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Impact of Beyond Design Basis Events like those at Fukushima on Used Fuel Management

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Abstract

Currently the only option for USA utilities for Used Nuclear Fuel (UNF) management is wet storage in the fuel pools and/or dry storage of UNF on site. The use of on-site dry storage systems on an Independent Spent Fuel Storage Installation (ISFSI) has become the preferred alternative for many utilities, especially in the USA. AREVA TN's proven safe and low risk horizontal above ground NUHOMS® storage system is one of the most widely used UNF dry storage system in the USA.

The safety, security and beyond design basis (BDB) events after the 9/11 events in the USA and the Fukushima earthquake and subsequent tsunami in Japan changed the landscape of UNF management in the world. These BDB events resulted in AREVA TN reassessing the safety basis of the NUHOMS® storage system for events like these.

The dry storage systems like NUHOMS® are expected to be stored at reactor sites for period longer than the initial licensed period of 20 years due to delay in final disposal solution. Therefore, blockage of air inlet and outlet cooling vents due to debris accumulation during flood, rain, mud or dust during longer storage period, effect of chloride induced stress corrosion and other corrosion induced cracks during longer storage periods were also reassessed for NUHOMS® system.

After evaluating the NUHOMS® system for BDB accident conditions more severe than those in the original design basis, AREVA TN concluded that NUHOMS® system will withstand such events, both natural and man-made. This presentation will discuss this reassessment.

Introduction

The original used fuel management plan in the USA was for the Federal Government to ultimately take the title of the used nuclear fuels (UNFs) and transfer them to a geological repository by 1998; however, this has not happened to date. Currently the only option for USA utilities for UNF management is wet storage in the fuel pools and/or dry storage of UNF on site. Nuclear power plant operators began transferring UNF to dry storage to retain enough space in their pools to safely discharge fuel from their reactor cores. The goal of on-site UNF storage is to provide a temporary facility to store the UNF in a safe condition until it can be removed to a federal repository, Monitored Retrievable Storage facility also called Consolidated Interim Storage Facility (CISF) or permanent mined geological disposal system.

The use of on-site dry storage systems on an Independent Spent Fuel Storage Installation (ISFSI) has become the preferred alternative for many utilities, especially in the USA due to lower operational cost and easy maintenance needed for these systems. By the end of 2013 roughly 30% of the nation's UNF are in dry storage facilities [1].

Originally these dry storage systems were supposed to be at the reactor site for 20 years but now they are being stored longer. The safety, security and beyond design basis (BDB) events after the 9/11 events in the USA and the earthquake near Fukushima and subsequent tsunami in Japan changed the landscape of UNF management in the world. UNF management now needs to consider the potential effects of BDB on the integrity of dry storage systems.

As of August 2, 2016 there are 2369 casks are in dry storage in the USA consisting of 97,757 fuel assemblies. These assemblies are stored in various cask designs offered by various cask designers. AREVA TN is the market leader and has the most proven experience since mid-1980 with more than 1000 loaded dry storage systems in the USA. AREVA TN's proven safe and low risk horizontal above ground NUHOMS® storage system is one of the most widely used UNF dry storage system in the USA with more than 832 systems loaded [2].

The systems that are licensed are based on US Regulations for storage under 10 CFR Part 72 and Transportation under 10 CFR Part 71. The reassessment of the NUHOMS® system for BDB accident conditions more severe than those in the original design basis is described in the following sections.

LICENSING FOR STORAGE UNDER 10 CFR PART 72

The Nuclear Regulatory Commission (NRC) and the U.S. Department of Energy (DOE) are primarily responsible for the regulation and disposal of the UNF. The NRC regulates storage and transport of UNF as well as construction and operation of ISFSIs and spent fuel repositories. The DOE is charged with ultimate disposal of UNF under the Nuclear Waste Policy Act (NWPA) of 1982, as amended.

UNF Storage Licensing for an ISFSI falls under 10 CFR Part 72, "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste" [3].

LICENSING FOR TRANSPORTATION UNDER 10 CFR PART 71

Transporting the UNF over public roads requires compliance with 10 CFR Part 71, "Packaging and Transportation of Radioactive Material" [4] and the applicable Department of Transportation regulations in 49 CFR Parts 170 through 189. Transportation licensing includes evaluations of a credible accident which leads to the most severe damage to the cask system containment including the canister.

