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

5013

Alternate Flexible Interim Dry Storage Solutions

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Abstract

Dry storage of Used Nuclear Fuel (UNF) is a necessary aspect of the safe management of UNF in the United States of America (USA) and internationally as the other alternatives such as an Interim Storage Facility (ISF), Recycling, or Deep Geological Disposal are not available options for storing UNF at this time. Some countries, like the USA, have been successfully deploying UNF dry storage systems for more than 30 years. Therefore the regulations and regulatory framework are well developed. Other countries are just initiating UNF dry storage programs and currently are developing new regulations and establishing a regulatory framework.

The requirements for dry storage system for management of UNF varies from one nuclear utility and/or regulator to another due to the differences in fuel assembly (FA) type (PWR, BWR, VVER or others), FA geometry (width, length, weight, number of fuel rods), FA operational history (burnup, enrichment, cooling time), FA condition (intact, damaged, failed), nuclear plant interfaces (crane capacities, reactor/fuel building floor load limits, doorway dimensions, space), economics (number of FAs per cask), natural phenomenon (temperature, marine environment, seismic stability, flood, tsunamis, tornadoes, beyond design basis events), safety against man-made threats (missile impact, aircraft crash), public acceptance (indoor, outdoor, concrete, metal cask, dose) and other factors.

AREVA TN is a recognized global leader in the UNF management with more than 50 years of experience in providing safe UNF management solutions at plant sites, in ISF, in road, rail, and maritime transport, and in recycling. With its international footprint, AREVA TN has a deep understanding of regulator and customer requirements as they apply to each specific country. AREVA TN has developed a versatile portfolio of solutions that ensures safe, cost-efficient, agile flexible dry storage systems. AREVA TN has an inventory of 150+ diverse cask designs that meet a range of regulatory requirements, technical specifications and plant scenarios.

This paper will describe how AREVA TN has consistently innovated and pioneered flexible and adaptive dry storage system solutions that are driven by market need, regulatory requirements and changing demands worldwide, all to ensure continued safety and advanced performance.

Introduction

Used Nuclear Fuel (UNF) management is a major challenge not only for the United States but also globally for other countries with nuclear power plants. As shown in Figure 1, the options available for the UNF currently stored in pool are limited to:

Interim solutions

- Retain in the pool if the capacity allows (high density re-racking is an option to increase the pool capacity)
- Transfer to an alternate pool at the reactor site if available
- Transfer to a common pool away from the reactor site
- Load to dry storage system at reactor site
- Go to Interim Storage Facility (ISF)

Long term/final disposal path solutions

- Transport to recycling
- Transport to geological disposal site

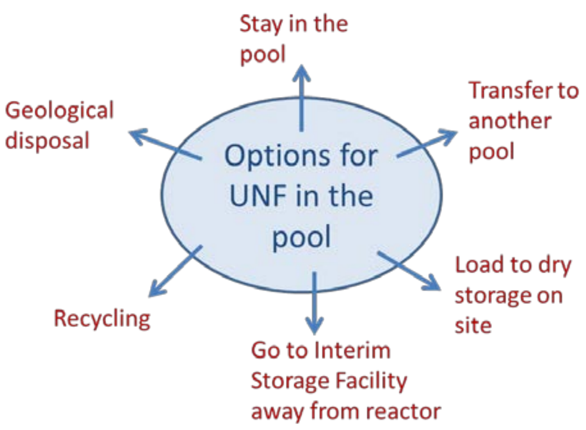

Figure 1: UNF management challenge

For many countries the UNF interim storage facility away from reactor, recycling or geological disposal are not available. For example: the original plan in the US was for the Federal Government to ultimately take the title of the used nuclear fuels and transfer them to a geological repository by 1996, however, this has not happened to date. Due to failure of the US government to take the fuel, the only options for UNF management currently in the US are either wet storage in the fuel pools or dry storage at the reactor site. The advantages of lower operational cost and easy maintenance have resulted in dry storage becoming the preferred alternative solution for many US utilities. By the end of 2013 roughly 30% of the nation's UNF are in dry storage facilities [1].

Dry Storage Management Design Basis

As UNF dry storage has become an important option for utilities, there is no single solution that fits all needs. Figure 2 outlines the primary factors that affect the selection of the right solution, and the factors vary across utilities as well as the geographical, regulatory and financial aspects of the customer. UNF management needs to take these into consideration to arrive at the appropriate solution that meets the specific needs of the utility.

