the requirements for the disposal packages are considerable:

In case of disposal in sedimentary rocks (clay and salt), in the long-term phase, barrier effectiveness mainly relies on the host rock together with the geotechnical barriers (principle of the containment-providing rock zone (CPRZ)). In these disposal concepts, the system consisting of backfill, sealings and host rock takes over the barrier function of containment and the protective function of the disposal packages after a transitional phase. The transitional phases determine the required lifetimes of the disposal packages during which containment of the radioactive waste must be ensured, i.e. integrity of the disposal packages must be given. For drift emplacement in salt formations, the transitional phase is up to 1,000 years and for clay several thousand years. For disposal in boreholes, these periods are shorter. Beyond the transitional phase, i.e. in the stationary long-term phase, no requirements are made for the disposal packages.

As regards disposal in crystalline rock, sufficiently effective containment by the host rock in combination with the geotechnical sealing system cannot be achieved due to the properties of the host rock and the site conditions to be expected in Germany. Accordingly, the disposal packages must ensure safety over the entire assessment period of one million years. This means that in particular the requirements regarding containment and integrity of the disposal packages must be met over the entire assessment period.

Depending on the disposal concept, different concepts of the disposal packages as engineered barrier are being planned. These must take into account all requirements that must be fulfilled by the engineered barrier during the respective phases. To meet the requirements, the disposal package can be designed, for example, as an integrally acting container (e.g. Pollux cask) or as a modular concept to distribute the requirements to several technical components, as is the case regarding the disposal of canisters in cased boreholes. The requirements to be met during operational processes (reloading, transport, emplacement) can be fulfilled by the disposal package (e.g. Pollux) itself or, otherwise, by shielding casks for on-site transport (transfer containers), depending on the disposal concept.

The disposal package consists of

a the waste package comprising the waste and the waste container, and

b the outer casing, which serves to maintain integrity over a defined period of effectiveness. It must allow retrievability during the operating phase and recoverability for a period of 500 years after emplacement.

The disposal package as engineered barrier for heat-generating radioactive waste has to fulfil the following basic functions in the system of multi-level barriers:

1 waste reception,

2 containment of the radioactive waste, prevention of radionuclide releases and maintenance of the containment properties of the required effective period of the barrier,

3 ensured fulfilment of the requirements from operational radiation protection,

4 compatibility with other barriers,

5 transfer of decay heat to the environment,

6 maintenance of structural integrity and maintenance of handleability in the different phases (in terms of stability and strength of the outer cover) during all on-site operations, including retrieval in the operating phase and recovery over a period of 500 years after emplacement in order to fulfil the requirements according to [1].

Technically, the disposal package can be of modular or integral design:

- In the case of the **modular** solution (Figure 1 (above)), the basic functions are fulfilled by various technical components. For example, the current concept of emplacement of canisters in vertical boreholes includes separate technical components each having different basic functions. The canister, for example, consisting of the waste container and the waste, performs functions 1 and 2. In this concept, the canister represents the waste package. After emplacement in the borehole, integrity of the canister is maintained by means of an appropriately designed borehole casing, backfilling of the annular space between the outer surface of the canister and the inner wall of the casing as well as borehole sealing. The modular system of waste package (canister), backfill, casing and borehole sealing represents the disposal package. The requirement of compatibility with other barriers of the disposal system and the removal of decay heat relates to all components of the disposal package. This concept is due to the requirement of retrievability of the waste packages according to [1]. The modular solution may require a transfer container to ensure the handleability of the waste package, compliance with the radiation protection requirements and the integrity of the waste packages during on-site operations.

- In the case of the integral solution (Figure 1 (below)), all basic functions are fulfilled by a single technical component, the disposal package. For example, existing drift emplacement concepts in rock salt include integrally acting packages (e.g. Pollux), which are intended to fulfil all of the above-mentioned basic functions 1 to 6.