BEYOND DESIGN BASIS (BDB) EVENTS

BDB basis events are those that were not applicable in the original design basis at the time of the design/analysis/licensing/deployment of a dry spent fuel storage system. Some of the examples of the BDB Events are:

- Air Craft crash and subsequent fuel fire
- Earthquakes greater than the original design basis
- Floods/Tsunami generated by BDB earthquakes
- Storage at the reactor sites greater than the initial license period due to delay in final disposal solution
- Storage first at ISFSI and then Transportation and then storage again before final disposal

REASSESSMENT OF AREVA TN's NUHOMS® DRY STORAGE SYSTEM DUE TO BDB EVENTS

The NUHOMS® system design consists of the Dry Shielded Canister (DSC), the Transfer Cask (TC), and the Horizontal Storage Module (HSM) as shown in Figures 1, 2, and 3 respectively.

The DSC is a stainless steel shell with redundant closure lids at the top and bottom. Steel or lead shielding is provided at each end to keep radiation exposure to workers during loading ALARA as shown in Figure 1.

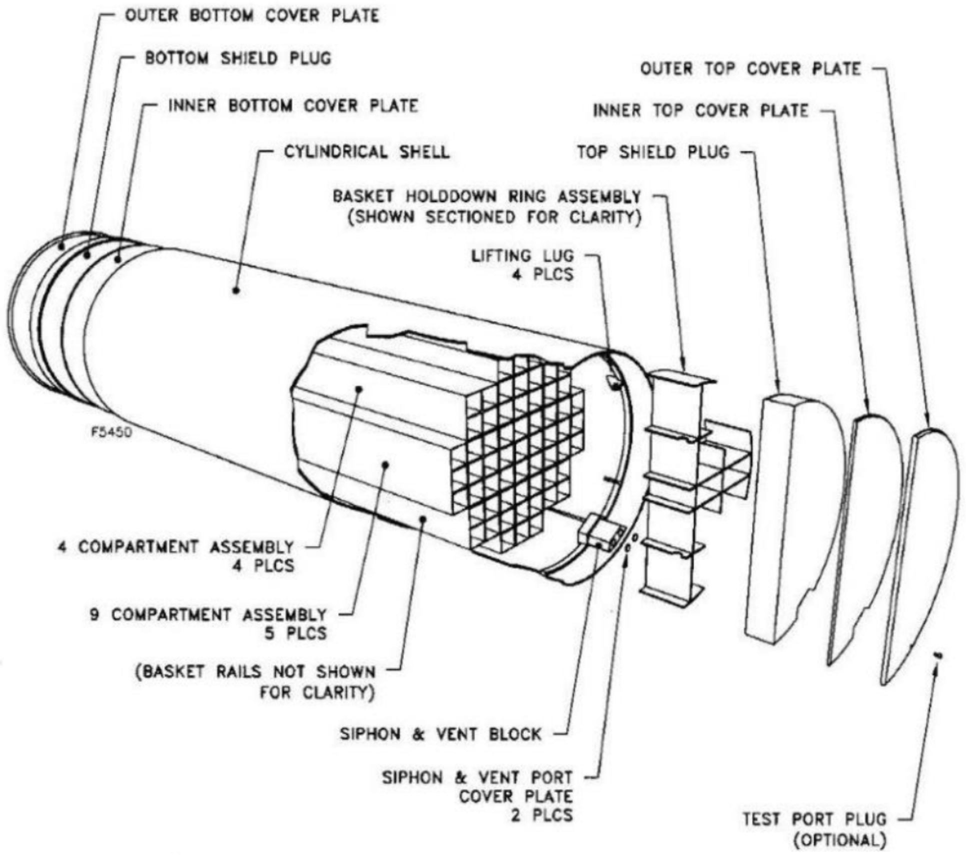

Fig. 1. Typical DSC construction with fuel compartments and basket rails

The TC includes steel-lead-steel radial gamma shielding and structural support with an outer liquid water jacket for neutron shielding. A bolted lid secures the main opening at the top. There is a penetration at the bottom of the TC for a hydraulic ram that pushes the DSC into the HSM as shown in Figure 2.

During loading operations, the TC with empty DSC is lowered into the spent fuel pool, fuel is loaded, and the TC/DSC is removed from the pool for closure and decontamination. The DSC is sealed and vacuum dried to ensure all water is removed. It is then backfilled with helium inert gas and transferred to the ISFSI.

