Note:
This is a translation of the ESK discussion paper entitled “Diskussionspapier zur verlängerten Zwischenlagerung bestrahlter Brennelemente und sonstiger Wärme entwickelnder radioaktiver Abfälle”.
In case of discrepancies between the English translation and the German original, the original shall prevail.

E S K

DISCUSSION PAPER of the Nuclear Waste Management Commission (ESK)

Discussion paper on the extended storage of spent fuel and other heat-generating radioactive waste

1 Introduction and objective

Against the background of the Site Selection Act (*Standortauswahlgesetz* – StandAG) of July 2013 [1] it is to be expected that the storage periods of up to 40 years assumed so far do not cover the period until commissioning of a disposal facility for spent fuel and other heat-generating radioactive waste. According to the StandAG, the decision on a site for the disposal facility is to be taken by 2031. This is followed by licensing, construction and commissioning, which, according to current experience, is estimated to take at least about 20 years (until about 2050). For a substantial part of the casks to be loaded by about 2027 after shutdown of all nuclear power plants (total of about 1.900[1] casks), storage periods of about 65 to 100 years will be inevitable. The current storage licences expire between 2034 and 2047. Irrespective of this, the period defined in the storage licences is to be seen for a period of 40 years which begins with the sealing of the casks after loading. For the first transport and storage casks, this period will end in 2032. Differences regarding the expiration of the 40-year period between cask and storage facility can for example be due to the circumstance that the cask first had been stored at an interim storage place. The licence holders generally have to provide information on the future whereabouts of the radioactive waste to the nuclear supervisory authority six to eight years before the licence expires. According to current law, § 6 (5) of the Atomic Energy Act (*Atomgesetz* – AtG) [3] applies additionally (quote):

"The storage of nuclear fuel at nuclear plants according to para. (3) in conjunction with para. (1) shall not exceed 40 years starting at the first emplacement of a cask. Licences according to the first sentence may only be renewed on imperative grounds and after it has been discussed in the German Bundestag."

The above storage periods of about 65 to 100 years are significantly beyond the periods already defined nationally and internationally (e.g. Hungary, Japan, USA) for dry cask storage of spent fuel of up to 50 years, see Figure 1 according to [4]. The extension of the licensed storage periods, which will become necessary in Germany in the near future in view of this situation, involves a number of safety issues that were not to be dealt with within the framework of the licensing procedures so far.

According to the German Atomic Energy Act (AtG) [3], all radioactive waste shall be disposed of in deep geological formations within Germany. The objective of disposal in deep geological formations is the safe enclosure of radioactive waste to exclude radiologically relevant releases into the biosphere over periods in the order of one million years [5].

The Nuclear Waste Management Commission (ESK) and many German expert organisations are of the opinion, also in accordance with international statements of the OECD/NEA, IAEA and the EU Directive on the responsible and safe management of spent fuel and radioactive waste adopted in 2011 [6] that ensuring safety of man and the environment without requiring active measures in the future can only be achieved with the disposal of radioactive and especially of high-level radioactive waste in deep geological formations ("passive safety").

[1] According to [2], about 1,100 casks from power reactors, about 291 casks with waste from reprocessing, 461 casks from the experimental and demonstration reactors, 18 casks from research reactors (additionally, 35 casks from research reactors in operation).

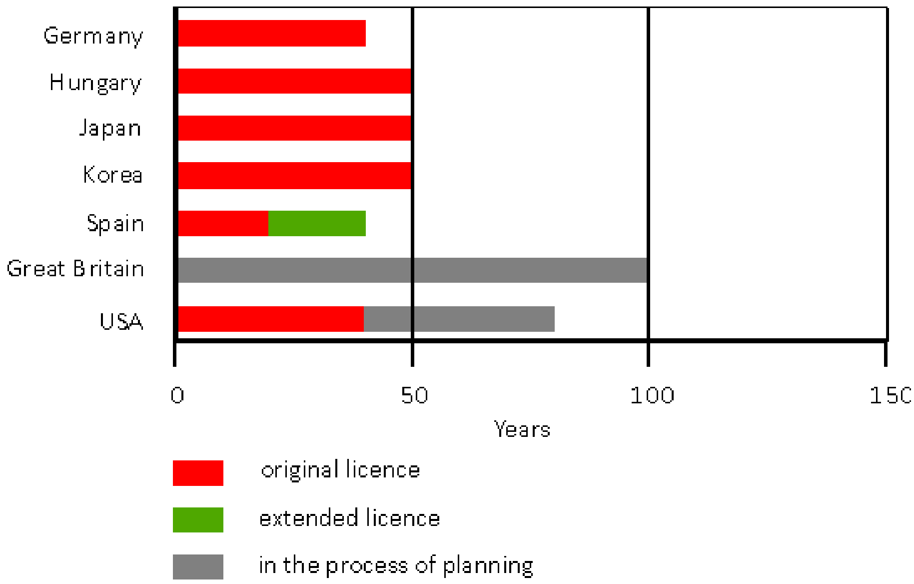

Figure 1: Currently licensed or planned periods for dry cask storage of spent fuel, nationally and internationally, according to [4]

From a technical point of view, the ESK believes that concepts such as storage facilities in deep geological formations to be kept open over long periods of time, long-term storage facilities located in shallow ground or directly at the surface are no equivalent alternatives to disposal in deep geological formations in terms of safety. This discussion paper does not extend to such alternative concepts.

In the view of the ESK, storage is to be limited to the strictly necessary period until transfer to a disposal facility in deep geological formations.

In this discussion paper, the ESK addresses those requirements that result from the safety aspects of an inevitably extended storage in Germany due to the periods stated above. Additional requirements that exist with regard to the protection against disruptive actions or other interference by third parties as well as the control of fissile material as required by international agreements are not dealt with here.

