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Dual Purpose Cask Safety Evaluation - Expertise in Dry Storage

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ABSTRACT

In Germany dual purpose casks for spent nuclear fuel (SF) or high level radioactive waste (HLW) are used for safe transportation and interim storage. Key safety issues in both fields are the safe enclosure of the radioactive material, the safe removal of decay heat, securing nuclear criticality safety, limitation of radiation exposure to acceptable levels and keeping it as low as reasonable achievable (ALARA principle).

Whereas these safety requirements during transportation are ensured by the Type-B(U)-design testing and approval procedure on basis of internationally agreed IAEA (International Atomic Energy Agency) requirements storage licenses are issued on national and site specific safety analyses.

This paper presents experiences from recent interim storage safety evaluation and licensing procedures in Germany on basis of a Type-B(U) certified cask designs concerning specific differences from operation and accident conditions inside the storage facility. The focus is laid on the interaction of cask and building structures with regard to shielding, heat removal and accident analyses including aircraft crash. Basic safety is assured by thick-walled metal casks with monitored double lid systems. They also reduce radiation to levels where workers can safely operate and maintain the casks inside the storage facility. The storage building e. g. provides additional shielding and protection against external hazards depending on the building construction. In addition, the storage building helps to reduce radiation levels at the boundary of the storage site well below regulatory limits given by the German Radiation Protection Ordinance (StrSchV).

INTRODUCTION

High level waste accrues from the production of energy by nuclear power stations spent nuclear fuel and from reprocessing of used nuclear fuel. The SF can be reprocessed whereby the SF and the radioactive residues have to be transported and stored for a period of time. An alternative approach as practiced in Germany is to directly transport the SF to an interim storage facility. In both cases, the SF or the HLW has to be transported and stored in a safe and secure way. After the interim storage the casks have to be transported again, this time to reach a final disposal. For their long-term interim storage different technical concepts have been established from wet storage in pools to dry storage in transport and storage casks. The events of Fukushima in March 2011 have shown different effects on both options with specific advantages and disadvantages and that dry cask storage is a concept with inherent safety margins to prevent activity release.

Currently the dry storage of SF and HLW gains more and more importance, because dry storage features advantages in safety and logistics. This paper describes different systems for dry storage of SF and HLW. This paper also explains exemplarily their specific advantage in combination with dual purpose casks during the process of licensing, erection and operation of selected German dry storage facilities based on BAM and TÜV experience.

SAFETY REGULATIONS AND REQUIREMENTS

As with the transport and storage of all radioactive materials, the transport and storage of SF and HLW must conform to safety requirements. The following safety aspects must be achieved during transport and storage:

- All unnecessary radiation exposure and contamination of man and nature must be avoided and
- All radiation exposure or contamination of man or nature must be kept as low as reasonably achievable (ALARA) and must comply with all international transport regulations (ADR/RID/IMDG-Code) /1,6,7/

These goals are achieved by

- Secure encapsulation of the activity
- Safe discharge of the decay heat
- Subcriticality
- Shielding of gamma and neutron radiation

Basic requirements are defined in several transport regulations as “European Agreement concerning the International Carriage of Dangerous Goods by Road” by the United Nations Economic Commission for Europe (UNECE) /1/ and its equivalents for carriage by rail or inland waterways. The “Guidelines for dry interim storage of irradiated fuel assemblies and heat-generating radioactive waste in casks” edited by the German Waste Management Commission /2/ were just released and set the requirements for dry interim storage in Germany. For storage, the IAEA formulates retrievability as another major safety goal /3/. This aspect can be fulfilled through shipping the SF or HLW in casks for further treatment after interim storage. Therefore dual purpose casks which are suited and approved for transportation and storage similarly are utilized in many countries.

The implementation of the safety requirements is achieved through different transport and storage systems in different ways. In case of wet storage the SF is stored in spent fuel pools with active cooling systems. The water in the pools has the function of heat dissipation and shielding; the activity is encapsulated as long as the fuel rods remain intact. Where necessary, additional filtration of the outgoing air must ensure that no activity is released into the environment. This concept of wet storage is used for spent fuel pools inside nuclear power plants, for central wet storage facilities and e. g. at the reprocessing facilities in Sellafield and La Hague; in this case transport casks are necessary as well. These systems are cheaper in installation but more expensive during operation compared to dry storage in casks. This aspect becomes more and more relevant with increasing storage periods.