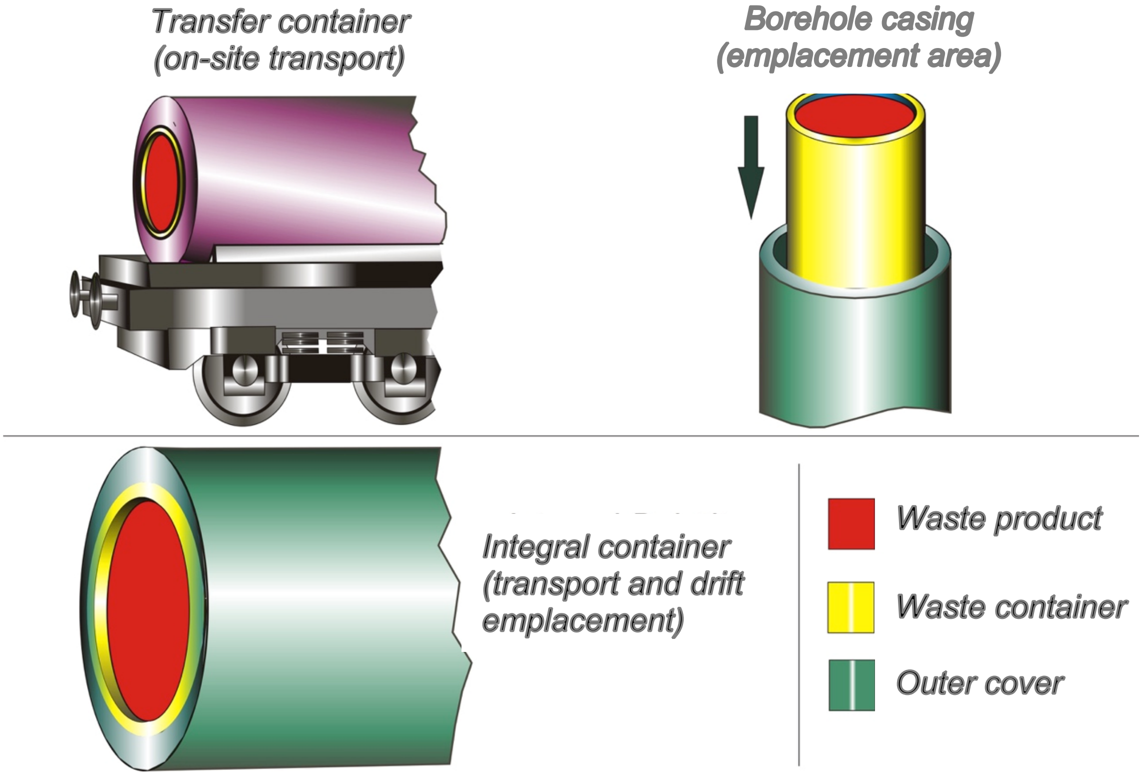

Figure 1: Modular (above) and integral (below) design of a disposal package

Based on these basic functions in the overall barrier system as well as those defined for the design of the barrier effectiveness, the main requirements for the disposal packages and their technical components can be formulated qualitatively, which in turn can be used to derive some quantitative more specific requirements. The requirements are implemented with the development of a disposal concept, the effectiveness of which is demonstrated by means of safety analyses. In this planning step, the required properties for the disposal package and its technical components are determined and the concept for the engineered barrier is drawn up. The detailed design depends on the disposal concept pursued, which in turn depends on the site conditions, i.e. the selected host rock, its properties and the geological conditions at the site as well as the safety concept based thereon. Examples of how the requirements have been implemented by way of example in various disposal programmes are given in Annex A3 for the host rocks crystalline, clay and salt.

In order not to limit future technical developments of disposal packages unnecessarily, only the basic qualitative requirements for disposal packages and their technical components are listed below.

2 Requirements for disposal packages for heat-generating radioactive waste

2.1 General requirements

The first step towards the development and design of disposal packages and their technical components is the determination of the basic and general requirements that must be met by the engineered barrier during its effective periods. Both the requirements in [1] and the Safety Standards Series No. SSR-5 [2] of the IAEA formulate general requirements for the disposal packages during the phases of the disposal process, which are largely independent of the host rock and disposal concept (see Annex A2). In addition, there are also host rock specific requirements for the disposal packages, in particular regarding the period for which certain properties must be ensured.

The detailed design for compliance with all requirements must be made step by step according to the progress of search for and selection of a site.

In the following, the general requirements for disposal packages and their technical components are derived from the regulatory provisions for compliance with the safety objectives and from the fundamentals on safety and safety demonstration concepts for implementing the safety principles. Based on the safety concept, the disposal concept is developed which includes the modular or the integral solution for the disposal packages. Disposal takes place in time sequences (operating phase and post-closure phase) with different processes and developments of the disposal system. From the disposal concept and the time sequences it follows that these processes and developments determine the stage-dependent general requirements which have to be fulfilled in both disposal package concepts by different components, for example in the modular concept by the waste package and in the integral concept by the disposal package.

When deriving the requirements, an explicit distinction between disposal concepts with modular or integral disposal packages is no longer made. Instead, the term waste package/disposal package is representatively introduced for the assignment of the requirements.

Both the operating phase and the post-closure phase include phases for processes and developments for which specific general requirements must be defined for waste packages/disposal packages. These phases of disposal are:

- the operating phase
  - loading and transport on site,
  - emplacement and backfilling of the underground emplacement areas, and
  - phase until final closure of the disposal facility (period of required retrievability of the waste packages/disposal packages);

- post-closure phase
  - period of 500 years during which recoverability must be ensured,
  - transitional phase: period depending on the host rock until the geotechnical system assumes the barrier function, and

- stationary long-term phase until the end of the assessment period.

Table 2.1 presents the specific general requirements for waste packages/disposal packages (representative for disposal concept with modular/integral disposal package).

Table 2.1: General requirements for waste packages/disposal packages in different phases of disposal

	Operating phase		**Post-closure phase**		
Requirements for the waste packages/disposal packages according to the conditions of the respective phase	**Loading and transport emplacement backfilling**	**Phase until closure**	**Phase of recoverability**	**Transitional phase****)	**Assessment period after transitional phase****)
Containment of the radioactive waste*)	**X**	**X**	**X**	**X**	
Structural integrity of the waste packages/disposal packages*)	**X**	**X**	**X**	**X**	
Exclusion of criticality	**X**	**X**	**X**	**X**	***)
Compliance with waste acceptance criteria	**X**				
Handleability (e.g. dimensions, mass, transportability, temperature, ionising radiation)*)	**X**	**X**	**X**		
Handleability for loading of the waste packages/disposal packages	**X**				
Shielding of ionising radiation	**X**	**X**			
Retrievability of the waste package/disposal packages	**X**	**X**			
Recoverability of the waste packages/disposal packages (handleability)	**X**	**X**	**X**		
Temperature limitation of the waste packages/disposal packages	**X**	**X**	**X**	**X**	
Labelling of the waste packages/disposal packages	**X**	**X**	**X**		
Compatibility of the disposal package with the barriers of the disposal system	**X**	**X**	**X**	**X**	**X**

*) Different requirements apply in the different phases.

**) These phases coincide for disposal concepts in crystalline rock.

***) Criticality safety is to be ensured in all phases. This, however, is no specific requirement for the containers within the assessment period after the transitional phase.

The general requirements for the waste packages/disposal packages (Table 2.1) are largely formulated in a manner independent of the host rock as well as of the disposal concept. Insofar as it is possible without prior determination, derived requirements are formulated on the basis of these requirements and the contribution to be made by the waste packages/disposal packages to meet the safety objectives for the respective phases of disposal.

Tables 2.2 and 2.3 present the general requirements and derived requirements, which are annotated, for the phases of the disposal facility development process. Table 2.4 shows the requirements for design and manufacture.