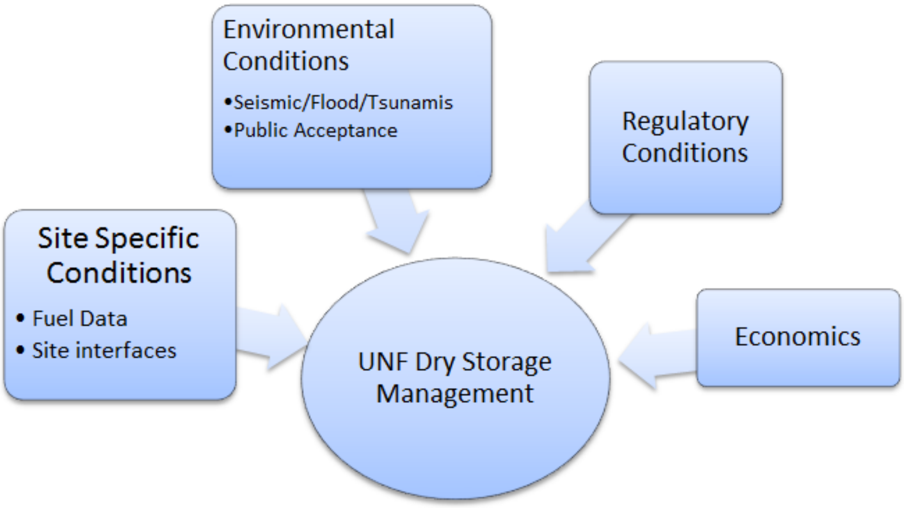

Figure 2: Design considerations for UNF dry storage

<u>Site Specific Conditions</u>

Fuel Types

There are many types of nuclear fuel used in nuclear energy industry today. While Pressurized Water Reactor (PWR) and Boiling Water Reactor (BWR) fuel are the two most common types used in the US, the fuel types used globally vary geographically. For example: CANDU fuel is used in Canada, PWR/BWR fuels are used in USA, while VVER fuel is used in Russia. Some countries rely on a combination of PWR, VVER and BWR assemblies for its nuclear power plants.

Table 1 lists typical PWR fuel assembly design characteristics, and Table 2 lists typical BWR fuel assembly design characteristics [2].

Table 1: PWR Fuel Assembly Design Characteristics [2]

Assembly Class	B&W 15X15	WE 17X17	CE 15X15	WE 15X15	CE 14X14	WE 14X14	CE 16X16
Fissile Material	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2	UO_2
Maximum Number of Fuel	208	264	216	204	176	179	236

Table 2: BWR Fuel Assembly Design Characteristics [2]

BWR Fuel Class	BWR Fuel ID	Example Fuel Designs
7 x 7	GE-7-A	GE-1, G2, GE3
8 x 8	GE-8-A	GE4, XXX-RCN
8 x 8	GE-8-B	GE5, GE-Pres, GE-Barrier , GE8 Type 1
8 x 8	GE-8-C	GE8 Type II
8 x 8	GE-8-D	GE9, GE10
9 x 9	GE-9-A	GE11, GE13
10 x 10	GE-10-A	GE12, GE14
10 x 10	GE-10-B	GNF2
7 x 7	ENC-7-A	ENC-IIIA
7 x 7	ENC-7-B	ENC-III, ENC-IIIE , ENC-IIIF
8 x 8	ENC-8-A	ENC Va and Vb
8 x 8	FANP-8-A	FANP 8x8-2
9 x 9	FANP-9-A	FANP-9x9-79/2, FANP-9x9-72, FANP-9x9-80, FANP-9x9-81
9 x 9	FANP-9-B	Siemens QFA, ATRIUM 9
10 x 10	FANP-10-A	ATRIUM 10, ATRIUM 10XM
8 x 8	ABB-8-A	SVEA-64
8 x 8	ABB-8-B	SVEA-64
10 x 10	ABB-10-A	SVEA-92, SVEA-96Opt, SVEA-100
10 x 10	ABB-10-B	SVEA-92, SVEA-96, SVEA-100
10 x 10	ABB-10-C	SVEA-96Opt2

Fuel Geometry

Different fuel types have varying geometry parameters like length, width, weight. Table 3 lists the detailed fuel parameters of two PWR fuel assembly examples; Table 4 lists the detailed fuel parameters of BWR fuel assembly examples [2]. The storage system needs to be designed to accommodate all the fuel parameters.