For the dry storage of SF and HLW different concepts are in use worldwide. These include HLW storage in concrete vaults with natural air-cooling, e g. at Areva, La Hague, or SF stainless steel canisters being stored in concrete over-packs. Other storage casks consist of various materials like concrete, forged steel or ductile cast iron. It depends on the entire transport and dry storage management system, if additionally storage casks or any reloading will be needed.

SPENT FUEL TRANSPORT AND INTERIMSTORAGE IN GERMANY

In Germany, SF and HLW from SF reprocessing are transported and stored in thick-walled metal dual purpose casks with a double lid system which are approved for transportation and storage. With this concept SF can be removed from nuclear power plants flexibly during operation or later decommissioning and can be stored on-site or elsewhere, e.g. in centralized storage facilities.

Initially, the dry storage of SF in Germany was performed in two central storage facilities in Ahaus and Gorleben starting in the 1980's. This concept was executed for BWR/PWR-SF and THTR (thorium high temperature)-SF from commercial nuclear power plants. High active vitrified radioactive waste from reprocessing of SF in France is already stored in Gorleben. The "contamination-scandal" in 1998 led to public discussion about the risk of transportation of SF and HLW in Germany. The finding of contamination on casks and transport vehicles used for the transport of these casks resulted in a transport ban and subsequent change of the legal basis. As a technical result the discussion led to the construction of on-site storage facilities, which are located adjacent to a nuclear power plant. This concept avoids any unnecessary transportation of SF. So until 2000, 13 applications for the construction of on-site storage facilities were submitted /5/. For these on-site storage facilities three different designs were chosen: two different storage building-types and a tunnel-design.

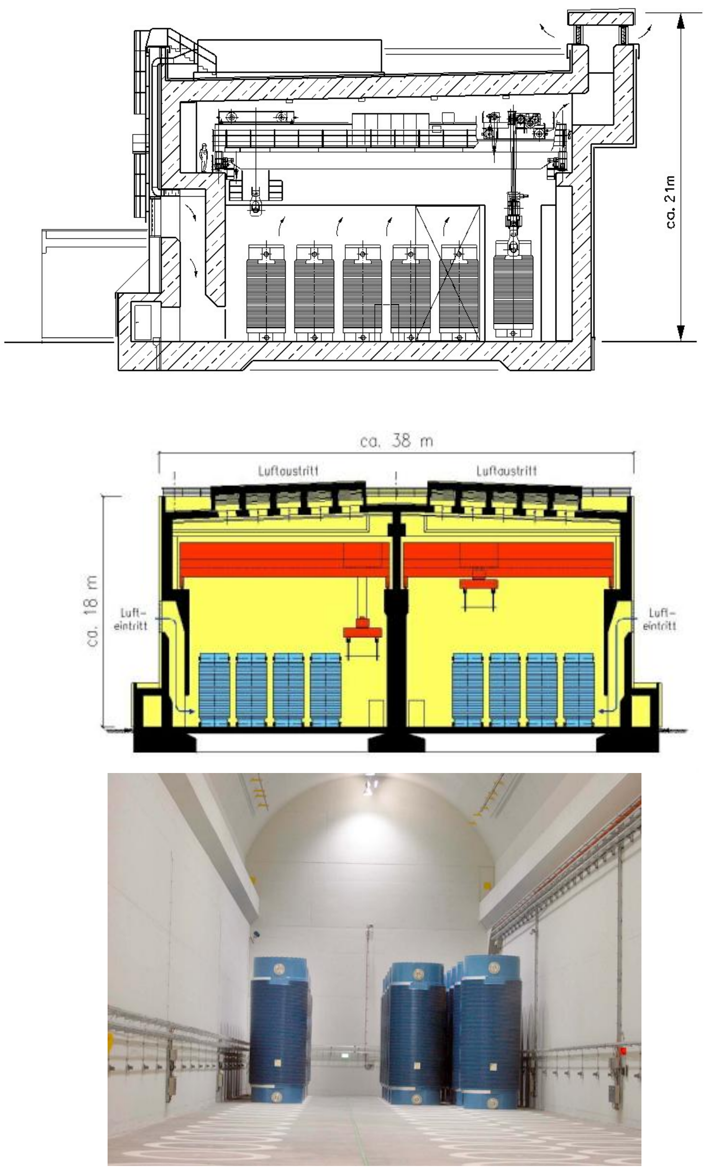

Figure 1: Storage buildings and dual purpose casks for SF and HLW interim storage