2 Consultations

At the 35th ESK meeting on 09.12.2013, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (now the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety – BMUB) stated that it considers consultations on the topic of extended storage by the ESK useful and appropriate to, inter alia, be prepared for possible questions of the Commission on the storage of high-level radioactive waste still to be established then. In response, the ESK asked the Committee on WASTE

CONDITIONING, TRANSPORT AND INTERIM STORAGE (AZ) to prepare the consultations. At its 28th meeting on 13./14.11.2013, the Committee AZ discussed what arguments and issues relating to the topic of extended storage would have to be considered. These were presented to the ESK at its 37th meeting on 12.12.2013. The ESK then established an ad hoc working group to deal with the aspects of extended storage and to prepare a discussion paper.

The first meeting of the ad hoc working group was held on 26. 08.2014 with a first exchange of views on the formulated arguments and issues. In the following meetings on 31.10.2014, 12.12.2014, 06.02.2015, 09.03.2015 and 29.05.2015 and during the subsequent work by way of circulars, the ad hoc working group prepared a draft text which was submitted to the ESK for further consideration and adoption at its 49th meeting on 03.09.2015 and its 50th meeting on 29.10.2015.

3 Definition of terms and protection goals

3.1 Definition of terms

This discussion paper uses the terms listed with the meanings formulated in the following. All definitions refer to spent fuel and other heat-generating radioactive waste.

Storage facility: Temporary storage place for spent fuel and other heat-generating radioactive waste.

Storage: Temporary storage of spent fuel and other heat-generating radioactive waste for a period licensed under nuclear law until delivery to a disposal facility.

Extended storage: Storage beyond the originally licensed period.

Above-ground storage: The spent fuel and other heat-generating radioactive waste are stored in transport and storage casks in storage buildings under controlled conditions.[2]

Near-surface storage: The spent fuel and other heat-generating radioactive waste are stored in transport and storage casks near the surface (e.g. covered with only a thin soil layer or at low depths up to about 100 m) under controlled conditions.

3.2 Protection goals

The primary radiological protection goals defined in the Guidelines for dry cask storage of spent fuel and heat-generating waste [7] of the ESK also fully apply to an extended storage *(quote)*:

1 *any unnecessary radiation exposure or contamination of man and environment shall be avoided (§ 6 (1) StrlSchV),*

[2] This also includes the on-site storage facility of the Gemeinschaftskernkraftwerk Neckarwestheim

2 *any unnecessary radiation exposure or contamination of man and environment shall be minimised, even if below the respective limit, by taking into consideration the state of the art and by taking into account all circumstances of individual cases (§ 6 (2) StrlSchV).*

The planning of structural or other engineered protection measures against design basis accidents is to be based on the requirements of §§ 49 and 50 in conjunction with § 117 (16) StrlSchV.

The fundamental protection goals derived from it are:

- *confinement of radioactive material,*
- *stable decay heat removal,*
- *maintenance of subcriticality, and*
- *avoidance of unnecessary radiation exposure, limitation and control of radiation exposure of the operating personnel and the general public.*

The requirements derived from it are:

- *shielding of ionising radiation,*
- *design and implementation of the installations in compliance with the requirements for operation and maintenance,*
- *safety-oriented organisation and performance of operation,*
- *safe handling and safe transport of radioactive material,*
- *design against accidents, and*
- *measures to mitigate the consequences of beyond design basis accidents.*

4 Aspects related to an extended storage

4.1 Overview

In Germany, dry storage of spent fuel and other heat-generating radioactive waste had been authorised under nuclear law as type of nuclear fuel storage for a period of up to 40 years so far. The safety assessments covered all the containers, their components and materials as well as the container internals and the radioactive inventories, also taking into account operational loads and accident scenarios to be postulated. For an extension of the originally licensed storage period, an assessment has to be made on the degradation phenomena to be postulated and their safety-related impacts. Here, the state of knowledge at the relevant time must be taken into consideration. The assessment of these issues requires, on the one hand, systematic analyses to identify and describe relevant processes of changes in properties over the relevant periods and, on the other hand, the provision of reliable data. To this end, the lessons learned from day-to-day operation of the storage facility including ageing management and periodic safety reviews as well as additional specific examinations can be referred to.

4.2 Long-term suitability of casks

The accident-proof transport and storage casks used for dry storage have been assessed in terms of safety and licensed under nuclear law for an operating period of up to 40 years. The main loading parameters to be considered, besides mechanical and thermal loads under the conditions of normal and abnormal operation, are the effects from neutron and gamma radiation as well as the influence of media (e.g. moisture, chemical reactions). For this reason, the casks are mainly designed using metallic materials including metal sealing systems. The pressure switch for monitoring the sealing function of the double-lid closure system also consists almost exclusively of metallic components. Surfaces of spent fuel casks are – as far as required – provided with corrosion protection. For neutron moderation, polymers are used, and elastomers are used as auxiliary seals. The cask interior is vacuum-dried and filled with inert gas, so that residual moisture and possible corrosion effects are limited to a technically feasible minimum. Outwardly, the cask closure system is additionally protected against environmental influences by a protective plate. Crevices and hollow spaces, e.g. in the area of the lifting trunnions, are sealed with silicone in order to prevent ingress of moisture and corrosion.

The operating experience of around 20 years does not indicate any safety-relevant changes in properties of the casks and their components. Regular exchange of experience takes place within the Technical Committee for Nuclear Fuel Cycle Matters (FA VE) of the *Länder* Committee for Nuclear Energy (LAA). The procedures for loading, handling and storage have meanwhile been performed in a safe manner with more than 1,000 casks. Related information and experiences are shared nationwide within the framework of the coordination office for information on cask handling (KOBAF). Cask handling for the purpose of maintenance became necessary in individual cases due to failure of a pressure switch and for inspection within the framework of ten-year refuelling outages as well as for renewal of the corrosion protection coating of the 305 CASTOR® THTR/AVR casks at the Ahaus storage facility. Problems with the handling of the casks in the storage facility have not emerged here.