Table 3: PWR Fuel Assembly Design Characteristics [2]

Assembly Type	**BW 15x15**				**BW 17x17**
	Mark B2 - B8	**Mark B9**	**Mark B10**	**Mark B11**	**Mark C**
Maximum Uranium Loading (MTU)	0.490	0.490	0.490	0.492	0.456
Fuel Parameters					
Clad Material	Zircaloy-4	Zircaloy-4	Zircaloy-4	M-5	Zircaloy-4
Number of Rods	208	208	208	208	264
Fuel Rod Pitch (in)	0.568	0.568	0.568	0.568	0.502
Clad O.D. (in)	0.43	0.43	0.43	0.416	0.379
Clad Thickness (in)	0.0265	0.0265	0.025	0.024	0.024

Table 4: BWR Fuel Assembly Design Characteristics [2]

Assembly Type	**7 x 7-49/0**	**8 x 8-63/1**	**8 x 8-62/2**	**8 x 8-60/4**	**8 x 8-60/1**	**9 x 9-74/2**	**10x10-92/2**	**10x10**
GE or Equivalent Reload Fuel Designation	GE1 GE2 GE3	GE4	GE-5 GE-Pres GE-Barrier GE8 Type I	GE8 Type II	GE9 GE10	GE11 GE13	GE12 GE14	GNF2
Max Length (in)	176.2	176.2	176.2	176.2	176.2	176.2	176.2	176.2
Rod Pitch (in)	0.738	0.640	0.640	0.640	0.640	0.566	0.510	0.510
No of Fueled Rods	49	63	62	60	60	66 full 8 partial	78 full 14 partial	78 full 14 partial
Fuel Rod OD (in)	0.563	0.493	0.483	0.483	0.483	0.440	0.404	0.404
Clad Thickness (in)	0.032 0.037(18)	0.034	0.032	0.032	0.032	0.028	0.026	0.0236
No of Water Rods	0	1	2	4	1	2	2	2

Burnup, Enrichment and Cooling Time

UNF characteristics of burnup, enrichment and cooling time are the technical design bases for the dry storage management solutions.

In the USA, the maximum assembly average burnups are typically 62 GWD/MTU for PWR fuel assemblies and 55 GWD/MTU for BWR fuel assemblies with maximum enrichment up to 5.0 Wt%U235. The cooling time is dependent on the dry storage solutions but can be as low as 2 years. In Europe, the maximum assembly average burnups are up to 75 GWD/MTU for both PWR fuel assemblies and BWR fuel assemblies with maximum enrichment up to 5.0 wt%U235.

Fuel assembly conditions

The dry storage system can be designed to store intact and/or damaged and/or failed fuel assemblies [2].

- Damaged fuel assemblies are assemblies containing missing or partial fuel rods or fuel rods with known or suspected cladding defects greater than hairline cracks or pinhole leaks. The extent of damage in the fuel assembly is to be limited such that a fuel assembly is being able to be handled by normal means. Missing fuel rods are allowed.
- Failed fuel is defined as ruptured fuel rods, severed fuel rods, loose fuel pellets, or fuel assemblies that cannot be handled by normal means. Failed fuel assemblies may contain breached rods, grossly breached rods, and other defects such as missing or partial rods, missing grid spacers, or damaged spacers to the extent that the assembly cannot be handled by normal means.
- Intact fuel assemblies are assemblies with no known or suspected cladding defects in excess of pinhole leaks or hairline cracks, and with no missing rods.

Nuclear power plants site interfaces

The UNF management solution needs to meet the specific utility site requirements. There are multiple interfaces need to be considered, comprising of but not limited to: size and weight limitations in the fuel pool area, crane capacity, geometry and weight limitations inside the fuel pool, fuel building areas, access entrance height and width, floor load limit, road conditions, other mechanical and electrical interfaces, and the future off-site transportation interface.

Environmental Conditions

Seismic / Flood / Tsunamis

The geological environment of a location affects the dry storage solution selected, the surrounding natural phenomena help define the design requirements. For example:

- Utilities in high seismic zone need systems with high seismic capabilities like San Onofre Nuclear Generating Station (SONGS) power plant.
- Utilities with coastal marine environment need a Stress Corrosion Cracking (SCC)/ Chloride Induced Stress Corrosion Cracking (CISCC) resistance system.

- Utilities with very high ambient temperature need high heat load capacity system; like Palo Verde in Arizona State in the USA.

