Proceedings of the 18th International Symposium on the Packaging and Transportation of Radioactive Materials
PATRAM 2016
September 18-23, 2016, Kobe, Japan

5006 Spent Nuclear Fuel and HLW Storage towards Disposal - Challenges and Perspectives of an Integrated Approach -

Holger Völzke
Bundesanstalt für Materialforschung und –prüfung (BAM)

Dietmar Wolff
Bundesanstalt für Materialforschung und –prüfung (BAM)

Abstract

The safe and secure interim storage of spent nuclear fuel and high-level waste (HLW) from nuclear power reactors is a major issue in the long term. Due to the lack of repositories for final disposal of high-level and mostly heat generating nuclear wastes and significant delays of related siting procedures throughout the world, safe interim storage for up to 80 years or even longer is inevitable from today's perspective. For this purpose dry cask storage is increasingly favoured. Thus, efficient strategies - whether technically, economically or politically - are requested to cover (extended) interim storage, subsequent transportation, and final disposal in an integrated approach.

This paper describes and discusses the major challenges of spent fuel management in Germany after the phase-out of nuclear electricity generation was decided in 2011 and a new repository siting procedure was implemented in 2013. Consequences from those decisions which were legally founded by amendments of the German Atomic Energy Act (AtG) result in the need to transfer all remaining spent fuel from limited reactor operation (last reactor shutdown until the end of 2022) into casks for subsequent dry interim storage on-site. Storage licenses are generally issued site-specific considering specific dual purpose casks (DPC) and their inventories and they are generally limited to 40 years so far. But the need for extending the interim storage period in the future has become obvious. Even though, this may not be an issue to be solved already today questions about additional safety demonstrations will arise as soon as licenses need to be extended. Certainly, these questions will ask for reliable data about the long term performance and safety of structures, systems, and components, e. g. the long term performance of cask components and materials like bolted closure systems including metal seals, or fuel rod behaviour concerning cladding materials under stress and temperature conditions. In case of dual purpose casks for storage and transportation this includes aspects on how to demonstrate transportability during or after several decades of interim storage. Long term investigations often require plenty of time and therefore need to be initiated timely.

Ongoing R&D programs addressing those issues and major findings of the German disposal commission concerning the upcoming disposal site selection procedure and requirements are mentioned including aspects regarding retrievability or recovery of potential disposal canisters (including the existing dual purpose casks) from a deep geological repository.

Introduction

Spent fuel from nuclear power plants in Germany is generally transferred into dual purpose casks approved for transportation and dry long term storage. After the phase out decision the last German nuclear power plants are going to be shut down by the end of 2022 and some years later all pools will be emptied and all fuel assemblies will be stored in almost 1,100 casks with a total amount of some 10,500 tons of heavy metal. The phase out decision became legally binding with an amendment of the Atomic Energy Act in August 2011 after the Fukushima accident.

Furthermore, two years later the German federal parliament decided to establish a completely new siting process to find the best suited deep geological formation to host spent nuclear fuel and HLW. As a major milestone the respectively amended Atomic Energy Act required the final site decision to be made by 2031. To establish a consent-based siting process, involving all stakeholders including the public, a 33 members commission was established which came out with its final report by the end of June 2016. This report is now open to public comments and will be finally discussed by the environmental board of the federal parliament in September 2016. Altogether, the repository siting process is expected to be very complex and time consuming and will probably lead to significant further delays beyond 2050 until a repository will be located, licensed, built, and placed into operation. Consequently, an extension or reissue of the current interim storage licenses whether at the existing or at new locations is inevitable and additional periods of some decades will have to be considered.

As a major prerequisite for the German spent fuel management towards disposal all DPCs require a permanent valid package design approval consistent with IAEA regulations and national regulations for the transportation of dangerous goods. On the other hand interim storage facilities are licensed by a different regulatory regime specifically according to storage site and the nuclear inventory to be stored. Concerning cask operation during storage and subsequent transportation whether to another storage site or already to the final disposal site interface issues like ageing effects and ageing management provisions regarding the long term need to be addressed. This includes casks, components and materials as well as the spent fuel assemblies and fuel rods. An integrated approach considering the needs and requirements for interim storage, transportation and transfer of spent fuel to final disposal offers significant advantages to manage all relevant interface issues regarding the safe and secure long term cask operation.