2.2 Requirements resulting from the operating phase

Table 2.2: Requirements for waste packages/disposal packages for the operating phase

General requirement	Derived requirements	Note
Integrity of the waste packages/disposal packages (containment of the radioactive waste)	- The system waste package/disposal package must ensure containment of the radioactive waste in all phases of disposal operation. - The system waste package/disposal package must be gas-tight. - The integrity of the waste packages/disposal packages must also be ensured after operational events (failures and design basis accident impacts).	- possibly in combination with a transfer container
Handleability	- The waste packages/disposal packages must ensure safe handling (e.g. reloading, emplacement) and safe on-site transport (e.g. transport to the shaft, transport through the shaft, transport to the emplacement area) and emplacement. In this respect, their dimensions, their weight and their design are of particular importance. - The handleability of the waste	Depending on the type of disposal concept, shielding transfer casks may be required which must meet the requirements resulting from handleability.

General requirement	Derived requirements	Note
	packages/disposal packages must also be ensured after operational events (failures and design basis accident impacts).	
Shielding of the ionising radiation	- The system waste package/disposal package must be designed such that the radiation protection conditions are fulfilled.	Depending on the concept, shielding transfer casks could be used.
Retrievability of - waste packages in the modular concept - the disposal packages in the integral concept for a given period of time	- The concept of the system waste package/disposal package must be such that it will be retrievable during the operating phase of the disposal facility. This requires, in particular, its handleability during the period mentioned. - The system waste package/disposal package must be gas-tight. - Measures for retrievability must not impair long-term safety.	The applicant has to submit a concept on feasibility of retrieval. Measures to ensure retrievability must not impair long-term safety. The special structural requirements for the waste packages/disposal packages and the technical equipment used for retrieval (e.g. claws, attachment devices, load gripping devices) are derived from the retrieval concept. In [3], the possibilities of retrieval were conceptually discussed for two disposal concepts.
Loading of the waste packages/disposal packages	- The waste packages/disposal packages must be designed such that their loading with waste and reloading of waste can take place safely and as simply as possible.	

2.3 Requirements resulting from the post-closure phase of the disposal facility

Table 2.3: Requirements for disposal packages for the post-closure phase

General requirement	Derived requirements	Note
Containment of the radioactive waste in the disposal packages	- The disposal packages must have the containment properties specified in the safety concept for their respective effective periods.	Concretisation of the containment properties of the packages and their required effective periods result from the site conditions and the disposal concept and are determined in safety analyses.
Maintenance of structural integrity of the disposal packages	- For the period during which the disposal packages must have the required containment properties, they must be designed against internal and external hazards such as to ensure their integrity. - The design of the disposal packages and their subsystems (e.g. waste packages, welding seams, sealing systems, residual stresses) must be carried out according to recognized standards such that integrity can be reasonably substantiated over the required period.	Concretisation of the periods of effectiveness results from [1] on the one hand and, on the other hand, from the safety analysis. - [1] Section 8.6 requires recoverability for a period of 500 years during which the release of radioactive aerosols is to be avoided. - According to [1] Section 7.2.3, the package is a barrier that must be immediately effective. The duration of effectiveness to be required depends on the periods during which the other barriers of the disposal system become effective (e.g. in salt a few hundred to a thousand years until tight containment through the rock salt, in clay several thousand years, and in crystalline rock over the entire assessment period). - For the proof of integrity, [1] Section 7.2.3 requires to take into account the stress conditions and the ageing conditions of the engineered barriers.

Temperature limitation	- The disposal packages must be designed such that • the maximum permissible temperature of the host rock and the backfill are not exceeded, and • the maximum permissible inventory and component temperatures are not exceeded.	[1] Section 7.2.1 stipulates to prevent inadmissible negative influences on barrier effects, in particular of the CPRZ, by temperature developments (e.g. disposal packages and backfill). This requirement shall also be applicable to the interaction of barriers.
Limitation of negative physicochemical influences of the disposal package on the barriers of the disposal system	- The disposal packages must not have inadmissible negative effects on the barriers of the barrier system (e.g. on salt or bentonite backfill).	This requirement must be implemented by the disposal concept. Concretisation takes place, inter alia, by safety analyses and concerns e.g. the limitation of the surface temperature of the packages (current state of discussions: approx. 200 °C for salt, approx. 100 °C for clay, and approx. 100 °C for crystalline rock), the limitation of the temperature at the sealing structures as well as the interactions between the package and the material selection: minimisation of the physicochemical reactions between waste packages/disposal packages (welding seams, etc.) and the backfill material and host rock, gas formation and gas pressure build-up.
Use of appropriate materials	- The disposal package must be made of materials that can ensure containment and integrity under the internal and external loads of the disposal facility (e.g. corrosion, thermal, hydraulic, mechanical and chemical loads). - Materials are to be used which, with a view to possible gas generation, are not expected to pose a threat to the integrity of the barriers.	
Recoverability of the waste for a period of 500 years	- The waste packages/disposal packages must be designed such	This requirement from [1] Section 8.6 can be implemented differently,

after closure	that their structural integrity will be maintained for a period of 500 years. - The waste packages/disposal packages to be retrieved must be designed such that releases of radioactive aerosols during recovery can be prevented. - Measures to ensure recoverability must not have inadmissible impacts on long-term safety.	depending on the disposal concept.
Exclusion of criticality	- The waste packages/disposal packages must be designed such that criticality of the inventory is excluded over the entire assessment period.	This requirement from [1] Section 7.2.4 is implemented by an appropriately designed disposal concept and requirements for the waste packages/disposal packages. Concretisation takes place by safety analyses.
Labelling of the waste packages/disposal packages	- The waste packages/disposal packages must be labelled to ensure clear identification in the case of recovery.	

