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NUHOMS® HSM MATRIX FOR CENTRALIZED INTERIM STORAGE OF A VARIETY OF SPENT FUEL CANISTERS

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ABSTRACT

In the United States, used fuel assemblies discharged from nuclear power plants (NPPs) have historically been stored on-site using licensed dry storage systems. Due to shutdown/decommissioning of several NPPs and delays in the implementation of the geological repository, there is a need to develop solutions to manage the storage of dry storage systems in interim storage facilities. The centralized interim storage facility (CISF) functions as an intermediate repository/staging area for dry storage systems for an extended duration of time prior to eventual transportation to a geological repository. The operation of a CISF will lead to a significant reduction in the number of independent spent fuel storage installations (ISFSIs) nationally and enable release of space in those decommissioned reactor sites that currently only maintain their respective ISFSIs.

The NUHOMS® System has been licensed in the United States for the on-site storage of used nuclear fuel for more than 35 years. The system consists of a dry shielded canister (DSC) containing the used nuclear fuel which is inserted into the concrete horizontal storage module (HSM) using a transfer cask (TC). Several DSCs designs have been licensed for storage and are characterized by differences in physical dimensions (diameter, length), allowable used fuel contents (BWR, PWR), performance parameters (heat load, burnup). The NUHOMS® MATRIX is an evolutionary design of the storage module that will provide for a two-tiered placement of DSCs resulting in improved storage efficiency, stability and self-shielding. The design of the MATRIX ensures that it is able to house the various DSC designs and therefore, serve as a universal over-pack. The consideration of a universal over-pack offers several advantages for the CISF leading to simplification in design, operations and aging management program implementation.

The paper provides additional insights into design and licensing of the MATRIX in a CISF with an objective to be employed as a universal storage over-pack for various DSC types. This paper also discusses the current efforts being undertaken to enhance the design of the MATRIX HSM for this purpose.

INTRODUCTION

The management of used nuclear fuel (UNF) from commercial nuclear power plants in several countries, including the United States is being effected using on-site dry storage systems. In the absence of a universal and comprehensive management of UNF, including final disposition, this current method of on-site storage at the independent spent fuel storage installation (ISFSI) has become necessary and more widespread. Storage of UNF on-site is partially necessitated in order to support continued plant operations. The issue of on-site management of UNF is widespread because several countries have recently embarked on dry storage or have plans to transition to dry storage.

Dry storage systems were originally designed and licensed for shorter storage periods, generally 20-40 years [1]. However, several ISFSIs in the United States have been operating for 20 or more years and the storage duration on-site continues to increase. For this purpose, effective licensing evaluations including aging management programs are required to allow for longer term storage. Simultaneously, the design of the dry storage systems, particularly the canister based systems, have also undergone a significant transformation during this period providing for enhanced heat removal, shielding, physical and environmental protection. With the shutdown and eventual decommissioning of several NPPs, there is a need to further consolidate the storage of UNF in one or more CISFs resulting in a reduction in the number of ISFSIs. It is therefore, important to design the dry storage system at the CISF to be able to house several different dry storage canister designs that have evolved over the last 25 or more years.

DRY STORAGE SYSTEMS

Dry storage systems are designed and licensed to provide for important-to-safety functions such as physical / structural protection, heat removal, radioactive material confinement, radiation shielding, and criticality control. In order to comply with the regulatory requirements for storage, the dry storage systems must be designed to withstand a variety of normal, off-normal and accident conditions.

Typical dry storage systems consist of a cylindrical container housing the spent nuclear fuel assemblies in fuel compartments. Prior to storage and after the fuel assemblies are loaded into container from the spent fuel pool, the container is dried, filled with an inert gas and sealed. Licensed dry storage systems world-wide are broadly classified as either a cask –type (metal cask) or a canister –type. Depending on the type of storage system, the container, usually made of steel, is either welded or bolted. This results in a leak-tight or near leak-tight confinement barrier and also physical protection to the fuel assemblies. In addition, depending on the type of storage system, the container is stored in the ISFSI directly (metal cask) or in a secondary housing (canister) that provides additional shielding and physical protection.

ORANO TN dry storage systems

ORANO TN (TN Americas) has developed several dry storage systems [2] for the storage of UNF which are in operation in various countries around the world.