The German Interim Storage Concept [1]

The initial spent fuel management policy in Germany considered dry spent fuel and HLW storage in dual purpose transport and storage casks at two central interim storage facilities Gorleben and Ahaus. Since 1994 two options were addressed by the German Atomic Energy Act: Direct disposal and reprocessing of spent fuel. After the two central interim storage facilities started their operation minor contamination issues during spent fuel shipments to France for reprocessing finally led to a transport ban followed by the elimination of the reprocessing option in 2005 and to an end of the existing contracts with France and the United Kingdom. In addition, all spent fuel from nuclear

power reactors was decided to be stored at the nuclear power plant sites and therefore 12 on-site interim storage facilities were licensed, built and taken into operation. Additionally, fuel from the former AVR research reactor in Jülich is stored in an interim storage at Jülich research center, Thorium High-Temperature Reactor (THTR) fuel at Ahaus, and fuel from of Water-Water Energetic Reactors (VVER fuel) of former German Democratic Republic at Greifswald. In total, more than 1,100 loaded casks are currently stored at 16 interim storage sites.

The dry interim storage concept for spent fuel and HLW was established around the 1980s and has remained in force since that time. “Guidelines for Dry Cask Spent Fuel and Heat-generating Waste” [2] have been issued and published by the German Nuclear Waste Management Commission (ESK). The document describes major safety goals and related design requirements as well as the technical concept of accident safe dual purpose casks for transportation and storage. The storage period is generally limited to 40 years. This period results from the former spent fuel management concept consisting of centralized interim storage, a waste conditioning plant and a deep geological repository being available until 2035 at the latest.

The dual purpose casks consist of a monolithic thick-walled cask body made of ductile cast iron or forged steel and a bolted double barrier lid system equipped with metal seals. The lid system is permanently monitored to confirm proper leak-tightness. However, the lid closure system is qualified for the entire storage period of up to 40 years so far, a qualified repair concept in case of a hypothetical lid failure is established as well. The cask interior is vacuum dried and helium filled providing inert conditions throughout storage minimizing potential degradation effects of fuel assemblies and fuel baskets. All major safety goals are fulfilled by the casks, though they are stored in a storage building providing monitoring, handling and maintenance equipment as well as weather protection and additional shielding.

Concerning cask shipment, a permanently valid Type B(U) package design approval is required to guarantee transportability of all stored packages at any time during the entire storage period. This means revalidation of the package design approval is to be done periodically depending on the issued timeframe.

The storage of nuclear fuel, including spent fuel and radioactive waste with significant contents of fissile material requires a license under § 6 AtG (if the proportion of certain uranium and plutonium isotopes exceeds the limits specified § 2, para. 3 AtG). Since the end of July 2016 the licensing authority in this instance is the Federal Office for the Regulation of Nuclear Waste Management (BfE) (before that the Federal Office for Radiation Protection (BfS) was responsible), while supervision is performed by the competent authority of the respective “Land” (Federal State). Storage licenses issued by the competent authority contain all relevant safety evaluations to satisfy the protection goals “safe enclosure”, “shielding”, “subcriticality”, and “heat dissipation” under operational and accidental conditions at the specific storage facility and define conditions and requirements for safe and secure cask and facility operation. As mentioned, ESK guidelines [2] define basic design and approval requirements. “ESK Guidelines for Periodic Safety Inspections and

Technical Ageing Management for Interim Storage Facilities for Spent Nuclear Fuel and Heat-generating Radioactive Waste" [3] offer guidance concerning actions, documentation, and evaluation of storage operation including appropriate ageing management systems.