2.4 Requirements for design and manufacture

Table 2.4: Requirements for waste packages/disposal packages in terms of design and manufacture

General requirement	Derived requirements	Note
Waste acceptance requirements for disposal	- The system waste package/disposal package must comply with the waste acceptance requirements for disposal. - The system waste package/disposal package and its documentation must allow verification of compliance with the waste acceptance requirements for disposal.	The waste acceptance requirements for disposal can only be defined for a specific disposal facility (host rock, disposal concept). They essentially determine the properties and characteristics of the packages for disposal (type of waste, waste form, conditioning, amount of waste per package, activity, etc.) [1] Section 7.5 and Section 7.6.
Design of the waste packages/disposal packages	- The waste packages/disposal packages must be designed such as to comply with the waste acceptance criteria for disposal and with the requirements resulting from the requirements in terms of long-term safety and operation (in case of modular design, the latter only applies to the disposal package).	The properties relevant for disposal to be considered in the design are: - permissible total activity/waste package - activities of relevant radionuclides per waste package, - criticality safety (quantity of fissile material, absorber, moderator, fissile material distribution), - - thermal package properties, - dose rate at the package, - surface contamination, - quality requirements, - mass to be handled, - ensuring compliance with the requirements from the safety analyses.
Proof of quality	- Proof must be provided that the disposal package has been manufactured with the required quality.	See [1] Section 7.2.3

General requirement	Derived requirements	Note
Labelling	- The waste packages/disposal packages must be provided with a clear, distinctive and permanent labelling for the period of recoverability of 500 years.	The labelling must not have a negative influence on the fulfilment of other safety-relevant requirements.

3 References

[1] Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU):
Sicherheitsanforderungen an die Endlagerung wärmeentwickelnder radioaktiver Abfälle.
Bonn, Stand: 30. September 2010

[2] Disposal of Radioactive Waste for protecting people and the environment
Specific Safety Requirements; No. SSR-5, 2011

[3] Vorläufige Sicherheitsanalyse fur den Standort Gorleben
Endlagerkonzepte
Bericht zum Arbeitspaket 5
GRS 2011

A 1 Terms and definitions

Assessment period *(in the English version of [1] referred to as "reference period")*	For the assessment period, long-term safety is to be demonstrated [1].
Barrier	Barriers are natural or technical components of the disposal system. Examples of barriers include waste matrices, waste containers, room and shaft sealing structures, the containment-providing rock zone (CPRZ), and the geological strata surrounding or overlying the CPRZ. 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 inflow of liquids to the waste, or protecting the containment-providing rock zone from erosion, may be classed as safety functions. Elements of the disposal system which merely serve to distribute or dilute the substances released from the waste are not referred to as barriers [1].
Containment	Containment refers to a safety function of the disposal 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 where it is emplaced, and at best, minimal defined quantities of material are able to leave that rock zone [1].
Containment-providing rock zone *(in the English version of [1] referred to as "isolating rock zone")*	The containment-providing rock zone is part of the disposal system which, in conjunction with the technical seals (shaft seals, room seals, dam structures, backfill, …), ensures containment of the waste [1].
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 [1].
Decommissioning	Decommissioning comprises all measures implemented following the cessation of waste emplacement operations, including sealing of the disposal facility in order to create a maintenance-free state which guarantees the long-term safety of the disposal facility. Decommissioning may include measures carried out during the operating phase (e.g. sealing structures for filled emplacement rooms) [1].

Disposal package	The disposal package is an engineered barrier component of the disposal system, consisting of waste container and, where provided, shielding. After emplacement, the disposal package ensures compliance with the related requirements resulting from the remaining operating phase and the post-closure phase. The components of the disposal package meet specific requirements depending on the disposal concept. Examples: In the case of emplacement of canisters in cased boreholes, the requirements are distributed to the waste container, the backfill, the casing and the borehole sealing. In the case of drift emplacement of integrally acting containers (e.g. Pollux), these fully meet the set requirements.
Disposal system *(in the English version of [1] referred to as "repository system")*	The disposal system consists of the repository mine, the containment-providing 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 [1].
Integrity	The term integrity refers to the maintenance of the containment capacity of the containment-providing rock zone of a disposal facility [1].
Long-term safety	Long-term safety refers to the condition of the disposal facility for which related safety requirements are to be met following its decommissioning [1].
Operating phase	The operating phase begins with the emplacement of the waste in the disposal facility and ends with the final sealing of the shafts and the dismantling of the above-ground facilities within the framework of decommissioning [1].
Post-closure phase	The post-closure phase begins following completion of the decommissioning work [1].
Recovery of radioactive waste	Recovery is referred to as the retrieval of radioactive waste from the disposal facility as an emergency measure [1].
Retrievability	Retrievability refers to the planned technical option for removing emplaced waste packages/disposal packages from the repository mine [1]. Note: [1] requires that retrieval must be possible during the operating phase until sealing of the shafts or ramps.
Robustness	Robustness refers to the reliability, quality and hence insensitivity of the disposal system's safety functions and its barriers against internal and external influences and failures, as well as to the robustness of the results of the safety analysis against deviations from its underlying assumptions [1].

Safety function	A safety function is a property or process occurring in the disposal system which guarantees compliance with safety-related requirements in a safety-related system or sub-system or individual component. The combined action of such functions ensures compliance with all safety-related requirements, both during the operating phase and the post- closure phase of the disposal facility [1]. Note: Safety functions may be required for a limited time (example: gas tightness of waste containers).
Structural integrity of the disposal package	Maintenance of the required properties of the disposal package for the duration of its effective period, taking into account the internal and external effects acting on it (handling operations during the operating phase, during emplacement, retrieval, recovery, transitional phase).
Transfer container	The transfer container is used for transport of the waste packages/disposal packages within the facility and shielding against ionising radiation. In the case of the integrally acting disposal package, handleability and on-site radiation protection are inherent. For a waste package, a shielded transfer cask may be required on site.
Waste container	Container for the containment of waste.
Waste package	Unit consisting of the waste and the waste container. The requirements for the waste package result from the respective disposal concept. In a disposal concept in which the waste package has to fulfil the requirements from the operational and the post-operational phase integrally, the waste package is identical to the disposal package.
Waste, heat-generating radioactive	Heat-generating radioactive waste is characterised by high activity concentrations and thus by high decay heat, which involves specific requirements for a disposal facility (disposal in deep geological formations, use of shielded transport containers within the facility, application of special emplacement techniques, thermal design of the repository mine). This includes, in particular, waste in the form of spent fuel as well as vitrified fission product concentrates (possibly vitrified together with feed sludges) and supercompacted hulls and structural parts from reprocessing of spent fuel. In accordance with § 3(2)1a of the Radiation Protection Ordinance (StrlSchV), these are radioactive substances as defined in § 2(1) of the Atomic Energy Act (AtG), which, according to § 9a AtG, are to be disposed of in a regulated manner as radioactive waste [1].