Canister systems with storage module

The NUHOMS® system, the reference system for dry storage of UNF in canisters, was initially developed by ORANO TN in the United States for interim storage more than 20 years ago and has been in operation at several NPP sites. In the NUHOMS® system, the UNF is placed in a thin-walled canister, called the dry shielded canister (DSC), where the fuel is dried and back-filled with helium gas, welded and verified to be leak-tight. The DSC is housed in a massive concrete module called the horizontal storage module (HSM) during storage at the ISFSI. The loaded DSCs are transferred from the NPP to the HSM using a transfer cask. The DSCs are stored in a horizontal orientation within the HSM which results in a low-risk transfer operation and also results in enhanced thermal and shielding performance during storage.

The NUHOMS® system comprises several different types of DSCs that are designed and licensed to store BWR and PWR fuel in the United States. In addition, the NUHOMS® system is also licensed to store VVER fuel assemblies. The most recent innovation in dry storage is the NUHOMS® EOS [3] system with the MATRIX [4] concrete storage module that is capable of high-density storage with a high heat load performance

In the TN NOVA™ system, the DSC is designed for storage within a specially designed metallic storage module or overpack.

The DSCs designed by ORANO TN are also intended for transportation. Several DSC designs are licensed for both storage and transportation in the United States. Following licensed storage at the ISFSI, the DSCs are designed to be transported to an interim storage facility or a UNF processing facility using a certified transportation cask.

Metal casks

The TN 24 family [5] is an example of a versatile, metal cask system designed and licensed for dry storage and transportation in several countries. Thick-walled metallic casks, also known as dual purpose casks are designed for both storage and transportation and do not require an additional overpack. Because the metal casks are sealed using a bolted closure system, the cask confinement can be monitored during storage. In the United States, ORANO TN has designed and licensed the TN-32, TN-40 and TN-68 metal cask systems which are currently in service. ORANO TN has also developed several models of metal casks in Japan and Europe. Some of the metal cask designs are developed to be compatible with the site-specific requirements including spent nuclear contents, operational limitations and ISFSI locations.

NUHOMS® HSM MATRIX

The NUHOMS® HSM MATRIX (HSM-MX or MATRIX) is an innovative storage module design developed by ORANO TN with an objective to further enhance the performance of the storage cask, including extended storage operations. MATRIX provides for an above-ground, horizontal storage of DSCs and is currently under review by the USNRC for certification. It features an innovative two-tiered, modular horizontal loading and storage of DSCs within a cavity that provides for a high heat rejection capacity and enhanced shielding. Figure 1 shows the representation of the MATRIX module in an ISFSI array and associated transfer equipment. The transfer of a loaded DSC from the transfer cask into the MATRIX is performed using the Loading Crane (MX-LC) and the retractable roller tray (RRT). The MX-LC is a single-failure proof lifting and transfer system that is capable of lifting the transfer cask with the skid to align with the door opening. The RRT is a beam, consisting of rollers, which is inserted into the MATRIX via a special opening that facilitates the transfer of the DSC using the hydraulic ram. Once the DSC is fully inserted, the RRT is removed and the RRT opening is closed. The DSC inside the MATRIX is supported at the axial ends by the concrete structure. The use of the RRT in the MATRIX eliminates the need for the DSC support structure employed in the previous generation of HSMs, greatly enhances the airflow within the MATRIX. The two-tiered design of the MATRIX results in a significant reduction in the footprint of the ISFSI by approximately 40% compared to other dry storage systems. Although Figure 1 shows a single array of MATRIX modules, a back-to-back arrangement (similar to other NUHOMS® HSM models) is also permissible, leading to additional space savings. The closed packed-arrangement also increases self-shielding, thereby leading to further reduction of dose rates within and around the ISFSI.

