The German Aging Management Approach for Dry Spent Fuel Storage in Dual Purpose Casks

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Abstract: Since the decision by the German government to face out nuclear electricity generation the total amount of spent nuclear fuel and high level wastes from reprocessing is limited and well determined. In addition the siting and licensing procedure to establish a final repository has been ruled by a new law in the mid of 2013 and further delays are very likely until a deep geological repository may start its operation.

In the meantime dry interim storage in dual purpose casks being permanently certified for interim storage as well as transportation is the established technical solution. Several on-site as well former centralized facilities are operated successfully for many years but storage licenses are generally limited to 40 years and future lifetime extensions are predictable. Permanent aging management for storage facilities and casks is necessary to demonstrate compliance with safety requirements and furthermore to gain relevant data and information about the technical conditions of the facilities and their components for future lifetime extensions.

For that reason procedures and measures are currently improved and the approach is explained in this paper. In addition, the current status and latest experiences concerning periodic safety inspections and aging management measures are discussed.

Keywords: Interim Storage, Dual Purpose Casks, Spent Nuclear Fuel, Aging Management

1. INTRODUCTION

In Germany, spent nuclear fuel (SNF) and vitrified high level radioactive waste from SNF reprocessing (HLW) are stored in thick-walled metal dual purpose casks equipped with a double barrier lid system which are approved for transportation and up to 40 years of interim storage. With this concept SNF can be removed from nuclear power plants flexibly during operation or decommissioning after shut-down and can be stored on-site or elsewhere, e.g. in centralized storage facilities.

Initially, dry storage of SNF in Germany took place in two central storage facilities at Ahaus and Gorleben starting in the 1980's. Furthermore, the Gorleben interim storage is located adjacent to the investigated salt dome for potential future final disposal in that deep geological formation and a so-called pilot conditioning plant was built on site as well. But political decisions changed the situation and the national approach for SNF and HLW management significantly during the past 15 years. At first, a transport ban for SNF shipments was followed by ending reprocessing in France and the UK and direct disposal of SNF remained as the only option for the future. Consequently, 12 on-site interim storage facilities were built to store the SNF from the adjacent nuclear power plants without any public transportation. However, the remaining shipments of reprocessed HLW from France to Gorleben resulted in enormous public opposition and extreme efforts for safety and security measures along the transportation route in Germany. Secondly, in 2011 after the Fukushima disaster the German government decided to shut down eight of 19 operating nuclear power plants immediately and to face out nuclear electricity production until the end of 2022. Details were fixed by a German atomic energy act amendment. One of the consequences of that decision is the need for an increased number of casks to unload all shut down reactors including their cores within the next decade.

With regard to the disposal policy the investigation of the Gorleben salt dome was interrupted by a ten year moratorium in 2001. This decision delayed the establishment of a final repository significantly which was initially planned to be ready until 2035. At the end of difficult political discussions about the future repository policy and whether Gorleben should be considered as a future option or not a so-called „Repository Site Selection Act“ [1] was agreed and entered into force on July 27, 2013. The new act means a complete restart of the site selection procedure taking into account all potential host rock formations throughout Germany and to establish a broad participation of all relevant stakeholders including the public along the entire process. At the beginning the site selection procedure has to be prepared by a 33 member commission comprising all parts of society. The commission is to draw up and present proposals concerning i.e. security requirements and geological selection/exclusion criteria by the end of 2015. In parallel a Federal Institute for Nuclear Disposal will be established in 2014 being responsible for the site selection procedure, site proposals, exploration programs and evaluation criteria. Generally, a broad participation of public, political, and scientific stakeholders is foreseen. Based on developed and fixed criteria the site selection for underground exploration shall be performed and finished until 2023. Based on the investigation results the final site selection shall be completed until 2031. The final site selection is followed by the licensing procedure and construction of the repository. If all this takes at least another ten to fifteen years a repository will not available before the mid-2040's followed by an operation phase of about 30 years to dispose of all disposal packages. In addition one should keep in mind that the mentioned timeframe does not consider any delays caused by likely lawsuits during all phases of the process. In parallel current interim storage licenses expire between 2032 and 2043 and quite obviously extended interim storage periods will be needed for the future ensuring safe SNF and HLW management towards final disposal.

