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Original Article

Dry storage of spent nuclear fuel and high active waste in Germany—Current situation and technical aspects on inventories integrity for a prolonged storage time

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A B S T R A C T

Licenses for the storage of spent nuclear fuel (SNF) and vitrified highly active waste in casks under dry conditions are limited to 40 years and have to be renewed for prolonged storage periods. If such a license renewal has to be expected, in accordance with the new site selection procedure, a final repository for spent fuel in Germany will not be available before the year 2050. For transport and possible unloading and loading in new casks for final storage, the integrity and the maintenance of the geometry of the cask's inventory is essential because the SNF rod cladding and the cladding of the vitrified highly active waste are stipulated as a barrier in the storage concept. For SNF, the cladding integrity is ensured currently by limiting the hoop stress and hoop strain as well as the maximum temperature to certain values for a 40-year storage period. For a prolonged storage period, other cladding degradation mechanisms such as inner and outer oxide layer formation, hydrogen pick up, irradiation damages in cladding material crystal structure, helium production from alpha decay, and long-term fission gas release may become leading effects driving degradation mechanisms that have to be discussed.

1. Introduction

In Germany, the dry storage of spent nuclear fuel (SNF) in casks was implemented in 1995 with the establishment of the first cask in the independent interim storage facility at Gorleben. The first casks with vitrified highly active waste (HAW) from spent fuel reprocessing arrived in Gorleben in 1996. With the amendment of the German Atomic Energy Act [1] in 2002, which ruled out the reprocessing of SNF that took effect from 2005, the dry storage is the only SNF treatment option or a so-called "temporary" disposal option in Germany. For the interim storage of SNF in casks under dry conditions, 16 storage facilities are available. Twelve of them are on sites of nuclear power plants and operated by the utility companies. The remaining four—located in Ahaus, Gorleben, Jülich, and Lubmin—are operated by companies in contract with the federal government. Casks with HAW are stored in Gorleben and Lubmin. Besides SNF casks, 113 casks with HAW are currently stored in Gorleben and Lubmin. Germany still has the obligation to take back some casks with HAW and moderately active waste from fuel reprocessing abroad. The expected amount of radioactive waste for a final repository in Germany is approximately 1100 casks with SNF from the LWRs (light water reactors) and more than 200 casks with HAW and moderately active waste from reprocessing. In addition, approximately 300,000 m^3 of low active waste will go into the final repository in Konrad, and approximately 220,000 m^3 of waste is expected from retrieval of low active waste from the first nuclear research repository in Germany, the salt mine ASSE II.

From 1973 to 1979, a site selection procedure for a deep geological final repository was carried out. The selected sites at that time were part of a controversial public discussion. In 1977, the government of the state of Lower Saxony, where most of the possible sites were located, selected the Gorleben salt dome as the location for a deep geological final repository and Gorleben for a nuclear waste–processing center. In Gorleben, a pilot conditioning plant for SNF was built but was never used until today; an interim storage facility was built, and the salt dome was explored for its suitability as a final repository. These developments were accompanied by further controversial public discussion and violent protests. The lack of political consensus led to several breaks in the geological exploration of the salt dome with the last break in 2012, lasting until now.

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A new understanding of the public participation in the political decisions in nuclear issues after the Fukushima accident caused a restart of the process of finding and exploring a final repository site in Germany; this was from a technical point of view in works already done in the 1980s at the Gorleben site. With the amendment of the Site Selection Act [2] in 2013, discussion about a final repository for nuclear and other radioactive waste started from scratch again. According to this act, the site selection procedure should be finished in 2031. Based on the experience with nuclear installations in Germany, one can assume a time delay of more than a decade for finishing this process and another decade for commissioning. Therefore, 2050 or even later may be a more likely date for realizing and operating a final repository for SNF and HAW in Germany.