Other extreme natural phenomena like tsunamis and tornadoes will also need to be considered for some utilities (for instance: Fukushima).

For Beyond Design Basis events (BDB), even though the regulator may not have explicit requirements for BDB events, the user and the surrounding community might have an expectation that the system be able to withstand BDB events, for example, the 9-11 event in US and Fukushima earthquake/Tsunami event in Japan.

Public Acceptance

Public acceptance is very important and could impact the implementation of the selected dry storage solution. Events that occurred in Taiwan is one such example: while dry storage systems was licensed by the Taiwan Nuclear Regulator for the Chinshan and Kuosheng plants, the systems were not implemented due to public opposition

Regulatory Conditions

There are some differences in the regulatory requirements, regulatory expectations and processes globally among the regulators of different countries. Typically the regulatory differences are showing on the following requirements:

- Allowance of considering burnup credit for criticality safety analysis
- Allowance of considering soluble boron credit for criticality safety analysis
- Secondary impact during transportation accident conditions
- Aircraft crash / missile impact
- Different cladding temperature limits for normal and accident conditions
- Credit for moderator exclusion in criticality safety analysis
- Difference in g-load allowed on fuel assemblies for accident conditions
- Transportation accident sequence for demonstrating the safety of the system
- Allowed boron credit in the neutron absorbers for criticality control
- Site boundary dose rate requirements for storage facilities
- Occupational exposure requirements during loading operations
- Initial license period for dry storage systems
- Intact/damaged fuel/failed fuel definitions for safety analysis
- High burnup fuel storage/transportation regulatory expectations
- Indoor or outdoor storage for dry storage systems
- Drop test on full scale vs. partial scale models for safety analysis

- Demonstration to meet the transport requirements when licensing
- Regulatory involvement during fabrication process

Economics

Economics is a significant part in UNF management solution. Utilities need to make decisions on how many fuel assemblies per dry storage system, how many and what types to load for a campaign and how often to load.

Flexible & Versatile Portfolio of UNF Solutions From Pool to Recycling/Repository

AREVA TN has been global leader and innovator in the field of UNF management solutions. Since 1965, AREVA TN has developed a versatile portfolio of solutions that ensures safe, cost-efficient, agile flexible storage and transportation for UNF worldwide, the solution overview is shown in Figure 3.