A 2 Regulatory requirements

Safety requirements for the disposal of heat-generating radioactive waste [1]

[1] defines direct requirements for waste, waste packages and waste containers. Furthermore, indirect requirements can be derived from [1] for waste packages. These are as follows:

A: Direct requirements for waste packages

- *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 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.*

- *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.

B: Indirectly derived requirements for waste packages

- According to the definition of the term barrier, the waste containers represent an engineered barrier ([1] Chapter 2).

- *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.

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

- *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.*

- *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.*

Disposal of Radioactive Waste requirements No. SSR-5 Specific Safety Requirements [2]

- *2.11. No releases of radionuclides, or only very minor releases (such as small amounts of gaseous radionuclides), may be expected during the normal operation of a radioactive waste disposal facility and hence there will not be any significant doses to members of the public. Even in the event of an accident involving the breach of a waste package on the site of a disposal facility, releases are unlikely to have any radiological consequences outside the facility.*

- *3.33. Requirements are established in this section for ensuring that there is adequate defence in depth, so that safety is not unduly dependent on a single element of the disposal facility, such as the waste package; or a single control measure, such as verification of the inventory of waste packages; or the fulfilment of a single safety function, such as by containment of radionuclides or retardation of migration; or a single administrative procedure, such as a procedure for site access control or for maintenance of the facility.*

- *3.42. Containment is most important for more highly concentrated radioactive waste, such as intermediate level waste and vitrified waste from fuel reprocessing, or for spent nuclear fuel. Attention also has to be given to the durability of the waste form. The most highly concentrated waste has to be emplaced in a containment configuration that is designed to retain its integrity for a long enough period of time to enable most of the shorter lived radionuclides to decay and for the associated generation of heat to decrease substantially. Such containment may not be practicable or necessary for low level waste. The containment capability of the waste package has to be demonstrated by means of safety assessment to be appropriate for the waste type and the overall disposal system.*

- *4.37. Fissile material, when present, has to be managed and has to be emplaced in the disposal facility in a configuration that will remain subcritical. This may be achieved by various means, including the appropriate distribution of fissile material during the conditioning of the waste and the proper design of the waste packages. Assessments have to be undertaken of the possible evolution of the criticality hazard after waste emplacement, including after closure.*

- *Requirement 20: Waste acceptance in a disposal facility: Waste packages and unpackaged waste accepted for emplacement in a disposal facility shall conform to criteria that are fully consistent with, and are derived from, the safety case for the disposal facility in operation and after closure.*

- *5.1. Waste acceptance requirements and criteria for a given disposal facility have to ensure the safe handling of waste packages and unpackaged waste in conditions of normal operation and anticipated operational occurrences. They also have to ensure the fulfilment of the safety functions for the waste form and waste packaging with regard to safety in the long term. Examples of possible parameters for waste acceptance criteria include the characteristics and performance requirements of the waste packages and the unpackaged waste to be disposed of, such as the radionuclide content or activity limits, the heat output and the properties of the waste form and packaging.*

- *5.2. Modelling and/or testing of the behaviour of waste forms has to be undertaken to ensure the physical and chemical stability of the different waste packages and unpackaged waste under the conditions expected in the disposal facility, and to ensure their adequate performance in the event of anticipated operational occurrences or accidents.*

- *5.3. Waste intended for disposal has to be characterized to provide sufficient information to ensure compliance with waste acceptance requirements and criteria. Arrangements have to be put in place to verify that the waste and waste packages received for disposal comply with these requirements and criteria and, if not, to confirm that corrective measures are taken by the generator of the waste or the operator of the disposal facility. Quality control of waste packages has to be undertaken and is achieved mainly on the basis of records, preconditioning testing (e.g. of containers) and control of the conditioning process. Post-conditioning testing and the need for corrective measures have to be limited as far as practicable.*

A 3 Requirements for disposal packages in the context of disposal concepts (examples from disposal projects in other countries)

Note: The following examples only serve to describe the state of affairs in different countries. Thus, the terms used cannot be consistent and may differ from those in the preceding part of this recommendation.

Based on the explanations in Chapter 1, the disposal package has to fulfil basic requirements. It is stated that the implementation of the requirements for the disposal package can only be implemented in the context of the disposal concept. After site selection (including selection of the host rock), a disposal system, consisting of the site conditions and the technical components of the disposal facility, is developed which can ensure the required safety and whose components and subsystems have to fulfil specific safety functions. The disposal package represents an engineered barrier within the disposal concept.

However, the requirements for the disposal packages are determined to a large extent by the disposal concept, which in turn depends on the selection of the host rock. In the respective disposal concepts, the disposal packages take on a specific role. Their development and design must take into account the boundary conditions resulting from the site conditions (e.g. host rock and its characteristic properties, groundwater supply, groundwater chemistry) and from the disposal concept (e.g. engineered barrier system such as disposal package, backfill and sealing systems, depth of emplacement, integral or modular solution, emplacement in drifts or boreholes) in order to fulfil their task as a barrier (see Figure A 3.1). The disposal concept and the boundary conditions largely determine the specific design requirements for the disposal packages. This means that the requirements for the disposal packages can only be implemented in the context of the disposal concept.