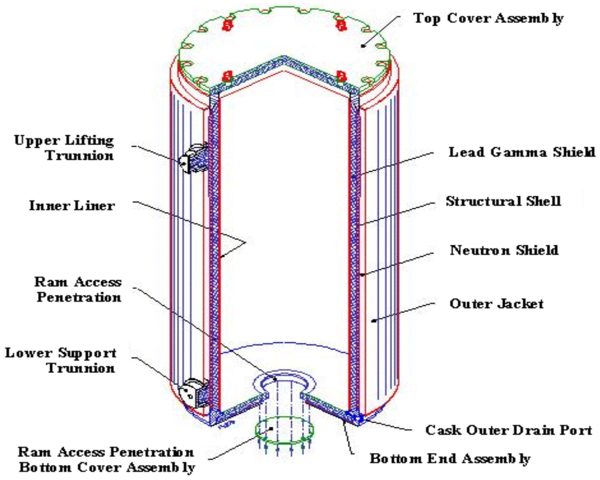

Fig 2. NUHOMS® transfer cask

The NUHOMS® HSM is a reinforced concrete, fortress-like structure. Multiple HSMs may be placed side-by-side and back-to-back in an array (Figure 3). Additional concrete walls are used at the end of the array for radiation shielding and physical protection. The HSM has vents at the top and bottom for heat removal due to natural convection. Air enters from the bottom and exits at the top. Coated hardened steel rails in the HSM support the DSC. The HSM provides for long-term physical and radiological protection of the DSC containing the UNF during the storage period. The HSM provides protection for the DSC from tornadoes, penetrating objects thrown by tornados (tornado missiles), earthquakes, and floods.

Fig.3. NUHOMS® HSM in an array at ISFSI.

Safety Margin to Safety Limits:

The latest NUHOMS® EOS System features a 37PTH DSC for 37 PWR UNF assemblies and an 89BTH DSC for the 89 BWR UNF assemblies [5]. The EOS DSCs are stored inside a HSM that is a robust, fortress-like concrete storage overpack. NUHOMS® EOS is optimized for high capacity, high burnup, high enrichments, and very low cooling times for UNF assemblies. It enables the highest heat load per canister (50 kW) and low dose rates.

Designed with the lessons learned from the Fukushima event in Japan in mind, EOS has robust margins for BDB events and offers the lowest risk and highest safety margin of any dry storage system design for recovery from BDB events. The system has margins in fuel cladding temperature limits, protection of canister integrity, dose rate limits and others as described below.

Aircraft Crash and Subsequent Fuel Fire:

The NUHOMS® system has been evaluated for aircraft impact, which is not a required accident condition under 10 CFR Part 72 storage regulations. The time-load curve for the impact of an F-16 fighter plane bounds most aircraft impacts, including the heavier, but slower, commercial aircraft impacts. Analysis of end, front, and top impacts shows concrete deformation and sliding of the module but no breach of the DSC, and thus no release of its radioactive contents. Due to its aboveground design, any likely fuel spill from a crashed aircraft cannot pool inside the HSM. Even in the unlikely scenario where pooling near the base of the HSM may occur, a conservative calculation showed that any resulting fire would burn out long before the DSC materials or the fuel cladding reach their temperature limits or the DSC cavity internal pressures reach their limits.

Earthquakes Greater than the Original Design Basis:

As discussed earlier, horizontal storage is especially effective for stability in earthquakes. NUHOMS® modules were installed at the North Anna Nuclear Generating Station when an earthquake struck it in August 2011. Minor cosmetic damage and movement was discovered with no impact on the safe operation of the system as shown in Figure 4.

Fig. 4. Cosmetic damage to HSM after North Anna earthquake.

Utilities in high seismic zone need systems with high seismic capabilities. AREVA TN's Advanced NUHOMS® System has the seismic design capacity which is almost twice the plant's design basis for seismic loads [6] & [7].

Floods/Tsunami Generated by BDB Earthquakes:

The NUHOMS® horizontal aboveground system is not vulnerable to flooding. Since the HSMs are easy to visually inspect and access, flood debris can easily be seen and removed. DSC cooling is uncompromised because the heat conduction capability is engineered into the DSC basket and not reliant upon internal closed cavity convection. This remains true even in the event of a "smart" flood that blocks the lower inlet air vents but is not high enough to submerge and cool the DSC.

Floods are not merely water. The floodwater can be contaminated with runoff including road salts, oils, fertilizers, and other waste, which can cause corrosion. Since the NUHOMS® DSC is stored about four feet off the ground at its lowest point, most floods would not affect its shell. This limits the degradation potential of the DSC shell. Floods that block vents can also be remediated quickly as the system is above ground and easy to inspect and clear. All vents and airflow paths are accessible without removing the HSM door or lifting and/or removing the DSC.

Horizontally Stored Casks were Safe during Fukushima Event:

AREVA TN-designed metal casks were used for dry storage of UNF at the Fukushima site in Japan. They were stored horizontally above ground. The massive earthquake and subsequent tsunami devastated most of the plants but the horizontally-stored AREVA TN dry storage casks performed safely, as designed, and there was no damage to the stored fuel (Figure 5). The NUHOMS® dry storage design has a very distinguishable feature where the canister and the UNF are stored horizontally during dry storage period. The horizontal design by nature is very stable for the tip over due to seismic or tsunami events. This is also demonstrated by the events at the Fukushima site where horizontal storage performed the best.