In addition, periodic inspections after about ten years of storage on individual CASTOR® MTR2 casks were carried out with a view to removal from the storage facility in Ahaus. Comparable periodic inspections were performed on numerous CASTOR® THTR/AVR casks in the AVR cask storage facility at Jülich in preparation for removal after the licensed storage period of only 20 years. Here, 20% of the stored casks were successfully subjected to leak testing of the primary lid barrier, and also checks on the screw fittings for tightness did not show any abnormalities.

The potential changes in properties of all cask materials and components are to be considered with a view to an extended storage, taking into account the relevant load conditions for an extended period of time, and to be assessed in terms of safety relevance. So, for example, for more than 40 years (the first tests were started in 1973), accelerated tests on long-term behaviour with representative cask seals are conducted on the basis of which the sealing behaviour can be well predicted. Although, according to the information and experience available so far, there are basically no doubts as to the maintenance of the existing level of safety of the casks also in case of extended storage, proofs are explicitly to be provided and substantiated by reliable data. The same applies for the proof of transportability after the extended storage (see Chapter 4.4).

Moreover, the question arises whether replaceable components, such as pressure switches, metal seals, lifting trunnions and screws, will be available in the long term. Based on the experience available so far, a systematic failure and need for replacement is not to be expected within the licensed storage periods. However, it has not been clarified yet whether this also applies to extended storage periods. It would therefore have to be demonstrated for extended storage that the functionality will continue to be reliably ensured also for replaceable components and that for any necessary replacement, the required spare components will be available.

Whether the casks could generally be suitable for disposal after extended storage depends on the disposal-specific load conditions and requirements, taking into account aspects of handleability and host rock-specific aspects. This also includes requirements for the casks regarding retrievability during the operating period and, if applicable, regarding recovery within a period of 500 years after sealing of the disposal facility [5] and, if applicable, requirements for the casks as technical barriers.

4.3 Inventory behaviour

The cask inventories mainly consist of spent LWR fuel (also including WWER fuel), vitrified HLW in canisters (vitrified fission products CSD-V) from reprocessing as well as spent fuel from THTR and AVR pebble-bed reactor in stainless steel cans. In addition, spent fuel from prototype and research reactors as well as CSD-B (intermediate level vitrified waste) and later possibly also CSD-C (compacted hulls and structural parts, start of return around 2025) are also to be considered. All these inventories are enclosed in containers with identical safety functions.

For vitrified HLW in stainless steel canisters, no processes are known under the inert conditions of the sealed container interior that would suggest the occurrence of relevant changes in properties, even for long periods, so that their full handleability would not have to be called into question even after extended storage [8], [9]. In Marcoule, the HLW canisters have been stored already for 40 years. In 2008 and 2013, the CNE recommended providing proof of safety including research programme and sampling so that experience-based data and values will be available. Irrespective of this, the ESK holds the view that it should be verified at plausible intervals whether there is new knowledge available on relevant changes in properties.

The THTR- and AVR fuel is stored in so-called stainless steel cans inside the storage casks. Due to the fuel properties in combination with the low fuel temperatures under storage conditions, there are no changes in properties foreseeable so that full handleability is to be expected also after extended storage [10]. However, the level of knowledge on relevant changes in properties of THTR and AVR fuel under storage conditions is lower compared to that on changes in properties of HLW glass canisters so that it should be verified that no relevant property changes will occur.

For spent LWR fuel assemblies from reactors of Western design, proof of their integrity is provided before loading. It is assumed that during loading, drying and storage, leak tightness of the fuel rod cladding is maintained, and systematic cladding failure is excluded. This has been demonstrated so far for 40 years, taking into account the mechanical (internal pressure), thermal and radiological loads, so that full handleability of the fuel is also to be expected at the end of this storage period. For defective LWR fuel rods, special solutions are provided in the form of tightly closed quivers inside the casks.

In addition, fuel assemblies of the WWER-type are also to be considered. For these, cladding leak tightness during emplacement in casks for storage could not be verified individually. Therefore, additional mineral moisture absorbers (so-called filter cartridges) were inserted into the casks for potentially not dryable moisture reservoirs in individual fuel rods.

For extended storage, the need for additional safety assessments in terms of long-term behaviour and potential changes in properties and condition of all above-mentioned inventories and additional cask internals (such as baskets and filter cartridges) is foreseeable. The same applies to later transports and cask handling (see Chapter 4.4).

Such issues are currently discussed internationally for LWR fuel assemblies, e.g. by the US Nuclear Regulatory Commission (US NRC) [11], [12]). Major topics of these discussions are, among other things, the reorientation of hydrides in fuel rod cladding tubes under decreasing temperatures and thus possibly increased susceptibility to brittle fracture under mechanical loads with subsequent cladding failure during handling processes or transport or also in accident scenarios (“cladding integrity”). In this respect, the influencing factors are the specific cladding materials and the condition of the fuel (e.g. burnup) when loaded into the casks. These factors may have an impact on the handleability of the fuel after storage. Whether full handleability must be given with regard to the respective disposal concept provided is still an open question. However, limitations in handleability may have an influence on the potential disposal concepts.

As a consequence of the internationally discussed need for safety proofs in terms of fuel integrity during extended storage, the USA, Japan and Korea currently start demonstration programmes with representatively loaded casks (see e.g. [11], [13], [14], [15], [16], [17]) for which accompanying measurement programmes, studies on reference fuel rods and final inspections are provided. In the past, a loaded CASTOR®-V/21 cask was opened and inspected in the USA after 15 years, and this was accepted as proof of the proper condition of the fuel assemblies (burnup up to 45 GWd/tHM) and the cask to extend an existing 20-year storage licence [18]. Also in Japan, individual loaded casks were subjected to visual inspections of the interior, however, without further examinations on material and condition [19].