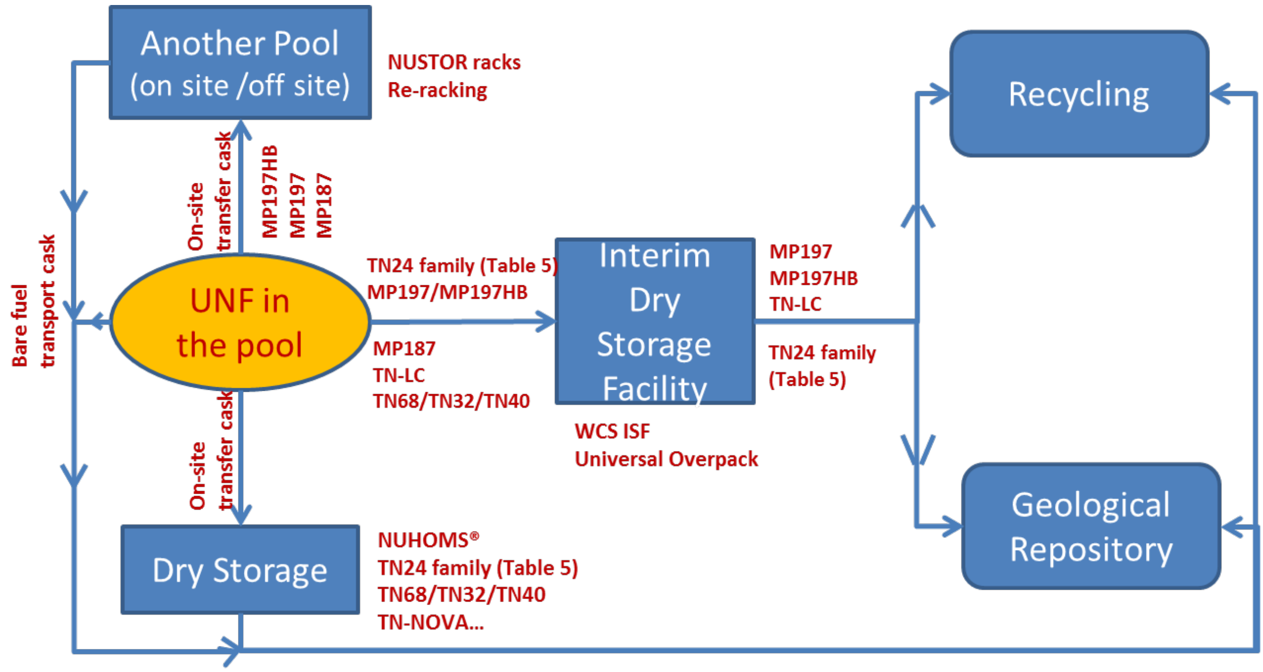

Figure 3: AREVA TN's UNF management solution overview.

Wet Storage (pool)

With more and more UNF pools approaching full capacity, AREVA TN provides racks for fresh fuel and used fuel assemblies and also provides re-racking support to maximize existing pool storage capacity. This is primarily achieved by using higher density racks and the addition of neutron absorbers.

In cases where a customer has the option of an alternate pool either at the reactor site or away from it, AREVA TN's transfer cask (onsite) or transportation cask (offsite) are used to safely move UNF and relieve the utility's fuel pool capacity restraints.

Dry Storage:

AREVA TN has diverse cask designs that meet or exceed a range of regulatory requirements, technical specifications and plant scenarios. There are two major technologies for dry storage, as shown in Figure 4: canistered system and metal cask/dual purpose cask system.

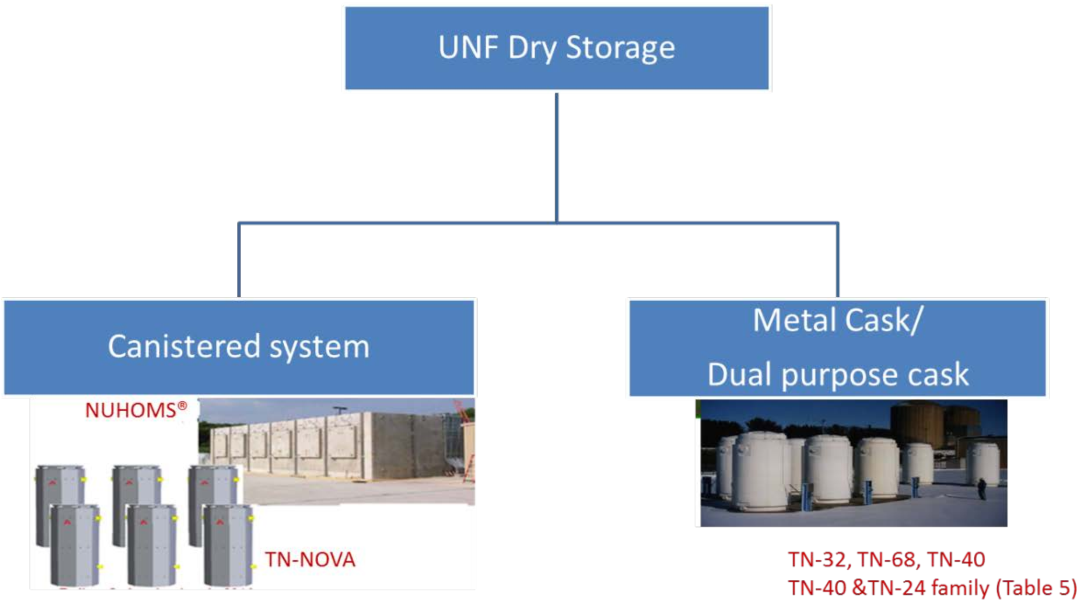

Figure 4: UNF dry storage technologies.

Here we would like to highlight the NUHOMS® and TN-NOVA® as the canistered systems and TN® 24 family as the metal cask/dual purpose cask system.

NUHOMS® system includes Dry Shielded Canister (DSC), concrete Horizontal Storage Module (HSM) overpack and transfer cask, as shown in Figure 5. NUHOMS® offers high capacity, burnup, heat load, thermal and seismic options, superior shielding and lower operation risk due to horizontal transfer; it has been safely loaded in US and other countries for more than 900 units, and been proven to be robust, practical and simple to operate in the industry. The models approved by NRC include: NUHOMS® -7P, -12T, -24P, –24PHB, –24PTH, –32PT, –32PTH1, –37PTH, –52B, –61BT, –61BTH, and –69BTH. And the NUHOMS® next generation EOS 37PTH and 89BTH systems which provide the highest capacity, higher heat load improved shielding and lower cost. NUHOMS® EOS is scheduled for implementation at nuclear power plants in US by 2019.