At present, the storage time for SNF and HAW is limited to 40 years by cask licenses, starting with the loading date. The same time span applies to the storage facility starting with the first stored cask. Having a date later than 2050 in mind, the storage period has to be extended to more than 60 more years; meanwhile, a period of one hundred years is under discussion. As a consequence, licenses have to be renewed for both the casks and the storage facilities. The storage facilities and their installations can be maintained as every other building and technical installation, even if the requirements for the storage facilities are higher than those for other installations. If the requirements of the facilities are not met in future, a new facility can be built, and the casks can be transported to the new site. The situation is quite different for the casks and their inventory. After the phaseout of nuclear power production in Germany [1] in 2022, the nuclear power plants will be decommissioned, which means that further maintenance of the casks and their inventory is no longer possible at the nuclear power plants. There are concepts available to restore cask tightness after detection of a leaking seal, but repacking the inventory of SNF and HAW in a new cask is not possible with the available facilities. Therefore, for transporting to the repository site and conditioning for later final disposal, the integrity and the maintenance of the geometry of the cask inventories are essential. Especially, the integrity of the SNF rod cladding and the cladding of the vitrified HAW are stipulated as barriers in the storage concept and are necessary to secure the specified geometry.

2. Verification concept for inventory integrity during dry storage

2.1. Regulatory framework

The verification concept for the dry storage of SNF and HAW in casks is—besides the scientific and technical knowledge—based on legal provisions and the derived regulations and technical rules for nuclear issues in Germany. This regulatory framework is the basis for safety assessments in the handling of radioactive substances, the operation of nuclear facilities, and the storage of radioactive substances. Only a condensed overview is given here to classify the activities of the technical expert in this framework. The rule set is structured like a pyramid in its level of detail. If one approaches the base from the top, the requirements become more and more detailed, up to the specification of concrete embodiments in the standards and technical rules.

The Table 1 will give an overview of the regulatory hierarchy of the German national regulations:

For the technical assessment of the protection objectives, concrete requirements are already set up in the ordinances, which must be taken as concrete evaluation criteria for the technical expert. For the dry interim storage of SNF and HAW, the guidelines on dry interim storage of spent fuel and heat-generating radioactive waste in casks [3], issued by the Nuclear Waste Management Commission (ESK) in 2013, are an important set of rules for the technical evaluation. They can be seen as an important part of the implementation of the generic requirements of the IAEA Safety Standard on Storage of Spent Nuclear Fuel [4] in the German national regulatory framework for the assessment of the dry storage capabilities and are comparable to the interim staff guidance for spent fuel storage and transportation of US NRC Regulations, Title 10.

2.2. Verification for a safe dry storage period of 40 years

The ESK guidelines [3] apply to the dry storage of spent fuel and heat-generating radioactive waste in tightly sealed metal canisters for a storage period of 40 years. It is already stated in these guidelines that for a period exceeding 40 years, additional and appropriate verification of the long-term behavior of the casks and their inventory have to be provided. With these verifications, the available experience of the 40-year storage period can be considered.

The guidelines of the ESK are found on the requirements of the German Radiation Protection Ordinance [5], which states that any unnecessary radiation exposure or contamination of humans and the environment shall be avoided and any necessary radiation exposure or contamination of humans and the environment shall be minimized, even below the respective limit, by taking into consideration the state of the art and all circumstances of individual cases. From these basic safety objectives, fundamental safety objectives of “confinement of radioactive material”, “safe decay heat removal”, “maintenance of sub criticality”, “avoidance of unnecessary radiation exposure,” and “limitation and control of radiation exposure of the operating personnel and the general public” were

Table 1
Regulatory framework for nuclear issues in Germany.

Issuer	Law, provision, standard, or rule	Legally binding nature
Federal legislator	German Basic Constitutional Law Atomic Energy Act	Generally
Federal government and federal council	Ordinances (e.g., Radiation Protection Ordinance) General administrative provisions	 For authorities
Federal government and state authorities	Safety requirements for nuclear power plants Regulatory guidelines by the BMUB (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety)	By specification in the license or by supervisory measures in the individual case
Guidelines and recommendations from advisory bodies	Reactor Safety Commission (RSK) The German Commission on Radiological Protection (SSK) Nuclear Waste Management Commission (ESK)	
Standards from the Nuclear Safety Standard Commission	KTA safety standards	
Standards and rules from the industry and utility operators	Technical specifications for systems and components, rules for organization and operation (e.g., quality management systems), and other rules and standards	

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