A decisive factor for the handleability of fuel rods after longer periods of storage is the condition of the cladding tubes. If cladding tube integrity is not ensured, degradation processes are to be considered in the fuel matrix with regard to their release potential that may make handling more difficult. Already during irradiation in nuclear power plants, crack formation and volume expansion occur in the fuel. During long-term storage, further processes may become relevant:

- Oxidation of uranium dioxide leads to volume increase and may lead to the destruction of the fuel matrix [20], [21].

- During alpha decay, helium accumulates in hollow spaces and at grain boundaries of the fuel matrix. When interacting with fission gases being present there, this can, under certain conditions, also lead to the disintegration of the ceramic oxide material due to pressure build-up [20], [21]. In particular for mixed-oxide fuel rods and at high burnups, such processes will have to be considered increasingly. In pellet rim regions, where burnup is particularly high, primarily microcracks may occur and fission gases be released. Although previous estimates show no significant influence of helium development on the integrity of irradiated nuclear fuel in a period of several decades, large uncertainties in understanding long-term processes are pointed out [21], [22].

The activities referred to reflect the internationally discussed need for investigations on extended storage of spent LWR fuel, in particular with burnups exceeding 45 GWd/tHM. Findings which allow an extrapolation of the statements on the cladding tube to periods significantly beyond 40 years have not been achieved yet. The transferability of the international investigation programmes has to be examined with regard to the specific conditions in Germany [20]. Comparable considerations on the other fuel types are currently not available.

4.4 Transportability of the casks at the end of the storage period

According to the current concept of the 40-year storage and in view of the ancillary provisions stipulated in the licences for centralised and decentralised storage with respect to the general transportability of the casks, the cask type approvals under traffic law are permanently maintained by the storage operators so far. Currently, as required by the provisions under traffic law, the type approvals are generally limited to periods of three to five years and, for cask types no longer manufactured, of ten years as a maximum, so that approvals are to be renewed regularly for a variety of cask types. This means considerable efforts for the operators as well as for the authorities and their experts consulted without having a direct influence on the safety condition itself during storage. In this respect, it is currently being discussed whether in the future even longer validity periods of well over ten years will be possible for cask types which are no longer manufactured and exclusively used in loaded condition in a storage facility.

In addition, possible alternatives to the permanent maintenance of approvals under traffic law are currently being discussed, albeit controversially. The Guidelines for dry cask storage of spent fuel and heat-generating waste [7] of the ESK currently provide the following: *"The measures to be provided during operation of the storage facility within the framework of periodic safety reviews and ageing management also require creating the conditions necessary for being able to demonstrate and verify the technically sound condition of the casks on a continuous basis and within the framework of in-service inspections required under traffic law before transportation."* Thus, maintenance of the approval during storage could be dispensed with while introducing monitoring under nuclear law if its results ensure that traffic law requirements are met during later removal from the storage facility. Currently, however, it is still open in which way a new type approval for the casks concerned can be obtained on this basis.

This makes it clear that it would be appropriate to establish alternatives to maintaining type approvals under traffic law within the framework of rules and regulations to be developed for extended storage. These would have to regulate, in particular, interlacing of the measures for ageing management during storage with the requirements for obtaining a transport permit after storage to ensure the removal of the casks at the end of their storage. In Switzerland, for example, a national regulation is provided for the last and one-time transportation to a disposal facility, which, however, has not been elaborated yet.

4.5 Alternative storage concepts

In Germany, spent fuel and other heat-generating radioactive waste is kept dry in transport and storage casks in storage buildings (halls) according to a uniform concept [7]. The casks ensure all essential safety functions and, if required, transportability. A deviation from this principle – e.g. a transition to wet storage (similar to the CLAB facility in Sweden for spent fuel) or a vault storage (analogous to the HABOG in the Netherlands for reprocessing waste and spent fuel from research reactors) – would require opening and unloading of the storage and transport casks and reloading of inventories into other containers or a wet storage pool. Given the significant technological and safety-related efforts, this paper does not consider concepts that involve handling of inventory and represent a substantial change in the storage concept.

Virtually, all storage facilities are built above ground. Only at one site, a near-surface storage facility has been built that is covered with a thin soil layer due to the local conditions, but it is approached at “ground level”. The decisive factor for the assessment of technical safety is the compliance with the protection goals referred to in Chapter 3.2. The location of a storage facility – above ground, near the surface, in depths up to 100 m, or in deep geological formations – does not relieve from this task.

Through continuous operational implementation of the regulations and ancillary provisions stipulated in the storage licences, including regular periodic safety reviews every ten years [23] and a continuous ageing management, it is ensured that the condition of the storage facilities in terms of safety as well as of the checkable accessible cask areas is maintained, any deviations are identified in a timely manner and remedial action is taken. The operating experience of meanwhile more than 20 years currently does not indicate any need for action to implement alternatives to above-ground storage after expiry of the storage periods licensed so far, but it cannot generally be ruled out. At present, it is expected that the currently established concept of dry storage (storage building and casks) should maintain its safety functions also for significantly longer periods than 40 years. An explicit verification according to the then current state of the art in science and technology will certainly be necessary for extension or renewed granting of storage licences.

A change in the storage concept, however, is likely to create considerable challenges in terms of technology, licensing and finances. Near-surface storage facilities at low depths are technically feasible, but will involve great expenses and efforts already for their construction, since “new ground” would be broken technologically and as regards licensing without recognisable safety advantages. Even safety-related disadvantages, e.g. with regard to the safe removal of decay heat, cannot be excluded. The safety aspects discussed so far, taking into account design basis accidents and beyond design basis events, would remain nearly fully applicable. Advantages could result at most with regard to direct mechanical and thermal influences from impacts outside the facility (e.g. by explosions and aircraft crashes). With increasing depth, however, expenses and efforts for construction and operation of a storage facility continue to increase significantly.

