Perspectives on Interim Storage Solutions of Used Nuclear Fuel in the Long Term – 14041

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ABSTRACT

In 2013, the total amount of stored Used Nuclear Fuel (UNF) in the world will reach 225,000 metric tons heavy metal (MTHM). UNF inventories will continue to grow with a projected 50% increase of nuclear energy within the 20 coming years. In terms of final UNF management strategy, recycling is a well proven solution that represents an annual capacity of about 4,800 MTHM in only four countries. UNF is generated in 31 countries at a rate exceeding 10,000 MTHM per year. An alternate solution to recycling is a disposal facility but no country has yet received a license to construct or operate such a facility. Due to on-going public and political debate, in many countries, past assumptions related to the availability of UNF disposal facilities have often been wrong resulting in the need to extend interim storage solutions.

While it is essential to develop those long term optimized solutions, interim wet and dry storage solutions are important components of an integrated UNF management strategy. Safety and reliability of interim storage solutions are well established, but storage durations are constrained by regulatory limits. In the US, limits are 20 years, however can be extended for as much as an additional 40 years. Wet storage has been implemented for more than 40 years and dry storage has now reached the 35-year point in a few countries. Moving forward, interim storage periods are not known with certainty and additional technical evaluations are needed to better understand the safe duration of such solutions due to potential change in fuel behavior and aging of the storage systems. In parallel, appropriate infrastructure should be developed to ensure safety and security independently of time.

An overview of the wet and dry storage technologies implemented in countries with long histories of UNF storage will be presented. Information on industrial experience with alternative interim solutions will also be included. In conclusion, progress that needs to be made by R&D investigations to maintain longer term safety will be described.

INTRODUCTION

Interim storage solutions for UNF have been safely developed and deployed in different countries for many years providing important industrial experience feedback. By definition, interim storage solutions are only temporary solutions before a final disposal path(s) is selected: recycling and/or direct disposal of UNF. However, governments are not always very proactive or prompt and often face unexpected challenges to implementing a final disposal option, which results in a need to extend interim storage solutions. Until recently, a storage period up to 40 years was considered to provide sufficient time to make decisions and implement a solution to the back-end fuel cycle and/or establish final waste management options. Now, however, it appears that the storage duration will have to be extended to much longer timeframes, potentially beyond a century. For example in the USA, based on the most updated plan from the Department of Energy, a geological repository will be available at the earliest in 2048, at least 50 years after it was originally expected to become operational. Safety and security of the UNF over this timeframe when various activities involving the UNF may take place (e.g., interim storage at site, transfer and transportation operations to the final disposal site) is a critical element of a comprehensive and sustainable used fuel cycle. An integrated approach [1] must be developed to include safety, security, public acceptance and economic factors as a result of these activities and the timeframe they occur over. The longer it takes to decide and implement a final disposition path, the more complex the solution will become and also the more costly the total fuel management costs will become.

I. OVERVIEW OF FUEL INVENTORY

In 2013, the total amount of stored UNF in the world will reach 225,000 MTHM. The UNF inventory in wet storage will take up over 80% of the available total spent fuel pool (SFP) capacity, which places pressure on the operators of the reactors to provide the space needed in the SFPs to maintain a full core offload capability. Disposal of UNF is not an available option yet in several countries due to lack of an integrated UNF management approach and, in some cases, the cessation of planned disposal facility development.

In countries lacking an integrated UNF management approach, the UNF is discharged from the SFPs to interim storage (mostly to dry storage) at the same rate as UNF is being discharged from reactors, because the SFPs at the reactor sites are becoming full. This is now the case in USA, Taiwan, Switzerland, Spain, South Africa and Germany and appears to be the future direction of other countries that do not have an integrated UNF management approach. With time, dry storage may become perceived as a solution for management of UNF instead of a flexible intermediate step before decision making. As a result, the accumulation of radioactive material in the pools and in on site dry storage is expanding. Presently this does not present safety or security issues. However, with the need to extend interim storage solutions, new safety and security considerations have to be taken into account as the result of time affecting fuel material properties and potential degradation of the components of the storage systems. The environment specific to each site (marine, seismic, freeze-cycles, etc.), although considered in the initial licensing activities, may pose additional factors that may exacerbate these degradation issues over an extended storage time.

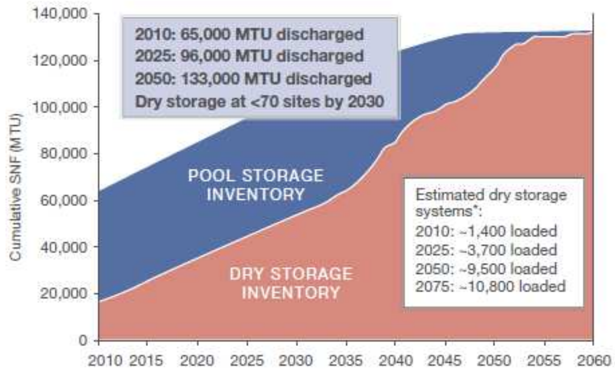

Fig. 1. EPRI Projection of cumulative spent fuel from commercial NPP in the US in pool storage and dry storage, 2010-2060.