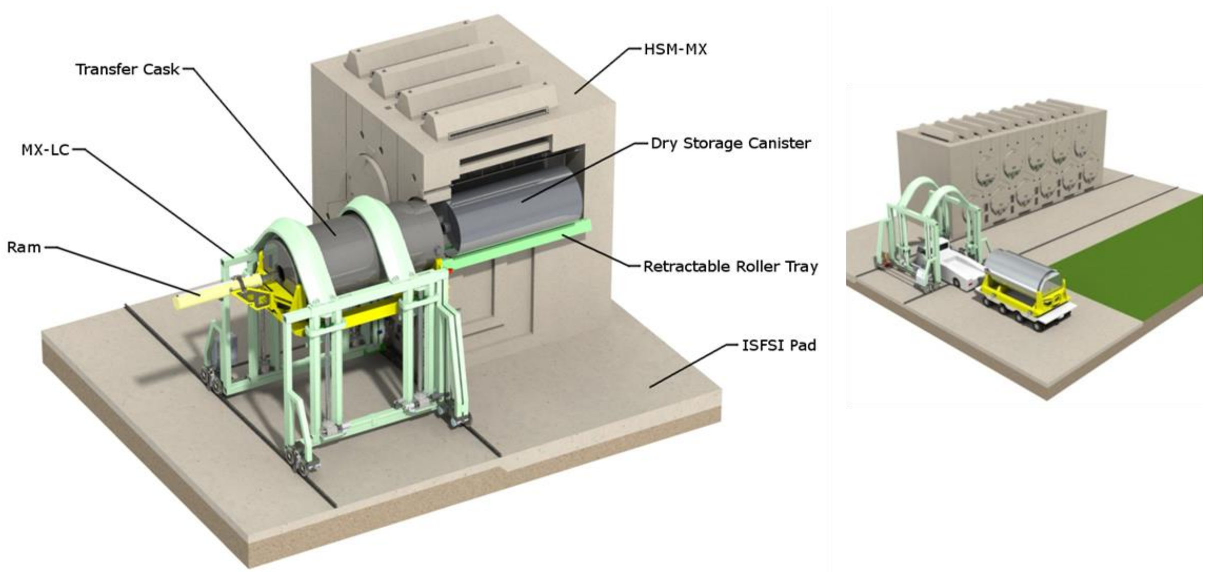

FIGURE 1. NUHOMS® MATRIX HSM ARRAY.

CENTRALIZED INTERIM STORAGE FACILITY

The centralized interim storage facility (CISF) is an intermediate staging area for housing UNF dry storage systems. The use of a CISF provides a location where fuel assemblies are allowed to age prior to subsequent or final processing. Most importantly, for decommissioned reactor sites which continue to operate their ISFSIs, the CISF will serve a very important function of reducing the geographical footprint of UNF storage. For this purpose, the UNF will need to be transported to the CISF prior to intermediate or extended storage.

In the United States, with a widespread distribution of NPPs around a much larger geographical area, combined with a large number of NPPs, the on-site storage of UNF evolved as a necessity. While the earlier storage systems were licensed on a site-specific basis, the newer systems were certified such that they are implemented under the provisions of the general license. This widespread distribution of operating ISFSIs also makes it more imperative to consider the development of regional facilities that function as the CISF since UNF is currently stored in more than 3,000 dry storage systems. Storage of the UNF in dry storage systems at an appropriately sited and constructed CISF offers significant advantages over traditional on-site ISFSIs. Storage at a CISF will require the following considerations:

- Dry-storage system type–metal cask or canister to be stored;
- Number of years of prior storage at the NPP ISFSI;
- Design of the storage module at the CISF;
- Additional licensing requirements, if applicable, at the CISF;
- Storage duration at CISF prior to subsequent disposition such as recycling or disposal.

DRY STORAGE SYSTEM FOR THE CISF

ORANO TN has designed and licensed several DSC models housing PWR and BWR UNF which total more than 1,000 loaded canister-based dry storage systems in the United States. The dry storage systems are typically licensed for initial storage duration of 20 years. In the United States, a robust regulatory framework has been developed for the renewal of the storage duration by an additional 40 years [6]. The dry storage systems at the CISF (for canister based designs) will comprise arrays of storage module that house the DSCs that are transported from the NPP ISFSIs. Due to the considerations for potential extended storage of DSCs at the CISF as outlined above, the choice of the storage module design is very important. The storage modules can be either based on the same design the DSCs were originally stored at their respective ISFSIs, or based on a newer evolutionary design that is specifically optimized for CISF storage. The use of a single design for storage of several NUHOMS® DSC models in a "universal" storage module is proposed herein. The criteria and advantages of a universal storage module are detailed in the following sections. The applicability of the universal storage module to store other DSC models is also discussed.