Principally, underground storage is supposed to be considered as an anticipated disposal facility by society also at small depths; this could make acceptance even more difficult. Site selection would thus to be expected to involve far more expenses and efforts than for an above-ground storage facility and probably not less expensive than the site selection procedure for a deep geological repository.

Overall, the ESK is of the opinion that the variant of alternative storage concepts in principle seems to be technically feasible, even though a relevant increase in the level of safety of such facilities would not be recognisable. Thus, the following realistic scenarios remain that should be considered for extended storage:

- extended storage at the current sites, or,
- construction of a centralised storage facility, possibly at the disposal facility site provided for this waste, or
- construction of and concentration on a few regional storage facilities.

All of these options require that compliance with the protection goals can be demonstrated for the extended storage of spent fuel and other heat-generating radioactive waste in the currently used cask types also beyond the storage period licensed so far (see Chapter 4.6).

All three options require nationwide and regional acceptance within the social and political sphere.

If a new storage facility is not built at the site provided for the disposal of this waste, this will require numerous additional transports. In any case, a time frame of many years is to be considered for necessary transports of about 1,900 casks.

4.6 Safety analyses in the licensing procedure for extended storage

According to the applicable licensing regulations, the extension of an already licensed storage period represents a new licence. According to § 6 (5) AtG, licences may only be renewed after prior referral to the German *Bundestag*. For extended storage, the characteristics of the concrete inventories (e.g. decay heat, source strengths, and fission products) and casks being safety-relevant at this time can then be considered. Experiences, such as with the tightness measurements on loaded and already for 20 years stored CASTOR® THTR/AVR casks can be used.

With the currently starting periodic safety reviews on the basis of the ESK guidelines for the performance of periodic safety reviews and on technical ageing management for storage facilities for spent fuel and heat-generating radioactive waste [23], the condition of the currently operated storage facilities will, in future, be comprehensively documented and assessed on a regular basis. Knowledge gained from it and any measures derived serve to maintain the existing level of safety and can also be used for future licensing procedures. Comparable programmes for the determination of safety-relevant developments in inaccessible cask areas and inventories are currently not available and can hardly be realised within the framework of storage facility operation.

Overall, the required safety proofs for casks and inventories as part of licensing procedures for extended storage are to be furnished on the basis of sufficiently reliable data and knowledge that can be generated from both the operating experience continuously gained of facilities operated so far as well as from additional investigation programmes. Regarding the inventories, it has neither been clarified until now how the necessary data will be obtained, nor is it foreseeable whether the safety proofs required can be carried out.

4.7 Maintenance of know-how

Under the current conditions with storage until commissioning of a disposal facility not expected to be available before 2050, the question arises how the necessary know-how can be maintained of all the organisations involved in Germany. Continuously dealing with waste management tasks can help – paying due attention provided – to ensure the maintenance and further development of competencies. However, there is a considerable risk that existing competencies in dealing with the radioactive waste and disposal can be maintained increasingly less or only under difficult conditions, especially if no new waste management projects are implemented.

It is to be expected that in the next few decades during the decommissioning of all nuclear power plants and their subsequent dismantling, there will be changes in Germany, since the number of actors will decrease in a sector which is practically exclusively focused on waste management, since responsibilities and competences both at the side of the operators and the authorities with their authorised experts will diminish. For the remaining actors, maintenance of competence will largely depend on whether projects and tasks can be realised and advanced with appropriate practical orientation, for which a sufficient number of experts have to be engaged continuously and that make working in this sector so attractive that the need for personnel and junior experts can be covered. The necessity of maintaining competence does not only apply to nuclear expertise, but also to other conventional areas important for waste management, such as planning, construction and operation of mining facilities (shaft hoisting, mine operation, mine safety).

4.8 General consideration

The current legal regulations of the Atomic Energy Act (AtG) and the Radiation Protection Ordinance (StrlSchV) provide that the waste producers shall deliver radioactive waste that has originated at facilities according to § 7 AtG and during work as defined in §§ 5, 6 and 9 AtG to a federal facility for disposal (§ 76 (1) StrlSchV) and store it until delivery (§ 78 StrlSchV). In which way the waste producers have to deliver in terms of conditioning and packaging is defined by the Federation as the operator of the disposal facility (§ 74 (1) StrlSchV). Thus, except for waste disposal, all waste management steps (storage – transport – conditioning; in this or possibly a different order) remain the responsibility of the respective waste producer in terms of implementation and costs incurred (see Figure 2).

The responsibility for the management of waste and spent fuel related to the operation and decommissioning of nuclear power plants lies with the operators of nuclear power plants – in the case of the Greifswald and Rheinsberg nuclear power plants with the Federation.

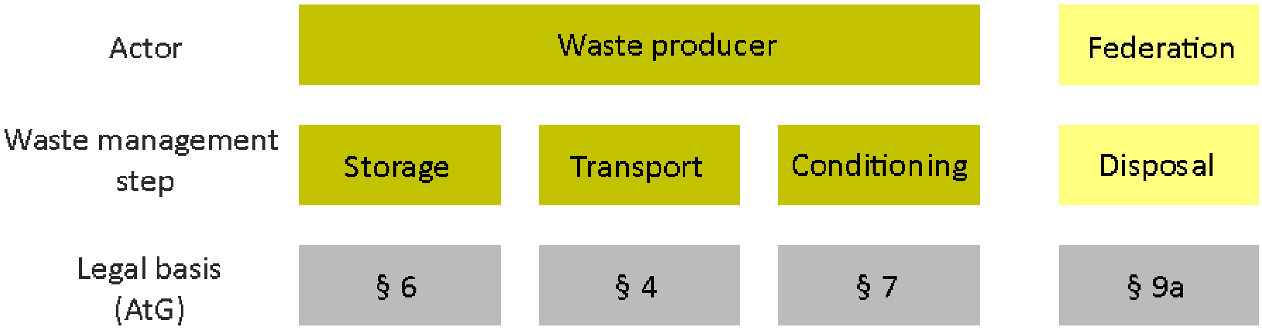

Figure 2:
Responsibilities and legal basis (AtG: Atomic Energy Act [3]) in the field of management of spent fuel and other heat-generating radioactive waste