At the end of 2003, the last license for these 13 applications has been granted. In 2002 the first and in 2007 the last on-site interim storage facility started operation /5/. In a few cases SF dual purpose casks were stored in small concrete shelters (short term interim storage limited to 5 years) prior to completion of licensing and construction of the main interim storage facility.

Together, the cask and building assure the compliance with the safety requirements. The building protects casks additionally from harmful weather conditions, external effects or man-made hazards. Safe and secure enclosure of the radioactive material as well as the subcriticality is ensured by the cask design. The secure heat removal and shielding is conducted by interaction of cask and building structure. Therefore it is possible to apply only passive systems on the basis of natural convection, which are nearly maintenance free and can ensure their function for a long time without intervention. The double lid systems of the casks represent redundancy of the tight enclosure system and, regarding a hypothetical seal failure during an interim storage period of up to 40 years, allow installing a self-monitoring system. Besides the self-monitored seal function of the casks, periodic reviews monitor the overall conditions of the interim storage facility during storage operation. Furthermore, an ageing management concept is active to monitor long-term and ageing effects of the whole facility.

TÜV NORD Nuclear and BAM were assigned as independent experts by the competent authorities in the licensing procedure for their safety expertise about the application, erection and the operation of the storage facilities on all of these sites. TÜV NORD Nuclear and BAM have checked and reviewed all safety assessments and documentations in the fields of cask designs, location, building structures and technical equipment, heat removal, shielding, subcriticality and safety under operational and accident conditions with state-of-the-art methods and computer codes before the license approval. For some of these sites the TÜV NORD Nuclear and BAM are still in charge on behalf of the competent authorities for supervision of the sites during operation. New cask designs and changes in operation procedures, the building structures or the technical equipment are checked and reviewed by BAM and TÜV NORD Nuclear continuously. Furthermore TÜV NORD Nuclear and BAM lead a German-wide interchange-platform of experience concerning all loadings of SF and HLW into casks, so all relevant information is available to all involved experts organizations, competent authorities, and utilities.

Based on this long-standing and fruitful common work, BAM and TÜV NORD Nuclear have gained huge and unique knowledge and experience that can be used beneficially for similar studies or projects in other countries, especially where dry storage concepts may be considered for the safe long-term management of SF and HLW at present or in the future (http://www.tuev-nord.de/de/storage.htm).

CASK DESIGN TESTING AND APPROVAL

As mentioned above thick-walled dual purpose casks are the main safety component of dry interim SF and HLW storage in Germany. These casks have to demonstrate safety with regard to all relevant objectives as mentioned before. The concept implies a monolithic cask body with integrated neutron shielding components and closed by a monitored double lid barrier system with metal gaskets. Further details are described in the recent ESK guideline /2/.

BAM is the competent authority in design testing and evaluation of all quality assurance measures within the transport license approval procedure and BAM is also involved in the storage licensing procedures by the competent authority for the same cask related aspects. This enables high efficiency and comparative evaluation methods for the same technical and scientific aspects. A major aspect of BAM design testing for interim storage are safety demonstrations for a cask drop onto the ground of the storage building without shock absorbers and in the most severe drop orientation. This requires a systematic study of handling procedures to determine from which positions a cask drop has to be considered and which the most severe scenarios with regard to drop orientation, drop height and target are. Subsequently, safety demonstration for selected most severe drop

scenarios can be performed by experiments and/or numerical calculations. For better public acceptance it is necessary to review the results of the calculations. Therefore, whenever possible, the cask investigation is accompanied by hard cask drop tests, heating tests and immersion tests in original containers /5/.
BAM operates state of the art equipment in both fields with a large drop test facility for cask gross masses up to 200 metric tons and a 2.400 metric tons unyielding concrete foundation in compliance with IAEA requirements and with capable computer systems and different finite element codes such as ABAQUS®, LS-DYNA® and ANSYS®. The analysis of hard cask drop scenarios needs demanding dynamic measurements and/or calculations including specific material data and sophisticated stress and strain evaluation procedures. Verification of numerical models and calculation results by full-scale, model or component tests is usually necessary and also adequate modeling of the foundation or impact limiting structures is essential. BAM has broad experience and competence in these experimental as well as numerical test methods.