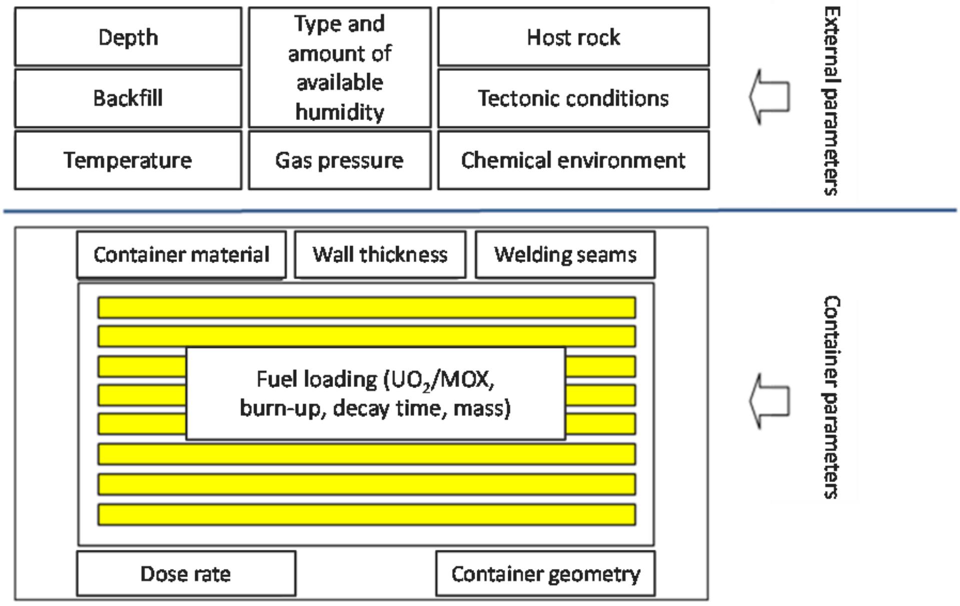

Figure A 3.1: Parameters influencing container integrity (source: [A1])

Examples of the implementation of the requirements for disposal packages are presented below. For this purpose, reference is made to documents that have been prepared for different host rocks and disposal concepts in the context of waste management concepts in other countries. In most waste management programmes in other countries, container designs are presented; final specifications have not been made. Nevertheless, the container designs show what consequences result from the implementation of the requirements regarding the design of the disposal packages

The examples presented are limited to container designs for the management of spent fuel from light water reactors and do not address the large number of container types for other waste streams. Thus, the following examples give a rough overview of the consequences of the implementation of the requirements for the disposal packages. The container types considered and their dimensions are summarised in Table A 3.1.

A 3.1 Requirements for disposal packages (integral solution)

After selection of the host rock and a disposal concept, the implementation of the requirements for the disposal packages is influenced, in particular, by the determination of their lifetimes and the emplacement depth as well as the mechanical and geochemical conditions prevailing at this depth.

A 3.1.1 Determination of container lifetime, containment of radioactive waste in the disposal package

Integrity of the disposal packages

The specification of the container lifetime is based on the course of interaction of the technical and geological barrier systems over time. In the disposal concepts for the host rocks clay and salt, the system consisting of backfill, sealings and host rock takes over the barrier function of the containment and the protective function of the disposal package. The transitional periods determine the package lifetimes required during which the containment of the radioactive waste must be ensured, i.e. the integrity of the disposal package must be given. In the case of the crystalline host rock, the barrier function must primarily be ensured by the disposal package in combination with a bentonite backfill. This leads to the following package lifetimes in the disposal concepts:

- Disposal project with the host rock crystalline (Finland)
  - The lifetime of the disposal packages is 100,000 years.

- Disposal project with the host rock Opalinus clay (Switzerland)
  - The lifetime of the disposal packages shall be at least 1,000 years.

- Disposal project with the host rock salt (Germany)
  - The lifetime of the disposal packages should be up to 1,000 years.

A 3.1.2 Requirement: temperature limitation

The type of host rock or backfill selected results in limitations regarding the maximum permissible temperature in the host rock.

Maximum container surface temperature:

- Disposal project with the host rock crystalline (Finland) 100 °C
- Disposal project with the host rock Opalinus clay (Switzerland) 100 °C
- Disposal project with the host rock salt (Germany) 200 °C

A 3.1.3 Requirement: exclusion of criticality

The loading of the disposal packages and the configuration of the spent fuel assemblies in the package must ensure that criticality is reliably prevented.

The effective neutron multiplication factor k_{eff} is used as an indicator for demonstrating exclusion of criticality that indicates the ratio of the number of neutrons generated in a nuclear fission process to the number of neutrons existing before this process. Criticality can be excluded with a value of $k_{eff} \leq 0.95$.

A 3.1.4 Requirements: design of the disposal packages, integrity, use of appropriate materials, compatibility with other packages of the disposal system

The implementation of the essential requirements, i.e. containment of the radioactive waste and integrity for the period of containment defined according to the respective disposal concept, leads in combination with the respective characteristic site conditions – such as the host rock (crystalline, clay, salt), depth of emplacement (mechanical load, hydrochemical environmental conditions (corrosion) – to thick-walled containers made of steel or cast iron for absorbing the mechanical forces. These are, for example, isostatic load, shear load, and load caused by swelling of the rock and the backfill on the disposal package.

In order to minimise corrosion, a corrosion-resistant steel or grey cast iron, adapted to the site conditions (e.g. groundwater chemistry), is provided for the disposal container. Depending on the disposal concept, corrosion is counteracted by corrosion allowances in selecting container wall thicknesses or providing the container with a corrosion-resistant overpack (for example copper). The compatibility of the corrosion products, which may go into solution, with other barriers of the barrier system is taken into account.