Storage is therefore only one aspect as regards the management of spent fuel and other heat-generating radioactive waste. The entire waste management path usually consists of the intermediate steps storage, transport and conditioning/reloading into special disposal containers (if necessary), transportation to the disposal facility and disposal itself. These are not to be seen independently of each other but they are interlinked and influence each other. Thus, the handleability and conditioning of spent fuel may be affected in case of an unfavourable change in the condition during extended storage. Furthermore, the development of concepts for the disposal of spent fuel will be based on the type of host rock selected.

All steps of waste management up to disposal have already been considered in the past, but generally each one separately or in subsystems and, above all, with a view to disposal in salt formations (e.g. [9], [24] [25], [26]).

A safety-related connection between conditioning, disposal container and geological system of the disposal facility was considered in Germany for the first time with the preliminary safety assessment for the Gorleben site (VSG) [27]. It was found that this safety-related interconnection is essential for the assessment of disposal facility systems. The technical concept for containers (or packages) and for handling and possibly conditioning is to be developed in iterative development steps – geared to the geological requirements – to ensure that a technical concept suitable for the specific site will be available in a timely manner. Here, the conditions and circumstances relating to the already existing casks and inventories are to be considered in order to achieve a sustainable overall concept. The need for an iterative procedure has been confirmed in the VSG [27]. Taking into account the current time horizon, suitable container and conditioning concepts are to be developed for the respective site in parallel to the site selection for the repository. At least in a basic form, this will already be required for a comparison of different sites, particularly in case of different host rocks.

The mentioned safety-related connection between the geological system of the repository, the disposal container and conditioning unfolds possible impacts on the safety issues that may be of importance in case of extended storage: If it is required for intended disposal to repack e.g. spent fuel into special disposal containers, handleability of the fuel is to be ensured.

As already described in Chapter 4.4, the proof of safe transportability of the casks after extended storage plays an important role, too. The current regulations are not suitable for it or only to a limited extent.

Therefore, it seems to be appropriate to establish a specific regulatory framework for extended storage, taking into account the regulations for the required removal. Moreover, it is important that for the consideration and realisation of the overall system of waste management, clear responsibilities are defined with an appropriate coordinating body in terms of an integrated approach.

5 Economic and ethical aspects

Financing

The private operators make provisions to finance the decommissioning of nuclear power plants and the management of radioactive waste from the operation and decommissioning of their facilities, including the costs of later disposal of their waste.

Where the responsibility for waste management lies with the public sector, it is funded through items of the public budgets.

While for the decommissioning of nuclear power plants, relatively good estimates of the costs are possible by now due to experiences gained, the calculation of the expenses for disposal are subject to much larger uncertainties. This is partly due to the lack of national and international experience with actual planning, construction, operation and decommissioning costs for a disposal facility and, on the other hand, to the uncertainties regarding the cost development over the very long period of around 100 years.

In addition, no more profits will be generated after the phase-out of commercial use of nuclear energy for power generation in this sector but, on the other hand, considerable expenses for waste management will still arise. These boundary conditions are to be taken into account regarding the possibilities of intermediate- and long-term adjustments to the financial basis for waste management.
The more the solution to the issue of waste management will be postponed into the future or new technical waste management concepts and procedures are pursued, the greater are the economic uncertainties to be expected with regard to the amount of the expected costs and with regard to the availability of financial resources (for example due to company insolvency or financial disturbances associated with a loss in the value of provisions). In case of a delayed provision of a disposal facility and the resulting extended storage, further increase of the uncertainties regarding the amount of waste management costs and an increase in the share of costs to be financed additionally from the public sector is to be expected.

Intergenerational justice

The responsibility towards future generations is also referred to as intergenerational justice. By this is meant that the generation that benefits or has benefitted from a technology also bears the associated burden and, as far as possible, should not leave costly and extraordinarily binding tasks to the following generations. In the context of the use of nuclear energy, this means that the issue of waste management will be solved as soon as possible and without requiring active measures in the future. In this respect, the term "as soon as possible" is to be understood as without major delay. For the licensing of on-site storage facilities for spent fuel, this aspect was taken into account by limiting the durations of licences for storage to 40 years until delivery to a disposal facility, which, at that time, were considered to be sufficient.

Already with today's time perspectives, the administrative, financial and social responsibility and the practical implementation of waste management tasks are, in substantial parts, transferred to the following generations.

Would this period additionally be expanded by further delays in the site selection process until commissioning of a disposal facility and the resulting extended storage, further tasks would be transferred to generations of the even more distant future. The decision-making independence, resulting from the deferment of the issue of disposal to future generations, regarding the further use or disposal of the waste, taking into account any further developed technologies, is thus to be weighed against the obligations to ensure the safe operation of interim solutions against the background of unforeseeable socio-political developments and risks.

6 Summary of the main aspects of an extended storage

From a technical point of view, the ESK believes that storage of spent fuel and other heat-generating waste is to be limited to the strictly necessary period until transfer to a disposal facility in deep geological formations to ensure the best possible protection of man and the environment.

Operating experience with casks and storage facilities of more than 20 years combined with regular safety reviews and systematic ageing management measures principally justify the expectation that the existing safety functions will be maintained also for an extended storage beyond 40 years. Nevertheless, there are a number of aspects to be clarified with regard to the storage and subsequent waste management steps, which are summarised below:

- According to the applicable licensing regulations, the extension of an already licensed storage period represents a new licence which is to be based on the proof that the necessary precautions have been taken in the light of the state of the art in science and technology. For extended storage, the safety-relevant properties of the inventories and casks actually existing at this time must then be considered.