Figure 2: Container drop

Other major issues for the interim storage safety evaluation consider the long-term performance of cask systems and components under operational conditions during the entire storage period which is 40 years in Germany so far. Because dual purpose casks are equipped with a double lid system the proper function of the metallic barrier seals is essential. Not only for that reason quality assurance measures for fabrication, assembling and loading procedures and cask operation are of particular importance as well. Each cask has to be fabricated in accordance with approved manufacturing and testing plans. Finally, certificates of compliance are issued for transport as well as storage purpose and with these documents the cask can be loaded and assembled for transport and storage use. Cask loading under wet conditions in a spent fuel pool requires very accurate dewatering and drying procedures afterwards to prevent any relevant corrosion effect during the subsequent storage decades. On behalf of the competent authorities TÜV NORD Nuclear is in charge to witness the loading process and the process of radiological investigations. TÜV NORD Nuclear is also reviewing the loading documentations for SF and radioactive residues from reprocessing.
BAM safety evaluation reports on cask safety under normal operation and accident conditions in combination with TÜV NORD Nuclear safety evaluation reports on inventory and site specific safety aspects are the major basis for any storage license issued by the Federal Office for Radiation Protection (BfS) as the competent

authority in Germany. Licenses have been issued for all applied storage facilities so far and on that basis all storage facilities have been operated safely without any major problems.
For the future, extended storage periods are an upcoming issue due to delays of establishing a deep geological repository in Germany. With regard to that aspect and further international and European developments guidance documents for periodic safety inspections and ageing management have been improved recently and are currently tested with selected storage sites. Furthermore, additional research and development is essential to gain required data on the long-term performance of materials and components like metal seals and polymer components for neutron radiation shielding. BAM has already started such investigations by experimental and analytical methods and an additional test facility with heating and cooling chambers and specific measurement equipment is nearly completed on the BAM Test Site Technical Safety (BAM TTS, see http://www.bam.de/en).

SITE SPECIFIC SAFETY ASSESSMENT

Any application for SF and HLW interim storage has to assess safety under consideration of the above mentioned safety requirements, taking into account all site-specific aspects including cask handling and possible severe incidents or accident scenarios like fire or cask drop from a crane. In Germany, all safety assessments have to be reviewed and evaluated by the competent authority and their experts. Because of similar or identical technical solutions like buildings, casks, operational procedures, many aspects are equally relevant for several sites and safety demonstrations can be easily transferred from one site to another to reduce effort. Some common aspects are explained in the following:
Heat removal: All storage facilities are designed in such a way that the cooling of the casks is performed passively by natural convection of air. The cooling air enters the building at the sides, flows around the casks and is released at the roof, so the decay heat removal is ensured by natural convection without active systems, even under accident conditions and without the need of intervention by working personnel.