In the meantime loaded dual purpose casks are stored for up to almost 25 years without major technical problems. Respective safety demonstrations and evaluations were performed for maximum license periods of 40 years under consideration of potential accident scenarios on site and degradation effects. Due to robust design features and qualified and approved manufacturing, loading and storage procedures, relevant stress factors have been minimized. This includes potential corrosion from the interior and from the outside. Therefore, careful vacuum drying procedures are essential to ensure inert conditions in the cask cavity and also at the metal seal closure systems. From the outside, protection measures are established to avoid corrosion effects by moisture and air pollutants. For those reasons, inspection and maintenance measures during storage operation could be minimized and all relevant safety functions are passively guaranteed.

Considerations with Regard to Extending Interim Storage beyond the Initial License Period

Due to the delayed availability of a final repository, extended interim storage of spent fuel and HLW beyond 40 years is an upcoming issue in Germany. Although the initial time limit is not a technical limit, any license renewal will require additional safety demonstrations taking into account potential degradation effects, ageing mechanisms, adequate assessment methods and the current technical and scientific state of the art. For this purpose, systematic analyses are required to identify relevant degradation mechanisms and stress factors (thermal, mechanical, radiological, environmental). Furthermore investigations will be necessary to provide information and data about quantitative changes in material properties and component or system functions over time periods of up to 100 years.

For various and sometimes similar reasons many other countries also face the need for extended spent fuel storage towards reprocessing or disposal. This encouraged many organisations such as IAEA and OECD/NEA to draw increasing attention to this subject. Several programs, e.g. IAEA Coordinated Research Programs (CRP) or the Extended Storage Collaboration Program (ESCP) in the U.S., were established with the main purpose to identify, address and close relevant technical data gaps and to share and discuss gathered experience on an international level.

A specific IAEA consultancy has been working on "Extending Spent Fuel Storage until Transport for Reprocessing or Disposal" and a Technical Meeting with broad international contribution and participation has been held in Vienna in October 2012. The proposed technical report as drafted in early 2016 identifies issues and challenges relevant to the development and implementation of options, policies, strategies and programs for ensuring safe, secure, and effective storage of spent fuel until transport for reprocessing or disposal. Major topics include ageing management, design and siting for future spent fuel storage systems, spent fuel storage configurations, regulatory and policy considerations, public confidence and last but not least managing interfaces throughout the

fuel cycle. Further information is given by [4].

BAM has early identified the needs to provide data about the long term performance of major safety relevant components and systems and a research program has been initiated primarily with regard to the long term performance of metal seals of bolted closure systems. Laboratory tests under various temperatures with original seal types are running for several years and are supposed to be continued and expanded in the future. The latest status and results are presented by [5].

In addition, the German Waste Management Commission (ESK) has issued a "Discussion paper on the extended storage of spent fuel and other heat-generating radioactive waste" [6]. This paper addresses at first long term aspects of cask suitability and future expectations based on the current experiences. Moreover, potential lack of knowledge regarding spent fuel and other inventories is discussed followed by issues on transportation after storage. It is stated that *"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"*. Furthermore, alternative concepts for the extended interim storage are discussed: (1) Extended interim storage at current sites, (2) Consolidated interim storage at a few regional sites, or (3) Centralized interim storage possibly at the future repository location. Other aspects being discussed in the paper are licensing issues with the clear statement that any extension of storage periods whether for existing or new sites requires a new storage license. It is also mentioned that a specific regulatory framework for the specific needs of future spent fuel management after shutting down all nuclear power plants should be advantageous. Further considerations include knowledge management to be provided by storage operators, cask manufacturers, authorities and technical expert organizations; economical and ethical aspects and finally a discussion of the current regulative system including responsible authorities and their interaction in the areas of storage, transportation, conditioning and disposal. Specific attention should be laid on the stepwise development of appropriate disposal container concepts for potential host rock formations taking into consideration the already existing packages and inventories in the sense of a holistic approach.

Interface Issues Concerning Interim Storage, Transportation and Final Disposal

As mentioned before and also addressed by [4] and [6] interface issues between interim storage, subsequent transportation and final disposal are key points for a future sustainable spent fuel management strategy.