Figure 5: NUHOMS® system

TN-NOVA® system is a newly developed system for UNF storage and transport, as shown in Figure 6. It is a canistered system with metal storage overpack which can be stored vertically, and it is compatible with MP197HB transport cask to allow UNF transportation. The plane crash test has been successfully performed on a 1/3 scale mock-up in 2010, and the results showed that the TN-NOVA® internal canister remained leaktight after the projectile's impact. The same canister is also used in the NUHOMS® dry storage system; and this crash test also demonstrated NUHOMS® can withstand intense impact without loss of integrity or safety.

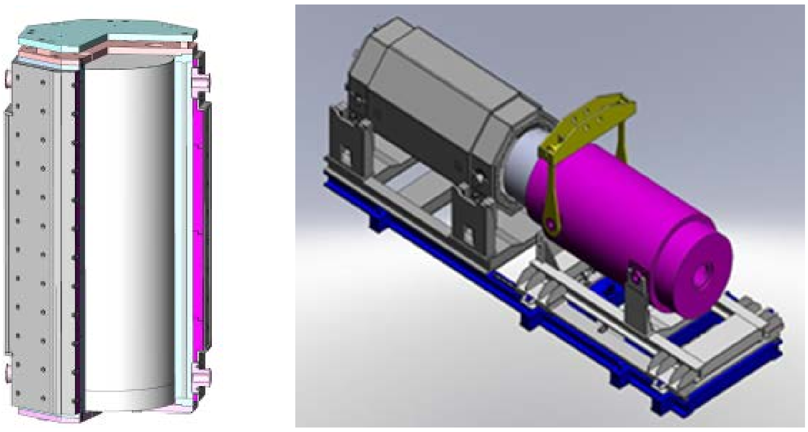

Figure 6: TN-NOVA®

Metal Cask system: AREVA TN has been developing the versatile TN® 24 family with more than 300 casks loaded, as shown in Figure 7 and Table 5. These metallic casks have been licensed for "dual-purpose" and can be used for both storage and transportation to avoid "handling" the fuel assemblies twice. These dual purpose casks are in operation in the USA, Japan, Belgium, Switzerland, and Germany. The cask capacities reach 40 assemblies for PWR fuel assemblies or 97 for BWR fuel assemblies with maximum burnup of 65 to 75 GWd/tU and typical cooling times of 3 to 7 years in these storage designs. The metal cask system provides customers the advantages of modularity, passive cooling, and dual purpose storage and transport capability.

Figure 7: TN® 24 cask

Table 5: TN® 24 cask family

Model	Number of Fuel Assembly	Fuel Type	Max Burnup GWd/tU
TN®24D	28	PWR	36
TN®24DH	28	PWR	55
TN®24XL	24	PWR	40
TN®24XLH	24	PWR	55
TN®24SH	37	PWR	55
TN®24G	37	PWR	42
TN®24(F1)	37	BWR	40
TN®24(F1)	52	BWR	40
TN®24E	21	PWR	65
TN®32	32	PWR	45
TN®40	40	PWR	45
TN®24P	24	PWR	33
TN®52L	52	BWR	55
TN®24SWR	61	BWR	70

TN®68	68	BWR	60
TN®97L	97	BWR	35
TN®24BH	69	BWR	75
TK®69	69	BWR	40
TK®26	26	PWR	47
TN®24ER	32	BWR(th)	13.7

Interim Storage Facility (ISF)

AREVA TN has teamed up with Waste Control Specialists LLC (WCS) to develop and implement Consolidated Interim Storage Facility (CISF) in Texas, USA. As shown in Figure 8, this interim storage solution will address the immediate need for UNF currently stranded at decommissioned sites around the country. The licensing request has been submitted to NRC in April, 2016. AREVA TN's universal transportation cask MP197HB, as shown in Figure 9 will be used for the fuel transportation.