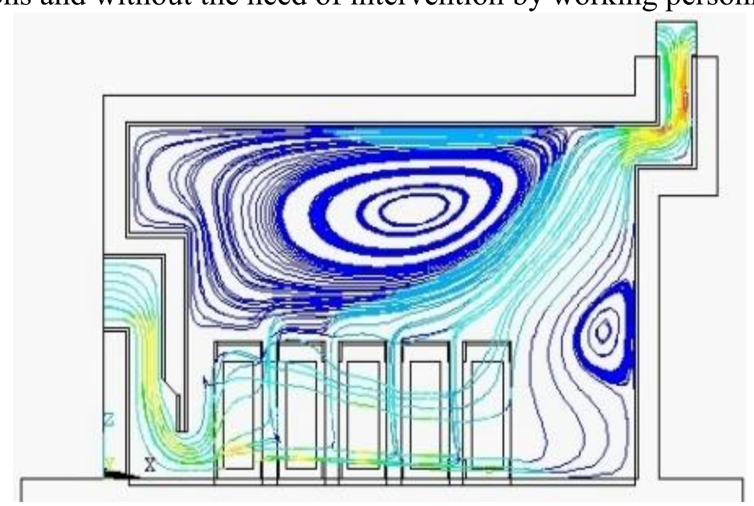

Figure 3: Heat removal from an interim storage facility

Apart from such surface storage halls, rock tunnels can also be used for dry storage of SF. At Neckarwestheim nuclear power plant (GKN), this concept is used due to the specific geography of the site location. There, decay heat removal is ensured by natural convection from the rock tunnel to the surface by additional shafts.
Shielding: On account of the thick concrete walls of the storage buildings, or for rock tunnels the surrounding rock, and the chosen thick-walled cask design, the dose rate outside the storage buildings is reduced effectively to acceptable levels where no further measures for the protection of the workers on the site or the public outside need to be established. Only due to the casks, the dose rate within the storage building is reduced to a level

where handling, emplacement and displacement of casks as well as service operation can take place whenever necessary.
Subcriticality: In order to secure nuclear criticality safety, possible effects of accidents are taken into consideration. In case of dry storage, e. g. re-positioning of fissile material inside the cask is excluded by the cask design including spent fuel basket.
Safe enclosure: The German concept of transport and dry storage of SF and HLW with dual purpose casks gives a maximum level of safety for design base accidents and even beyond design base accidents. This includes on the one hand transport accidents and on the other hand accident conditions while storage like external hazards such as fire, earthquakes, flooding, landslip, shockwave, lightning strike or airplane crash and internal effects such as handling failures or casks drop. The casks and the storage building provide effective protection of the encapsulated activity and guarantee the compliance with the safety requirements. Even after a collapse of the storage building, caused by a beyond design base accidents (e.g. aircraft crash), the casks remain intact and no activity will be released. This high level of safety is established by using passive safety systems and a matching combination of cask and storage building. Even in the Fukushima event, storage casks with SF were not affected significantly by the earthquake or the tsunami /4/. But the storage pools inside the nuclear power plants, depending on active cooling systems, caused massive problems and release of activity after their cooling failed. By using thick dual purpose casks with double lid sealing systems, the activity stays encapsulated under normal operation and even under severe accident conditions without active measures.
If casks have to be repaired, for example in the case one barrier of the double lid sealing system failed, different concepts exist. The casks can be unloaded in the nuclear power plant or – if this option is no longer available – the double lid system can be reestablished by adding an additional third lid above the secondary lid that e. g. is welded to the cask body.

CONCLUSIONS

In Germany, transport and storage in dual purpose casks is the established concept for long-term interim dry storage of SF and HLW whether on-site or in centralized interim storage facilities. Dry storage systems are usually characterized by passive and inherent safety functions ensuring safety even in case of severe incidents or accidents. After the events of Fukushima, the advantages of such passive and inherent safe dry cask storage systems have become more obvious. Safety assessment and evaluation procedures are sometimes challenging but have been performed successfully for many interim storage facilities throughout Germany. Additional licenses are required for various new or modified cask designs and additional spent fuel configurations in the future and under consideration of the German phase out decision. Further delays in the national site selection for a deep geological repository will lead to extended interim storage periods with significant consequences for additional long-term safety demonstrations for storage as well as subsequent transportation. BAM and TÜV NORD Nuclear have broad experience and knowledge in safety evaluation of dry SF and HLW storage systems under all relevant safety aspects defined by international and national regulations. BAM supports also national and international organizations like IAEA with its expertise and cooperates with several international institutes. Both, TÜV NORD Nuclear and BAM, are willing to offer their expertise and support also to international organizations and projects in nuclear waste management if requested.

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/5/ BfS 2008
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/6/ Intergovernmental Organisation for International Carriage by Rail: Regulations concerning the International Transport of Dangerous Goods by Rail (RID 2013)

/7/ International Maritime Organization: International Maritime Dangerous Goods Code (IMDG-Code)