Regarding transportation after storage, IAEA has launched an initiative to identify and address specific transportation issues after long term storage and to develop suggestions on how to improve regulations in the future. The respective Joint Working Group on Guidance for an Integrated Transport and Storage Safety Case for Dual Purpose Casks for Spent Nuclear Fuel has been working from 2010 to 2015 and has finally issued a report. The report addresses topics regarding transport packages to be stored over long periods of time in storage facilities (usually separately licensed) under specific and well known operation conditions and limited access for periodic inspections, and

which are going to be shipped just once after the storage period. Specific adjustments to the Safety Standard Series SSR-6 and the related Advisory Material SSG-26 have been suggested under consideration of the outcomes of the aforementioned report and are now implemented into the regular revision process in the timeframe 2015-2018. Afterwards, the adaption to the national regulations takes some additional time; and therefore, the responsible authorities decided to consider additional specific aspects especially on long term and ageing management issues for design approval procedures of such kind of DPC already now.

With the reset of the German repository siting process for disposal of spent fuel and HLW, interface issues regarding potential concepts for disposal containers have also been discussed and major findings have been published by the final report issued by the disposal commission as mentioned already in the introduction of this paper. Prior to that final report the ESK has provided the document "Recommendations on requirements for disposal packages for the disposal of heat generating radioactive waste" [7] explaining prior generic safety requirements published by the former Federal Ministry for the Environment (BMU) in 2010 [8]. The ESK recommendations [7] explain generic safety requirements and the role of disposal packages in general and along with manufacturing, repository operation and the post-operational phase. All requirements are related to those topics and listed and explained in tables. Major aspects include the safe long term confinement of the radioactive inventory adjusted to barrier function needs of the repository, radiation protection, compatibility with other barriers, decay heat removal and package integrity during handling operations and along with retrieval and recovery options over 500 years after package disposal. Finally, this kind of requirements which are dependent on the specific host rock formation defines the criteria for potential design concepts for disposal packages. Some disposal container design concepts have been already developed and tested like the Pollux cask in Germany (salt), copper canisters in Finland and Sweden (granite), and steel canisters in Switzerland (clay).

With regard to the overall reset of the repository siting process in Germany, the disposal commission published its comprehensive final report on July 05, 2016 [9] for comments to the public and for final political debate in September 2016. This report has nearly 700 pages and addresses all relevant issues in two major parts. Part A contains the summary and recommendations while Part B represents the full report of the disposal commission. The recommendations include an interpretation of the term "highest possible safety level" and the procedure towards a disposal site with the highest possible safety level including the procedure in general, public participation, decision criteria and their role in the process. Other recommendations consider socio-political aspects including a re-arrangement of responsible authorities and recommendations to the legislator. Regarding interface issues the report addresses the fact of necessary interim storage prior to disposal in chapter 5.7 (Part B) and requirements for disposal canisters in chapter 6.8 (Part B). The Federal Office for the Regulation of Nuclear Waste Management (BfE) is to be established as new responsible organisation within the portfolio of the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). BfE tasks are e.g. specification of site based exploration programs and test

criteria followed by nuclear licensing. On the other hand the Federal Company for Nuclear Waste Management (BGE) is to be established to manage the site selection process, to provide safety assessments, repository construction, operation, and decommissioning.

Conclusions

Unexpected changes in national nuclear policy have significantly affected spent fuel management strategies in Germany during the last decades. The initial spent fuel and HLW disposal concept has been delayed and finally "reset" by federal law in 2013. Repository site selection criteria and procedures are going to be defined in the next time including amendments of the legislative basis. Overall this new site selection process is still going to be controversial and time consuming with the consequence that interim storage will have to be extended significantly even in the optimistic case of a stringent repository siting process.

The consistent German concept of dry interim storage in dual purpose casks has proven to be a safe and secure spent fuel management strategy over the last two decades without any relevant safety issues. But the need for the extended interim storage of spent fuel and HLW casks until disposal implicates additional challenges for the nuclear waste management strategy. Recently, governmental research programs have been adjusted to address technical and scientific issues also in the predisposal area and BAM has already initiated specific research projects to investigate the long term performance of safety relevant cask components, e.g. metal seals, taking into consideration storage periods of up to 100 years. Extended interim storage, whether on existing sites or at new locations, also needs a broad socio-political acceptance.