2. SPENT FUEL STORAGE IN DUAL PURPOSE CASKS

Dry spent fuel and HAW storage in dual purpose casks is one of the favorite technical options for a long-term safe solution. Specific casks are built and operated globally. By the end of 2013 exactly 1.000 casks have been stored in Germany and the number is increasing continuously. Totally between 500 and 600 additional casks are expected to carry all spent fuel from the Germany nuclear power plants including the cores until the end of their lifetime. A countrywide specific requirement is the ability of transportation from the interim storage site at any time. This means a valid transportation cask Type B approval is needed not only as a prerequisite to load and store the casks but also during the entire storage period. The reason is to guarantee shipment of any cask from the interim storage site whenever needed and finally at the end of the licensed storage period. As IAEA (International Atomic Energy Agency) transport regulations do not really consider this specific use of transportation casks consequences and additions to the regulatory framework are currently discussed and developed. Anyway, in addition to a valid design approval each cask has to demonstrate compliance with the approval certificate prior to its shipment, e.g. sufficient leak-tightness of lids, proper conditions of safety related components like trunnions, screws, etc. For that purpose a sufficient aging management regime during storage and finally, inspections and measurements prior to transportation are essential.

Generally, dual purpose casks are accident safe and made of a thick-walled cask body from ductile cast iron or forged steel and equipped with a double barrier lid system during the long-term interim storage, see Figure 1. Lids are screwed and equipped with metal seals and the lid interspace is continuously monitored during storage. However, the casks mainly guarantee for all relevant safety goals (subcriticality, shielding, safe enclosure, and decay heat dissipation) they are placed in a storage hall for weather protection and additional shielding. The storage building also contains all necessary technical equipment for cask operation including cranes, a service and maintenance station, and monitoring devices.

German Dry Spent Fuel and HAW Storage Concept

- Accident safe dual purpose transport and storage casks
- Valid Type B(U) approval required during storage
- Monolithic thick-walled metal cask body
- Vacuum dried and helium filled (≈800 hPa) cask interior
- Permanently monitored double barrier lid system equipped with metal seals
- Qualified repair concept in case of hypothetical lid failure
- Current storage licenses limited to 40 years

"Guidelines for dry cask storage of spent fuel and heat-generating waste"
German Waste management Commission (ESK), Revised version of 10.06.2013,
http://www.entsorgungskommission.de/englisch/downloads/eskempfehlungesk30llberevfassung10062013en.pdf

Figure 1: Major characteristics of dual purpose casks (pictures: Castor® V design by GNS mbH)

All technical requirements for the German dry interim storage concept are specified in guidelines edited by the German Waste Management Commission (ESK) and considered by the competent authority issuing the storage licenses [2]. Licenses for all 12 on-site storage facilities, two centralized facilities, one facility at the former Jülich research reactor and another one at the former WWER reactor site in northeastern Germany are based on that concept which was initially established more than 30 years ago. In the meantime several casks reach 20 years of successful storage operation without any relevant failure. So far all storage licenses are limited to 40 years (only one site had a limitation to 20 years and is now under an extension procedure) and it has to be pointed out that they are all site specific licenses concerning plant specific fuel properties and cask types which means that there are no general cask type licenses issued for storage purpose. On the other hand, storage periods were generally limited for administrative reasons expecting a final repository being available to dispose of all the spent fuel and HLW within that period of time. Consequently, all safety assessments and their evaluation have been performed concerning a 40 year timeframe. Longer periods of time have never been considered so far.

The robust cask design concept containing only passive safety relevant structures and components results in very little maintenance needs during storage. The complete cask design is configured to operate properly during the entire storage period. For that purpose very high quality standards have been established for all phases of manufacturing, loading and storage including strict criteria for drying the cask interior and demonstrating leak-tightness of the two independent barrier lid systems. This guarantees stable inert conditions specifically inside the non-accessible cask cavity added by protection measures for outer surfaces to prevent degradation caused by ambient conditions like air pollution and moisture. However, these accessible areas can be inspected during storage and maintenance measures can be performed if necessary but obviously should be minimized due to worker's dose minimization.