Criteria for a Storage Module at the CISF

The storage module at the CISF is designed and licensed to provide for maintaining the primary safety related design functions such as structural and environmental protection, radiation shielding and passive heat removal. Appropriate siting of the CISF can be performed to minimize the potential for accidents and environmental effects on the dry storage systems. For example, minimizing the potential for, and consequences of bounding environmental phenomena such as, floods, earthquakes, and tornadoes can be achieved by siting the CISF appropriately. Further, the effects of long term aging, particularly the susceptibility to chloride induced stress corrosion cracking (CISCC) of the DSC can be minimized by selection of the CISF in an environmentally "benign" location. Another important objective for the storage module is also to ensure operational simplification at the CISF. Principal CISF operations include receipt of the DSC within the transportation cask, processing of the DSC and Cask for handling and transfer including use of a transfer cask, preparation of the DSC and Cask for storage, transfer of the DSC to the storage module, monitoring and aging management inspections during storage. The use of a universal storage module ensures that the transfer and monitoring operations are simplified.

Advantages of a Universal Storage Module

For CISF operations, the use of a universal storage module leads to a significant safety, quality, performance and economic benefits. The universal storage module design can be optimized for the CISF to ensure effective utilization of space and adequate heat removal consistent with the expected contents. It is important to note that the performance requirements for heat removal at a CISF need not be the same as the design basis requirements for dry storage systems at the NPP ISFSI. Most, if not all, dry storage systems are designed and licensed to maximize the heat loads (minimize cooling time) of the UNF contents, they may not be optimized for CISF operations. By designing the storage module to meet the site-specific seismic requirements of the CISF at the "relatively" lower heat loads following transportation, the storage module can be optimized. The use of a universal storage module design also enhances safety and quality by minimizing the number of handling equipment and operational procedures. Depending on the various DSC and HSM designs, the type of transportation cask, transfer cask or transfer equipment (such as trailer, skid etc.) could be different which leads to the use and maintenance of several types of equipment at the CISF. Employing a single set of transfer equipment and a single storage module design leads to consistency and efficiency of operations. The potential extended duration of storage in the CISF would also make it necessary to incorporate certain design and operational features to the storage module to facilitate ease of inspections of the DSC external surface and storage module interior as part of an aging management program (AMP). A single storage module design would lead to incorporation of these features.

Development of a Universal Storage Module for the NUHOMS® System DSCs

Several models of the NUHOMS® system DSCs are in operation at various ISFSIs in the United States. These models can be grouped based on various features such as external diameter, payload weight, UNF fuel type (BWR or PWR), content specification limits (heat load, burnup, enrichment and cooling time), HSM type, compatibility with transportation cask design, etc. In order to develop a universal storage module, two important design features are external diameter (geometric compatibility) and decay heat. The external diameter is important because it provides for the availability of space for air circulation within the storage module for heat removal and additional space for inspections. Decay heat is one design input that is required to ensure the optimization of the storage module design in addition to site environmental parameters.

Table 1 shows the three broad groupings of the NUHOMS® system DSCs based on their diameters and the maximum licensed decay heat for each group. Note that there are more than 15 DSC models for the NUHOMS® system which also have several variations of basket types.

TABLE 1. NUHOMS® DSC GROUPS AND DECAY HEAT LIMITS

DSC Group	External Diameter	Decay Heat
Small	< 68 inches (1727 mm)	40.8 kW
Medium	< 71 inches (1803 mm)	40.8 kW
Large	< 76 inches (1930 mm)	50 kW

The universal storage module for the NUHOMS® system DSCs should be able to accommodate a difference in the diameter of approximately 8 inches (200 mm). Further, the structure where the DSC is supported horizontally during storage should also be able to account for the geometrical variations. In addition, the door opening should be compatible with the various licensed transportation cask designs such that the DSC can be transferred to the storage module directly from the transportation cask. The universal storage module should be capable of rejecting the maximum decay heat of the licensed DSCs, although it may be sufficient to consider the maximum licensed decay heat for the transportation cask. In summary, a universal storage module should be able to maintain the same safety and operational features of the NUHOMS® system, including horizontal storage. The use of a horizontal method of DSC transfer into the storage module significantly reduces the risk of handling, particularly following storage at the ISFSI. DSCs are transported in a horizontal orientation in the transportation casks, so horizontal storage will eliminate several high risk handling operations.