- The required safety proofs for casks and inventories as part of licensing procedures for extended storage are to be furnished on the basis of sufficiently reliable data and knowledge that can partly be generated from the operating experience continuously gained and partly have to be supplemented from additional investigation programmes.

- Programmes to investigate the long-term behaviour of cask components (e.g. metal seals) and inventories (e.g. fuel rod integrity) for extended storage are likely to involve high expenditures of time and costs and should be initiated at an early stage. Active participation in international investigation programmes is appropriate to be able taking into account findings as far as applicable.

- The availability of all replaceable cask components (e.g. pressure switches, metal seals, lifting trunnions and screws) must be ensured for the entire storage period, even though if after completion of the last cask manufacturing/loading in principle there is no more need for cask manufacturing.

- In view of the required removal of the casks, proof of safe transportability during and after extended storage is to be provided. Since the current regulations under traffic law are not suitable for this issue or only to a limited extent, it would be appropriate to establish alternatives to maintaining type approvals under traffic law within the framework of rules and regulations to be developed for extended storage. This has to include, in particular, interlacing of the measures for ageing management during storage with the requirements for obtaining a transport permit after storage to ensure the removal of the casks at the end of their storage.

- Whether the transport and storage casks may later also be suitable for disposal depends not least on the disposal-specific load conditions and requirements, taking into account aspects of handleability and host rock-specific aspects.

- Storage is only one aspect as regards the management of spent fuel and other heat-generating radioactive waste. The entire waste management path usually consists of the intermediate steps storage, transport and conditioning/reloading into special disposal containers (if necessary), transportation to the disposal facility and disposal itself. These are interlinked and influence each other.

- The fuel behaviour is essential for necessary and appropriate conditioning concepts for subsequent disposal. Limitations regarding the possibilities of conditioning of the fuel have an impact on the realisable disposal concepts and are therefore to be considered in the development of repository designs as early as possible.

- To ensure the integrated consideration and realisation of the overall system of waste management, an appropriate coordinating body is required, which should also pay attention to the interfaces with respect to the technical requirements and interactions as well as the organisation of responsibilities for the various steps of waste management, also taking into account the constellation of actors that is changing through the implementation of the nuclear phase-out.

- The ESK is of the opinion that alternative storage concepts in principle seem to be technically feasible, even though a relevant increase in the level of safety of such facilities would not be recognisable.

There would rather be significant risks with regard to licensing law and socio-political risks as well as problems in terms of acceptance of sites and additional transports, not to mention considerable additional costs and additional deadline risks with regard to timely operational readiness.

- Both the construction of new storage facilities as well as the extension of the storage periods at the 16 communities hosting the storage facilities will require nationwide and regional acceptance within the social and political sphere. From the point of view of the ESK, the following realistic scenarios remain for extended storage:

  - extended storage at the current sites, or
  - construction of a centralised storage facility, possibly at the disposal facility site provided for this waste, or
  - construction of and concentration on a few regional storage facilities.

- As a consequence of the decommissioning of all nuclear power plants and their subsequent dismantling in Germany, there will be changes in responsibilities and the number of actors will decrease. In case of a significant extension of the storage periods, there will therefore be a considerable risk that existing competencies in dealing with the radioactive waste and disposal can be maintained increasingly less or only under difficult conditions. The maintenance of competence over very long periods is therefore of great importance. It can be supported, among other things, by R&D projects with appropriate practical orientation and active participation in international research projects and cooperations.

- In case of a delayed provision of a disposal facility and the resulting extended storage, further increase of the uncertainties regarding the amount of waste management costs and an increase in the share of costs to be financed from the public sector is to be expected.

- Already with today's time perspectives, the administrative, financial and social responsibility and the practical implementation of waste management tasks are, in substantial parts, transferred to the following generations. Would this period additionally be expanded by further delays in the site selection process until commissioning of a disposal facility and the resulting extended storage, further tasks would be transferred to generations of the even more distant future.

7 Abbreviations

AVR: Arbeitsgemeinschaft Versuchsreaktor Jülich,
High-temperature reactor – experimental nuclear power plant in Jülich

CSD-B: Colis Standard des Déchets Boues, standard package for intermediate-level vitrified waste from reprocessing of German LWR spent fuel in La Hague

CSD-C: Colis Standard des Déchets Compactés, standard package for radioactive waste compacted under high pressure from reprocessing of German LWR spent fuel in La Hague

FA VE: Fachausschuss Nukleare Ver- und Entsorgung des Länderausschusses für Atomkernenergie
Technical Committee for Nuclear Fuel Cycle Matters of the *Länder* Committee for Nuclear Energy

HAW: High active waste

HLW: High level waste

KOBAF: Koordinierungsstelle für Informationen zur Behälterabfertigung
Coordination office for information on cask handling

LAA: Länderausschusses für Atomkernenergie
Länder Committee for Nuclear Energy

LWR: Leichtwasserreaktor
Light water reactor

THTR: Thorium-Hochtemperaturreaktor
Thorium high-temperature reactor

VSG: Vorläufige Sicherheitsanalyse Gorleben
Preliminary safety assessment fo rthe Gorleben site

WWER: Wassermoderierter wassergekühlter Energie-Reaktor
Water-cooled and water-moderated energy reactor, pressurised water reactor of Russian design

8 References

[1] Gesetz zur Suche und Auswahl eines Standortes für ein Endlager für Wärme entwickelnde radioaktive Abfälle und zur Änderung anderer Gesetze (Standortauswahlgesetz – StandAG) BGBl. I Nr. 41 vom 26. Juli 2013, S. 2553

[2] Programm für eine verantwortungsvolle und sichere Entsorgung bestrahlter Brennelemente und radioaktiver Abfälle (Nationales Entsorgungsprogramm)
Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit
August 2015