3. AGING MANAGEMENT ISSUES DURING DRY INTERIM STORAGE

With the storage license all relevant operation and maintenance needs including a repair concept for the hypothetical case of a lid failure are obliged. The complete operating regime of the storage facility is defined by an operating handbook. On that basis the storage facility is operated by the licensee under permanent supervision by the responsible atomic state authority supported by contracted independent expert organizations (e. g. TÜV, BAM).

So far aging management issues are considered routinely during operation. To address and discuss issues and experiences of general interest information exchange platforms have been established by operators on the one hand and by authorities and their experts on the other hand. Sharing operational experiences allows a more efficient optimization of procedures and evaluation of findings, especially the identification of systematic aspects when at first it might look like a single event from the perspective of an individual storage facility.

Concerning international requests on specific guidance, procedure and documentation needs for periodic safety inspections and aging management the German Federal Ministry for the Environment, Nature Conservation, Building and Reactor Safety (BMUB) has assigned the German Waste Management Commission ESK to develop specific guidelines addressing these issues. This has been done over the last three years including a test phase with two selected sites which performed first periodic safety inspections based on draft documents and supported by independent experts. The outcomes have been discussed in a stakeholder hearing in November 2013 and major aspects are considered for the final version of the guidelines which are planned to be established by mid-2014.

Periodic safety inspections shall evaluate and confirm the safety status of the interim storage facility every 10 years under consideration of all relevant changes during long-term operation. Major aspects are the ongoing safe and reliable operation, efficient and reliable control in case of accidents, control about aging mechanisms with regard to the storage facility, including the casks and their inventory, and compliance with safety requirements concerning safe handling and later transportation of the dual purpose casks.

Aging management represents a major part of the periodic safety inspection guidelines. It includes monitoring of safety relevant damage mechanisms which have been identified and evaluated during the licensing procedure as well as those which may have been identified later during operation. While each periodic safety inspection gathers, summarizes and evaluates all findings discontinuously from a holistic point of view, aging management is a continuous process integrated in the overall operation regime. It defines test and monitoring measures for systems, structures and components concerning their specific degradation and potential failure mechanisms under site specific ambient conditions and stress factors (e.g. temperature, radiation, corrosion).

As mentioned before, safety functions are all passive and mainly related to the casks. With the overall safety evaluation for a storage period of 40 years all aging related aspects have been addressed too, and inspection measures already been implemented if necessary. Examples are the continuous pressure monitoring of lid interspaces and visual inspections of outer cask surfaces looking for damages or changes. Because the cask interior including baskets and fuel elements is non-accessible inert conditions enable long-term stability without inspection needs.

In total the new periodic safety inspection guidelines provide a systematic approach to identify and manage safety related aging mechanisms of interim storage facilities. The procedure shall be implemented into the facility’s operational regime. Outcomes shall be used to improve monitoring programs, test and inspection plans to provide long-term safe operation of every storage facility including the loaded casks until the end of their lifetime. And this will likely be more than 40 years for what interim storages are approved today, see chapter 4.

In case generic aspects have to be addressed this may exceed the options of a single storage operator. E.g. systematic studies on relevant material or component degradation mechanisms usually need broader R&D programs which have to be established by involved stakeholders and independently from routine storage operation. This includes also questions potentially arising with regard to the inaccessible cask interior. Finally, site-specific experiences from all periodic safety inspections and aging management programs shall be shared regularly with other interim storage operators and responsible authorities to gain a broad and common level of understanding for the long-term safe operation of all national interim storage facilities and with regard to transportation of casks after interim storage.

Because dual purpose casks are ruled by two independent regulatory frameworks and transport regulations and requirements from cask design approval are still in place also during long-term interim storage periods, a feasible solution has to be established fulfilling all the needs to guarantee transportability. The international community under lead management by IAEA is already working on the improvement of procedures (e.g. periodic inspections) and requirements for transport casks during long-term interim storage which should finally lead to additions to the regulatory framework. While this work and the formal procedures need some more time to be finished German competent authorities work on establishing the necessary measures and procedures to demonstrate compliance with the valid design approval and safety requirements prior to transportation. This includes also aging management aspects. Publications [3] and [4] address these aspects in more detail. Obviouosly, all required measures from the transport cask design approval regime have to be considered and integrated into the interim storage operation regime, however they are legally independent from each other. Currently, appropriate options are under discussion and it is important to look for consistent, useful and practicable solutions leading to a holistic aging management program during the interim storage of dual purpose casks.