Figure 8: WCS Consolidated Interim Storage Facility

AREVA TN's universal transport cask MP197 HB (Figure 9) has been licensed for transportation of high burnup spent fuel under U.S. Nuclear Regulatory Commission (NRC) requirements of 10CFR Part 71, Certificate of Compliance (CoC) No. 9302. It is the first truly universal transport package and can be used for offsite transportation of different UNF dry shielded canisters to consolidated interim storage facility or future recycling or geological repository places. MP197HB consists of a containment boundary, structural shell, gamma shielding material, and solid neutron shield. It is transported in the horizontal orientation on a specially-designed shipping frame, and the package has been approved for exclusive use by rail, truck or marine transport. [5]

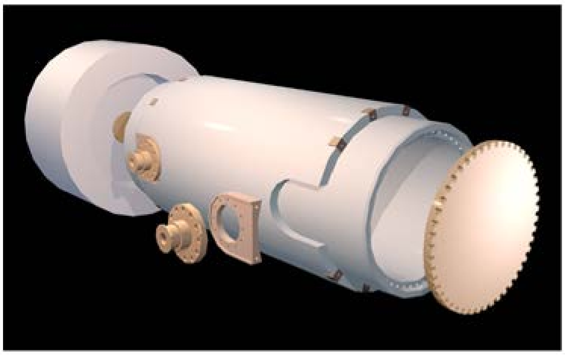

Figure 9: NUHOMS® MP197HB transport cask

AREVA TN has designed universal storage overpack, Honeycomb HSM, which is ideal for operating sites, shutdown sites and consolidated storage, as shown in Figure 10. This system offers significant footprint reduction, improved shielding, enhanced seismic resistance and aging management innovations; it is designed for unparalleled beyond design basis events protection to withstand natural disaster and man-made attack.

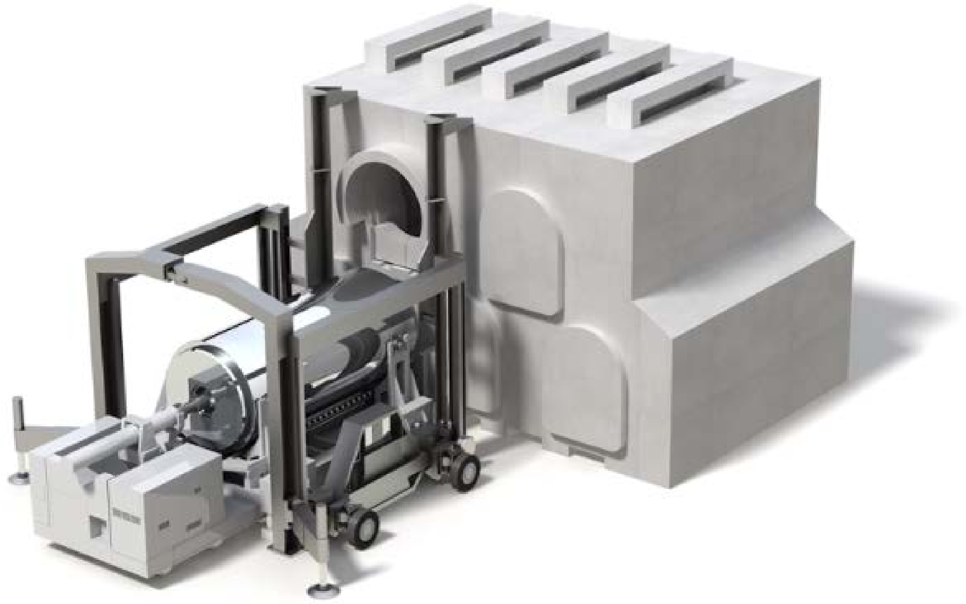

Figure 10: NUHOMS® Honeycomb HSM

Recycling / Geological Repository

With the already licensed universal transport cask MP197HB, AREVA is able to retrieve the dry storage canister from its storage overpack, and transport it to a recycling/geological repository location, which assures the reversibility of UNF dry storage.

Conclusions

We have seen that utilities across the world have a finite number of options today when it comes to dealing with UNF but the actual solution is defined by a number of contributing factors that are unique to the customer. AREVA TN is the solution provider that removes burden from nuclear operators by providing interim storage solutions until final disposal path becomes available.

With more than 50 years of experience, AREVA TN as a global leader to and pioneer has been consistently developing flexible and adaptive dry storage system solutions to meet market need in all environment and scenarios. AREVA TN provides the highest capacity of UNF with the largest burnups and shortest cooling times available in market, and offers the significant safety advantages that are proven in industry to meet various utility site operational requirements, safety and regulatory requirements today and prepare for the future needs of global UNF management.

References

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