MATRIX HSM as the Universal Storage Module

Innovation in the storage module design at the CISF could result in simplified operations and effective implementation of the AMP for canister based systems. The NUHOMS® MATRIX is an example of a universal storage module design that was specifically designed for extended storage and facilitating CISF operations including enhancement of the AMP. MATRIX HSM is sized to accept DSCs with the largest diameter currently licensed in the United States, providing the capability to house all licensed canister designs. Figure 2 shows a more detailed representation of the MATRIX module.

During storage, the DSC inside the MATRIX is supported at the front and the rear only, thereby obviating the need for the DSC support structure which results in enhanced air circulation around the DSC. Further, the height of the front and rear DSC supports can be adjusted to ensure ready accommodation and support for the required range of DSC diameters.

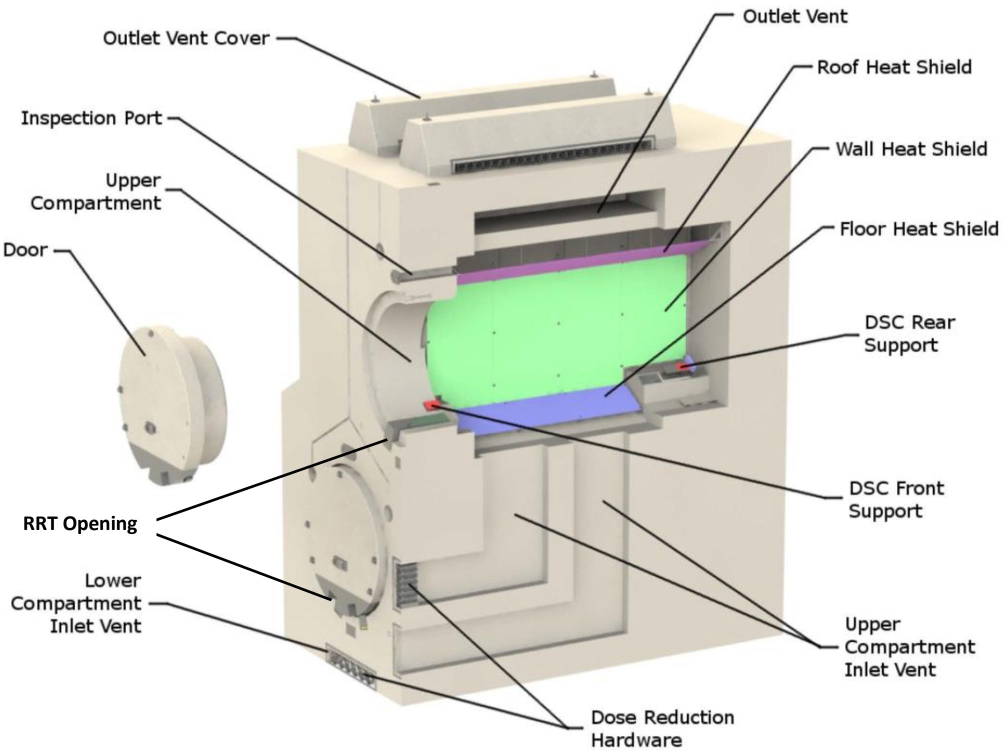

FIGURE 2. NUHOMS® MATRIX HSM UNIVERSAL STORAGE MODULE.

The safety analysis report for the MATRIX is under review by the NRC for the storage of the larger diameter (~76 inch, 1930 mm) [7] and the smaller diameter (~68 inch, 1730 mm) [8] DSCs. The maximum allowable heat load for the DSCs is 50 kW. With a monolithic structure, the MATRIX array with the loaded DSCs is inherently stable and is currently designed for seismic criteria of 0.85G in the transverse direction and 0.80G in the vertical direction. This capability ensures that the MATRIX can be installed anywhere in the United States with no additional seismic enhancements.

The MATRIX is designed with independent air flow paths (inlets and outlets) for the bottom and top tiers which results in optimized heat removal of each DSC in the array as shown in Figure 3. Heat shields are installed to protect the inner surfaces of the concrete from the radiative heat emanating from the DSC surface. Specially sized inlets and outlets, placement of dose reduction hardware and additional design features (shown in Figure 4) ensure maximized airflow and enhanced shielding performance.