4. EXTENDED INTERIM STORAGE

As explained in chapter 1 the need for the extended interim storage of spent fuel and HLW beyond 40 years is very likely due to the needed period of time to select, investigate, decide, license, and build a deep geological repository in Germany. From today's point of view concerning the new „Repository Site Selection Act" this process will not be finished before the mid-2040's followed by an operation phase of another 30 years, see Figure 2.

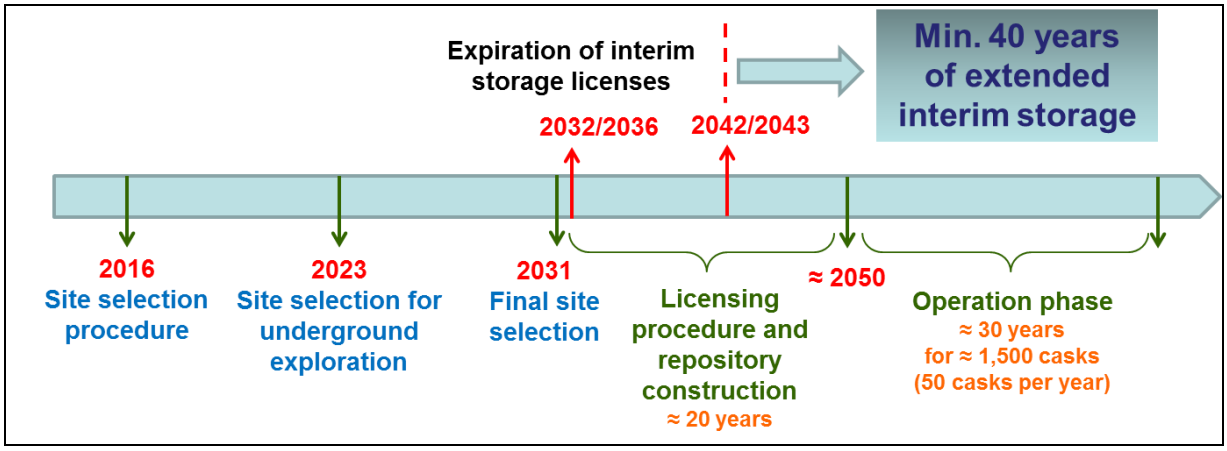

Figure 2: Future SNF and HLW management perspectives in Germany

Additionally, this timeframe is somehow optimistic because likely lawsuits throughout all phases of the process are not considered but may result in further significant delays. All this means interim storage will take place some more decades probably reaching time periods of some 80 years.

Even though interim storage facilities are far from reaching their license expiration today thinking ahead is essential to prepare for necessary technical and also political decisions. Technically the storage systems will have to be assessed and evaluated for significantly longer periods of time and therefore additional information and data have to be gathered starting as soon as possible. Various options exist whether to ship casks to another interim storage facility or to extend the existing storage period, see Figure 3.