In view of the German nuclear phase out, at least 25 years of just interim storage without any reactor operation have to be considered between 2025 and 2050. This leads to the conclusion that the establishment of an independent regulatory framework for the specific needs of interim storage and subsequent transportation of spent fuel and HLW would be beneficial. In addition, knowledge management and staff recruiting, education and training at all stakeholder organizations like cask manufacturers, storage operators, authorities and technical expert organizations are a major issue to be solved in the long term.

Finally, the development of suitable disposal canister concepts in due time at the interface between interim storage and subsequent transportation (including spent fuel and HLW conditioning needs) is essential whether new cask designs and their inventories are well adapted to the geological disposal environment or the existing dual purpose casks (DPC) are improved for final disposal.

Both options include specific pros and cons. In general interim storage, subsequent transportation and final disposal are closely linked. Integrated approaches concerning waste package designs and operations are supposed to be beneficial for the establishment of sustainable long term spent fuel and HLW management strategies.

References

[1] Völzke, H., and Wolff, D.: “Long Term Storage of Spent Nuclear Fuel and HLW in Dual Purpose Casks towards Disposal - Challenges and Perspectives”, Proceedings of the International Conference on the Management of Spent Fuel from Nuclear Power Reactors: An Integrated Approach to the Back End of the Fuel Cycle, Paper ID-17, Vienna, Austria, 15–19 June 2015.

[2] “Guidelines for Dry Cask Storage of Spent Fuel and Heat-generating Waste”, Nuclear Waste Management Commission (ESK), Revised version of 10.06.2013, http://www.entsorgungskommission.de/englisch/downloads/eskempfehlungesk30llberevfassung10062013en.pdf

[3] “ESK-Guidelines for Periodic Safety Inspections and Technical Ageing Management for Interim Storage Facilities for Spent Nuclear Fuel and Heat-generating Radioactive Waste”, Nuclear Waste Management Commission (ESK), Version of 13.03.2014, http: //www.entsorgungskommission.de/englisch/downloads/eskempfpsuezl20140313hpen.pdf

[4] Carlsen, B., Bevilaqua, A., Chiguer, M., Wasinger, K., Grahn, P., Saegusa, T., Sampson, M., Seelev, I., and Wolff, D.: “Extending Spent Fuel Storage until Transport for Reprocessing or Disposal”, Paper ID 5036, Proceedings of the 18th International Symposium on the Packaging and Transportation of Radioactive Materials PATRAM 2016, September 18-23, 2016, Kobe, Japan.

[5] Wolff, D., Völzke, H., Jaunich, M., Probst, U., and Nagelschmidt, S.: “DPC Ageing Management Issues and Long-term Investigations of Metal Seals”, Paper ID 5029, Proceedings of the 18th International Symposium on the Packaging and Transportation of Radioactive Materials PATRAM 2016, September 18-23, 2016, Kobe, Japan.

[6] “Discussion paper on the extended storage of spent fuel and other heat-generating radioactive waste”, Discussion Paper of the Nuclear Waste Management Commission (ESK) of 29.10.2015, http://www.entsorgungskommission.de/sites/default/files/reports/DiskussionspapiervZL29102015hpen.pdf

[7] “Requirements for disposal packages for the disposal of heat generating radioactive waste”, Recommendation of the Nuclear Waste Management Commission (ESK) of 17.03.2016 (only in German). http://www.entsorgungskommission.de/en

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

[9] Abschlussbericht der Kommission Lagerung hoch radioaktiver Abfallstoffe: Verantwortung für die Zukunft - Ein faires und transparentes Verfahren für die Auswahl eines nationalen Endlagerstandortes. Deutscher Bundestag Drucksache 18/9100, 18. Wahlperiode, 05.07.2016 (only in German)