The implementation of the above requirements leads, for example, to the following container dimensions:

- **Disposal project with the host rock crystalline (Finland)**

Loading with 4 PWR fuel assemblies or 12 BWR fuel assemblies

- Container diameter 1.05 m, container length 4.835 m
- Wall thickness of the grey cast iron container 49 mm
- Wall thickness of the copper container 60 mm
- Thickness of container lid 50 mm
- Use of “full penetration welding” methods for the lid

Figure A 3.2: Components of a BWR disposal container (source: [A2])

- **Disposal project with the host rock Opalinus clay (Switzerland)**

Loading with 9 BWR or 4 PWR fuel assemblies

- Container diameter 1.05 m, container length 5.30 m
- Wall thickness of the steel container 140 mm
- Thickness of container lid and base 140 mm and 180 mm, respectively
- Use of “full penetration welding” methods for lid and base

Figure A 3.3: Disposal package (source: [A3])

- **Disposal project with the host rock salt (Germany)**

The double-shell Pollux cask shown in Figure A 3.4 with inner and outer container represents a conceptual development for which a prototype cask was manufactured. The type approval procedure has not been completed.

Loading exclusively with fuel rods of either 10 PWR or 30 BWR fuel assemblies (without structural parts)

- Container diameter 1.56 m, container length 5.517 m
- Wall thickness of the cast iron outer container 274 mm and the steel inner container 161 mm

- Sealing system consists of a screw-fitted primary lid with a thickness of 318 mm and a welded secondary lid of the inner container with a thickness of 60 mm. The screw-fitted 168 mm thick lid of the outer container is optionally weldable.
- Thickness of container lid and base 140 mm and 180 mm, respectively
- Use of “full penetration welding” methods for the lid of the inner container

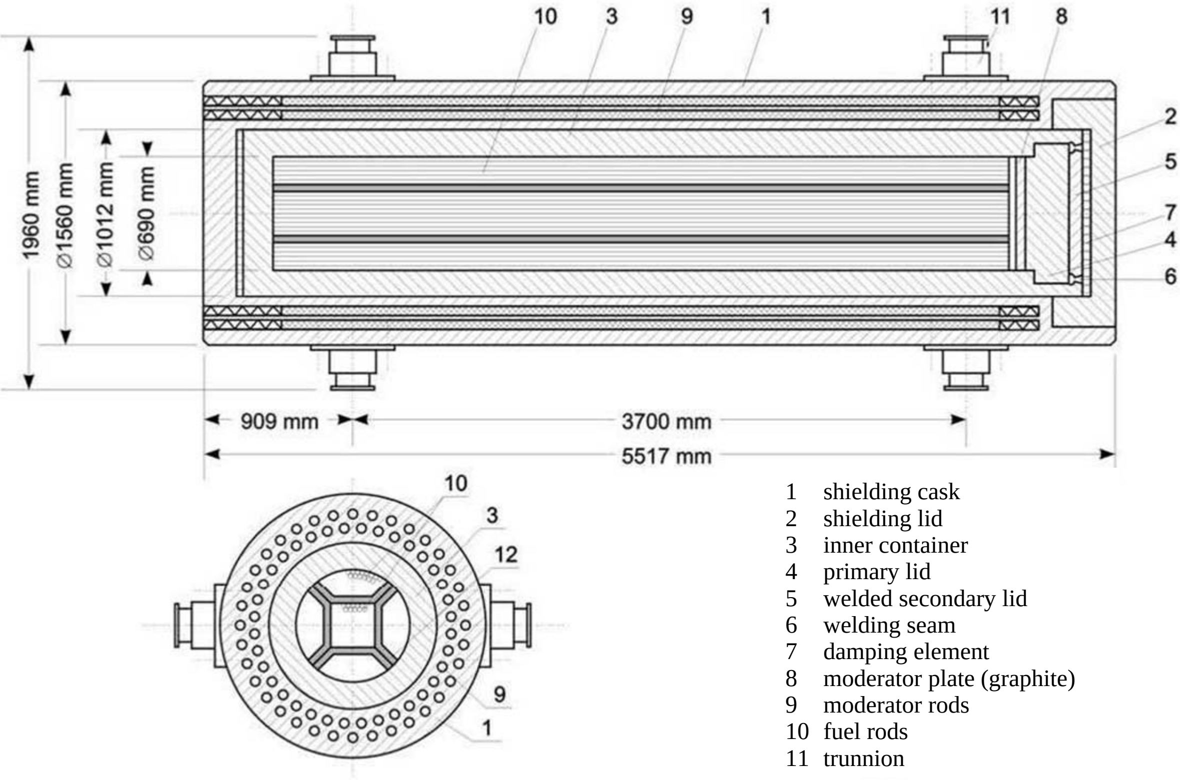

Figure A 3.4: Pollux cask (source: [A4])

A 3.1.5 Requirements: handleability (operation, retrievability, recoverability)

In the various disposal projects, the requirements for handleability during operations (loading and transport) as well as for retrievability and recoverability are implemented with different concepts.

- **Disposal project with the host rock crystalline (Finland)**

The disposal package must be designed in such a way that all handling operations can be carried out safely. In particular, the integrity of the package must be maintained after loading and sealing the disposal package during and after the handling operations.

It is required that the disposal packages must meet the requirements regarding retrievability during the operating phase for approx. 50 years. The lifting device must therefore be designed for the corresponding period. The design is based on the handling operations and the resulting loads. The analyses show that the loads caused by handling operations do not endanger the integrity of the package. The attachment device for coupling with the lifting device and for lowering down to the disposal position is located in the lid of the disposal package (Figure A 3.5).