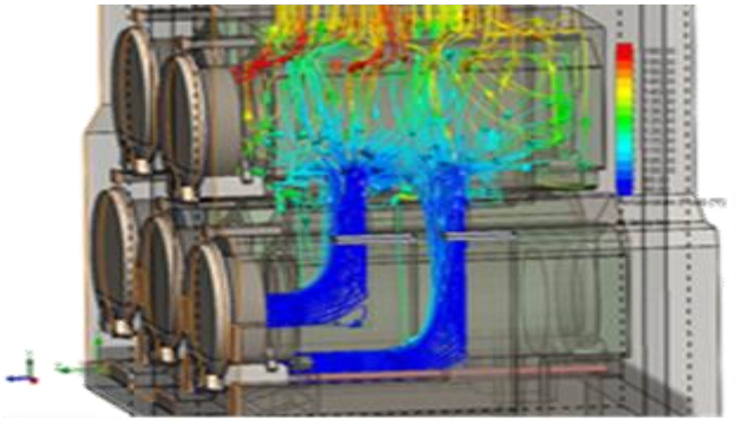

FIGURE 3. AIRFLOW WITHIN THE NUHOMS® MATRIX HSM.

The DSCs are loaded into the MATRIX modules using the new retractable roller tray (RRT) deployed through the specially designed RRT openings near the door. The RRT opening and the RRT system is also designed to be configured to perform 100% DSC surface inspections within the module. In addition, special inspection ports are also built into the MATRIX to access the DSC surface. The ability to perform inspections without removing the DSC from the MATRIX results in a significant reduction in risk and exposures. MATRIX HSM currently has the functionalities of the universal storage module.

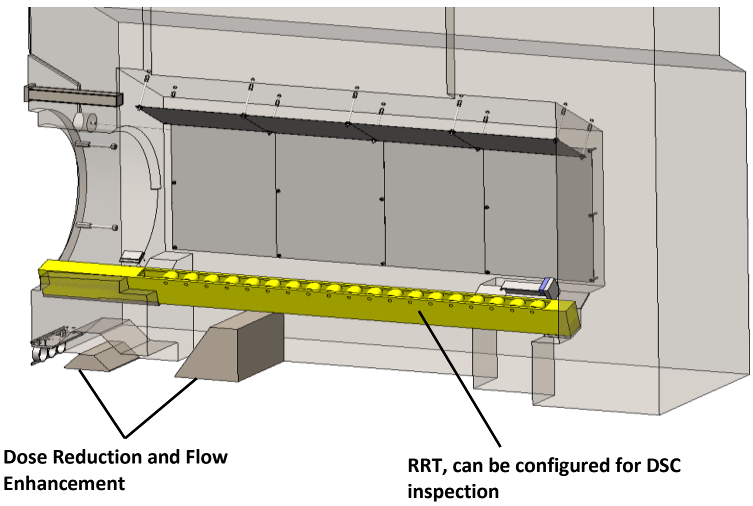

FIGURE 4. OTHER DESIGN FEATURES OF THE NUHOMS® MATRIX HSM.

The MATRIX can also function as the universal storage module at the CISF of other DSC models based on its geometric compatibility and high seismic and heat rejection capabilities. The DSCs are transported in approved transportation packages prior to storage at the CISF. Therefore, they can be stored horizontally in the MATRIX as long as it is demonstrated that the MATRIX provides for equal or enhanced protection to the DSC and its contents. The MATRIX is designed to meet higher performance criteria for storage of NUHOMS® DSCs compared to transport cask designs. With its significant safety, versatility and operational simplification features, MATRIX can be adopted as the storage module for the CISF.

CONCLUSION

Interim and potential extended storage of UNF in dry storage systems in the United States will benefit when storage is performed at centralized interim storage facilities. Due to a majority of the UNF being stored in canister-based systems, it is necessary that universal storage module be designed for implementation at the CISF. The NUHOMS® MATRIX HSM combines all of the advantages associated with above-ground, horizontal storage of UNF and provides for enhanced design features resulting in significant space savings and operational simplification. The unique design features of the MATRIX that enable adaptive DSC geometry and ease of inspection for aging management make it ideal for its consideration as a universal storage module.

NOMENCLATURE

NUHOMS® is a trademark of ORANO TN registered in the United States and other countries.

AMP–aging management program

CISCC–chloride-induced stress corrosion cracking

CISF–centralized interim storage facility

DSC–dry shielded container

HSM–horizontal storage module

ISFSI–independent spent fuel storage installation

LC–Loading crane

NPP–nuclear power plant

RRT–Retractable roller tray

UNF–used nuclear fuel (spent nuclear fuel)

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