Fig. 5. TN-24 Storage casks stored at Fukushima in Japan.

Tornadoes:

The HSM has been proven safe during tornadoes and has been analyzed for tornado-generated missiles. NUHOMS® systems in use at the Davis Bessie Nuclear Power Station have twice experienced a tornado crossing the ISFSI pad. The HSMs performed safely, as designed, and were free from any damage.

Long Term Storage at Reactor Sites Under Aging Management Program:

NUHOMS® also offers innovative aging management features with simple aging management program (AMP) to assure safe and low dose long-term storage at the utility sites. The NUHOMS® canisters can have a lifetime of more than currently licensed 60 years when using 304 stainless steel materials for the DSC shell with proper AMP. The greatest concern seen today is due to chloride-induced stress corrosion cracking (CISCC) in coastal marine atmospheres. For dry storage systems in a coastal or other corrosive environment, the NUHOMS® system offers the option of Duplex Stainless Steel (DSS) for the most reliable long-term resistance to all corrosion mechanisms including CISCC. The DSC shell operates in a temperature range where embrittlement of DSS is not a concern.

The DSS materials are suitable for lifetimes in excess of 120 years in a coastal environment with proper aging management. DSS is a proven material that has been used in the offshore oil and gas and desalinization industries as well as in other AREVA nuclear waste applications such as the TRUPACT-III transportation package containment boundary and high integrity radioactive waste containers. It has been successfully used for over 80 years in aggressive corrosive environments. With a proper AMP, the actual lifetime is longer.

NUHOMS® EOS system incorporates ports for AMP inspections. NUHOMS® EOS is stored horizontally and above ground, making it easy and quick to access for visual inspection, monitoring, and mitigating actions during AMP.

NUHOMS® DSCs are engineered to ensure continued safe thermal performance in the unlikely event of a crack after extended period of storage. Our DSC design is conservative; it does not credit for convective heat transfer in the closed DSC cavity. The helium backfill pressurization is only about 1.14 to 1.20 atmosphere (2 to 3 psig), so any compromise to the DSC containment where the helium fill gas could leak would not risk the ability of the used fuel to continue to cool. The low DSC cavity internal pressure provides a very long period for the discovery, analysis, and repair of a DSC so that preventive and corrective measures can be completed to minimize risk of UNF damage.

Storage First at ISFSI and then Transportation and then Storage Again before Final Disposal:

As the future of used fuel disposition will require the need to move fuel off-site to interim or consolidated storage facilities (CISFs), NUHOMS® is the ideal solution as it enables on-site loading and unloading operations that mitigate risk when transferring fuel on-site or transporting fuel off-site. The NUHOMS® design can be safely located in a traditional outdoor setting with fortress-like concrete reinforced HSMs that offer superior resistance to attack or can be safely operated inside of a building enclosure for those utilities desiring a more discreet siting for its used fuel storage systems. One very important design basis consideration for the NUHOMS® canister is that the canister when loaded with UNF is never lifted by itself, since the lift process, according to the US NRC, is the most risky aspect of the dry fuel storage operation. With the NUHOMS® system, the loaded DSC is only lifted once it is inside the robust onsite transfer cask (TC) which is designed for any drop events.

Figure 6: NUHOMS® system Loading and Unloading Operations

CONCLUSION

NUHOMS® has been operating safely across the USA for more than two decades and will continue to do so as AREVA TN develops advancements to meet each plant's critical needs. Not a one-size-fits-all system, the NUHOMS® system offers enhancements such as the ability to withstand and safely operate under BDB events like 9/11 and Fukushima events. If offers special materials for marine environments, advanced capabilities to meet seismic requirements for specific sites, and long-term availability of licensed and highly-engineered transport systems to be ready to move fuel to interim or final storage in the future. From the security perspective, NUHOMS® System is designed like a fortress and can withstand man-made attacks like 9/11 events and recovery from these types of events is the safest in the industry for clearing any debris from the air vents required to keep the fuel cladding safe from damage. As the industry evolves, the NUHOMS® systems offer significant safety and security advantages that are proven to offer highest performance and the most certain path to safe long-term interim storage.

Based on all these considerations, our advanced NUHOMS® system design retains the significant advantages of the proven horizontal and aboveground system and uses the same safe and superior conservative design philosophy that performs in all natural and man-made events. Thus, this evolution of a superior design is the ideal system for long-term and safe storage of UNF around the world.

After evaluating the NUHOMS® system for BDB accident conditions more severe than those in the original design basis, we have concluded that NUHOMS® system will perform at a high safety level and withstand such events, both natural and man-made.

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