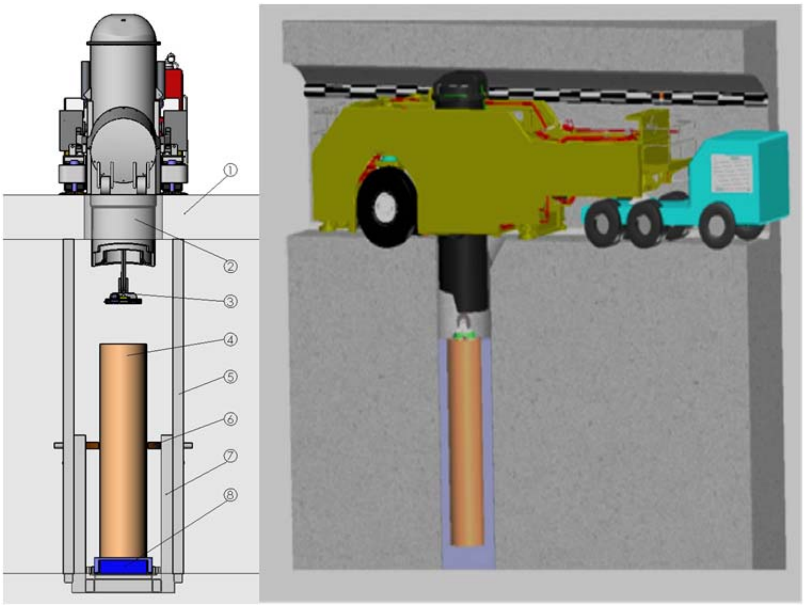

Figure A 3.5: Lifting device/emplacement device (source: [A2])

- **Disposal project with the host rock Opalinus clay (Switzerland)**

In the lid and in the base, hubs are provided as attachment points into which the lifting device engages for lifting or retrieval of the disposal container. The design of the lid and the base must take into account the loads resulting from handling operations (Figure A 3.6).

Figure A 3.6: Lid/base system for attachment of the gripping devices (source: [A3])

- **Disposal project with the host rock salt (Germany)**

The structural design and the material selection of the Pollux cask (Figure A 3.7) are such as to ensure that the essential requirements with regard to retrievability in the operating phase can be complied with.

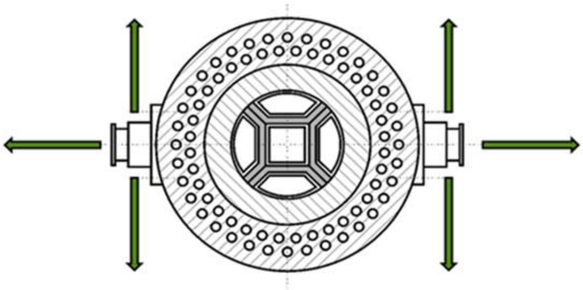

Figure A 3.7: Load attachment points for Pollux casks (source: [A5])

Table A 3.1 below includes examples of container types and the implementation of the requirements for the containers from the respective disposal projects of other countries.

Table A 3.1: Integral containers (examples)

	Crystalline Finland	Clay Switzerland	Salt Germany
Container type	copper container with cast iron container	steel container	inner container made of steel and outer container made of nodular cast iron
Loading	FAs: 4 PWR 12 BWR	9 BWR and 4 PWR FAs	POLLUX®-10/ exclusively fuel rods of 10 PWR FAs or 30 BWR FAs (without structural parts)
Weight	PWR: approx. 26.6 t BWR: approx. 24.6 t	FAs: 22.06 t	56 t (empty weight without shock absorbers)
Dimensions	diameter: 1.05 m length: 4.835 m	FAs: diameter: 1.05 m length: 5.350 m	diameter: 1.560 m width across trunnions: 1.953 m length: 5.517 m
Wall thickness	wall: 49 mm	FAs: 140 mm	inner container: 161 mm outer container: 274 mm
Cover/base	cover/base: 50 mm	FAs: 140/180 mm	primary cover (318 mm) and secondary cover (60 mm) of the inner container made of steel; outer container lid (168 mm) made of nodular cast iron
Outer cover	copper container with wall thickness of 60 mm		see outer container

Lifetime	100,000 years	1,000 (10,000) years	not determined; 1,000 years according to current safety analyses
Criticality safety	$k_{eff} < 0.95$	$k_{eff} < 1$	$k_{eff} < 0.95$
Dose rate container surface	< 1Gy/h	< 1Gy/h	< 0.1 mSv/h gamma, < 0.15/0.25 mSv/h neutrons (ICRP 21/60)
Thermal output	1,700 W	1,500 W per container	8 kW (without cooling fins), 20 kW (with cooling fins)*)
Bentonite buffer around the canister	350 mm thickness	1 m	
*) under interim storage conditions **Design/container integrity**			
• **Compressive stress**	< 15 MPa (7 MPa hydrostatic + 7 MPa bentonite swelling pressure)	vertical 22 MPa horizontal 29 MPa	isostatic pressure of 30-40 MPa
• **Loading caused by overlying ice**	< 37 MPa (hydrostatic pressure + swelling pressure + 3 km ice load)		
• **Inhomogeneous load**	due to uneven swelling pressure distribution in the phase before and after resaturation	horizontal and vertical	
• **Shear stress**	100 mm of the rock asymmetrical axial loads		
• **Thermal stress**	heating and cooling: limitation of expansion/contraction of the copper canister < 3 %		
• **Corrosion external by ground water**	copper: corrosion-resistant for 100,000 years	uniform corrosion 20 mm after 10,000 years local corrosion (pitting) hydrogen embrittlement stress corrosion cracking	
• **Corrosion internal by the atmosphere in the container**	filling with inert gas		
• **Design design limits designed against**		– ductile failure – excessive local plastic deformation – stress cracking – instability	
• **Handling**	top end with shoulder for gripping; design against shear stresses		
• **Design basis accident impact**	drop	drop from 5 m	drop from 5 m

• **Retrieval**	retrieval loads 50 years after emplacement	retrieval loads 50 years after emplacement	
• **Manufacturing defects**	are taken into account	are taken into account	

A 3.2 Requirements for disposal packages (modular solution)

In principle, the modular system must fulfil the same requirements as the integral one. The requirements are implemented according to the individual tasks of the components, such as canister, casing and sealing. While casing and sealing must withstand the mechanical and corrosive loads to protect the canisters, the task of the canisters is the containment of the radioactive waste in the atmosphere of the casing. For this concept, plans have been drawn up and conceptual considerations made. Furthermore, handling operations for loading of casings with containers of real dimensions and masses are demonstrated in experimental facilities.

A 3.3 References

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