[3] Gesetz über die friedliche Verwendung der Kernenergie und den Schutz gegen ihre Gefahren (Atomgesetz – AtG) in der Fassung der Bekanntmachung vom 15. Juli 1985 (BGBl. I S. 1565), zuletzt geändert durch Artikel 5 des Gesetzes vom 28. August 2013 (BGBl. I S. 3313)

[4] Extended Storage Collaboration Program, International Subcommittee Report:
International perspectives on technical data gaps associated with extended storage and transportation of used nuclear fuel. EPRI, Palo Alto, CA: 2012.1026481

[5] Sicherheitsanforderungen an die Endlagerung wärmeentwickelnder radioaktiver Abfälle
Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit, 30.09.2010

[6] Richtlinie 2011/70/Euratom des Rates vom 19. Juli 2011 über einen Gemeinschaftsrahmen für die verantwortungsvolle und sichere Entsorgung abgebrannter Brennelemente und radioaktiver Abfälle

[7] Leitlinien für die trockene Zwischenlagerung bestrahlter Brennelemente und Wärme entwickelnder radioaktiver Abfälle in Behältern, Empfehlung der Entsorgungskommission, revidierte Fassung vom 10.06.2013

[8] Arbeitskreis HAW-Produkte, veröffentlicht in Forschungszentrum Karlsruhe
Endlagerrelevante Eigenschaften von hochradioaktiven Abfallprodukten – Charakterisierung und Bewertung – Empfehlung des Arbeitskreises HAW-Produkte“; FZKA 6651, September 2001

[9] Direkte Endlagerung von Transport- und Lagerbehältern - ein umsetzbares technisches Konzept
R. Graf, K.-J. Brammer, W. Filbert
Jahrestagung Kerntechnik, Mai 2012

[10] 2. Änderungsgenehmigung vom 07.07.2005 zur Aufbewahrungsgenehmigung für das AVR-Behälterlager der Forschungszentrum Jülich GmbH vom 17.06.1993 – ET 3.1 – 2.4

[11] Einziger, R.E., Billone, M.C.: Hydriding Effects in HBU Cladding. International Seminar on Spent Fuel Storage (ISSF 2010）, November 15-17, 2010, Tokyo, Japan

[12] Velazquez-Lozada, A.: Extended Storage & Beyond. 30th INMM Spent Fuel Management Seminar, 12-14 Jan. 2015, Arlington, USA

[13] Kessler, J., Waldrop, K.: EPRI High Burnup Used Fuel Confirmatory Demonstration Project [The “High Burnup Demo”]. NEI Used Fuel Management Conference, St. Petersburg, USA, 8 May 2013

[14] High Burnup Dry Storage Cask Research and Development Project: Final Test Plan Contract No.: DE-NE-0000593. Prepared by: the Electric Power Research Institute (EPRI), Rev.0 (February 27, 2014)

[15] Kessler, J.: EPRI’s Long-Term Storage Projects. 30th INMM Spent Fuel Management Seminar, 12-14 Jan. 2015, Arlington, USA

[16] Yamamoto, M.: Demonstration Test Program for Long-term Dry Storage of PWR Spent Fuel. IAEA-CN-178/08-03, 02. June 2010

[17] Kook, D., Choi, J., Kim, J., and Kim, Y.: Review of Spent Fuel Integrity Evaluation for Dry Storage. Nuclear Engineering and Technology, Vol.45 No.1 February 2013

[18] NUCLEAR REGULATORY COMMISSION, Dry Cask Storage Characterization Project – Phase 1: CASTOR V/21 Cask Opening and Examination, NUREG/CR-6745, Washington D.C. (September 2001)

[19] WATARU, M., et al., “Long-term Containment Performance Test of Metal Cask for Spent Nuclear Fuel Storage”, PSAM, 25-29 June, 2012, Helsinki, Finland, (2012)

[20] Sicherheitstechnische Aspekte der langfristigen Zwischenlagerung von bestrahlten Brennelementen und verglastem HAW
Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH
GRS – A - 3597, April 2010

[21] FERRY, C., POINSSOT, C., CAPPELAERE, C., DESGRANGES, L., JEGOU, C., MISERQUE, F., PIRON, J.P., ROUDIL, D., GRAS, J.M., Specific outcomes of the research on the spent fuel long-term evolution in interim dry storage and deep geological disposal,
J. Nucl. Mat., 253 (2006), 246-253

[22] POINSSOT, C., TOULHOAT, P., GRAS, J.M., VITORGE, P., Long term evolution of spent nuclear fuel in long term storage or geological disposal. New findings from the French PRECCI R&D program and implications for the definition of the RN source term in geological repository,
J. Nucl. Sci. Technol., 39, Suppl. 3, (2002), 473-476

[23] ESK-Leitlinien zur Durchführung von periodischen Sicherheitsüberprüfungen und zum technischen Alterungsmanagement für Zwischenlager für bestrahlte Brennelemente und Wärme entwickelnde radioaktive Abfälle, Empfehlung der Entsorgungskommission vom 13.03.2014

[24] Direkte Endlagerung ausgedienter Brennelemente DEAB (02 E 8191)
Handhabungsversuche zur Streckenlagerung, Abschlussbericht Hauptband
September 1995, DEAB T 60

[25] Referenzkonzept für ein Endlager für radioaktive Abfälle im Tongestein (ERATO)
Abschlussbericht, Dezember 2008
DBE Technology GmbH; Pöhler, M. et al.

[26] Optimization of the Direct Disposal Concept by Emplacing SF Canisters in Boreholes, Final Report (DBE TECHNOLOGY GmbH, Filbert, Bollingerfehr)

[27] Synthesebericht für die VSG
Bericht zum Arbeitspaket 13
Vorläufige Sicherheitsanalyse für den Standort Gorleben
Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH
GRS - 290, März 2013