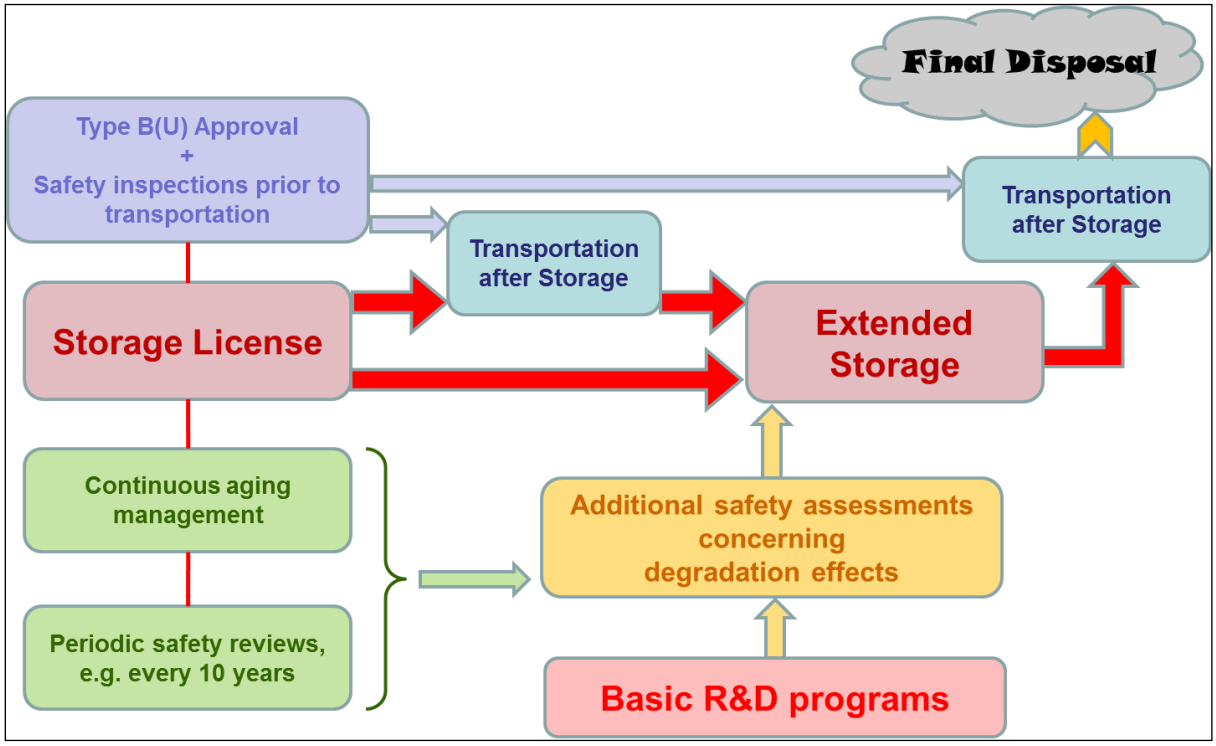

Figure 3: Path forward to extended Storage

To minimize worker dose rates handling and inspection measures should minimized and repackaging should be avoided whenever possible until final preparation for disposal. To reach these goals the dual purpose casks have to demonstrate their sufficient safety levels concerning all safety goals for extended periods of time. Needed information can be gathered from periodic safety inspections and aging management programs added by results from generic R&D programs with regards to long-term performance of specific structures, systems and components.

Some years ago BAM has started first investigations concerning the long-term performance of metal seals with regard to decreasing pressure forces and elastic recovery depending on temperature and holding time. Findings show no influence on the high-quality seal function with required standard helium leakage rates below 10^{-8} Pa·m^3/s. Extrapolation to longer periods of time seems to be easily possible but has to be verified by continuation of the tests. Detailed information about the test series and preliminary results can be found in recent publications [5], [6], [7]. Exemplarily these tests demonstrate how to gain additional data timely for demonstrating long-term performance of structures and components used for interim storage. Other tests performed by BAM consider degradation mechanisms of polymers used for neutron shielding purposes. Radiation doses and thermal aging provoke structural changes of the material resulting in degradation of certain material properties, see also [7]. Nevertheless, safety relevant loss of function is not to be expected from today's perspective and in addition neutron radiation doses and thermal loads from spent fuel and HLW decrease over time.

5. CONCLUSIONS

The current status of the German spent fuel and HLW management program shows significant tendencies towards dry interim storage in dual purpose casks exceeding the so far approved 40 year period. Existing knowledge and experiences from more than 20 years of cask operation demonstrate high levels of safety and reliability of the approved storage and cask systems. While Germany faces out nuclear electricity production and is going to shut down all nuclear power plants within the next decade interim storage facilities will have to operate safely and reliable for a much longer period of time and lastly independent from adjacent nuclear installation. This makes improved safety inspection and Aging management programs indispensable and for that reason they are currently developed and established as explained in the paper. Findings and results from these programs will help to satisfy data needs when application of lifetime extensions for interim storage facilities becomes relevant in the future. Other data needs will have to be satisfied by generic investigations of materials, structures and components including the inaccessible cask interior. For that purpose a kind of a national R&D program might be a sufficient approach involving all relevant stakeholders.

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