II. INDUSTRIAL EXPERIENCE WITH ALTERNATIVE INTERIM STORAGE SOLUTIONS

With the lack of an integrated final UNF management disposition approach, technical solutions have been developed in different countries to meet the needs of the utilities to allow the continued operation of their reactors while meeting the current requirements of their Safety Authorities. These solutions are very diverse and may be divided in four categories for which AREVA has developed different solutions worldwide:

- Dry storage canisters on pads
- Vaulted dry storage
- Dual-purpose casks (dry storage and transportation)
- Centralized pool storage

A brief description of each solution is provided below.

- **Dry storage canisters on the pad**

This interim solution was developed initially for short term interim storage on reactor sites. The UNF is placed in leak tight inerted welded canisters inside a massive concrete overpack that provides physical protection and shielding. Canisters will have to be transferred into a transportation cask for transport to centralized storage or final disposal path (e.g., recycling or disposal).

NUHOMS® systems (Fig. 2), for example, are widely used in the USA. In total, more than 500 NUHOMS® systems have been ordered. The NUHOMS® system can accept BWR and PWR used fuels.

The advantages of the pad solution using dry storage canisters are modularity, passive cooling and low up front cost. However, over time, fuel retrievability may become more challenging to ensure, especially for high burn-up fuel assemblies, and for canisters in a coastal environment. Furthermore, when there is no pool or hot cell available on site to examine and/or recondition the fuel (especially at shutdown reactors), an additional complexity may arise and lead to additional costs if these activities are necessary.

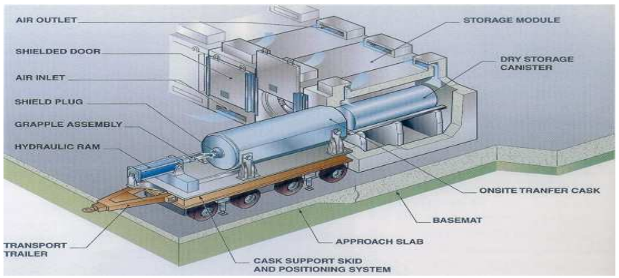

Fig. 2. Example of Dry Storage Canisters on the Pad

- **Vaulted dry storage**

The vaulted dry storage solution has been developed in several countries for the storage both of glass waste from recycling as well as used fuel assemblies (implemented in France in CASCAD for fuel assemblies from research reactor and at the Habog Facility in the Netherlands). This concept is being developed at the Spanish ATC facility (Fig. 3). Small canisters (typical capacity of 6 used fuel assemblies) are stored in a protected building with natural convection cooling. This storage approach allows for canisters containing vitrified fission products (generated from recycling) and canisters containing UNF to be stored until a final disposition path is established.

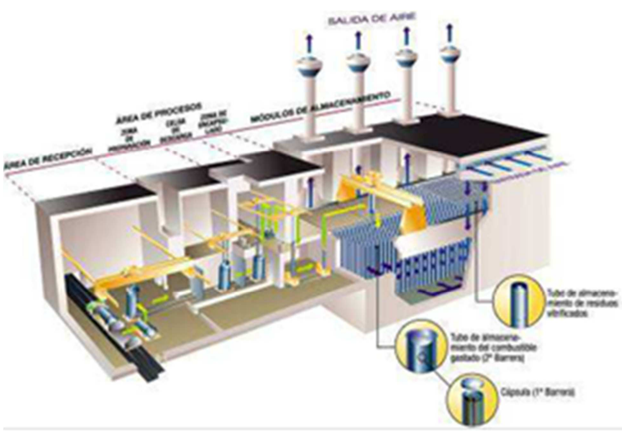

Fig. 3. Conceptual Design of the Spanish ATC Facility

In this facility, each well can be designed to provide continuous remote monitoring. In addition, the vault system is equipped with a hot cell to allow for unloading of the transportation casks and the repackaging of the UNF into canisters. The same hot cell can be used to periodically extract and examine fuel to monitor its condition. Furthermore, after interim storage, the hot cell enables repackaging of UNF assemblies into transportation casks destined for recycling and/or disposal, providing the flexibility to deal with multiple end-of-life scenarios.

Vault facilities are designed so that vault halls can be added in modular fashion to cope with future needs for an increased capacity, without the need to duplicate the hot cell, cask maintenance, and other components of the facility. Like dry storage canisters, cooling is passive. Physical protection and shielding are provided by the concrete structure surrounding the vault halls and hot cell. Because all operations are remote, personnel exposure is very low. One challenging aspect of vault system design is the design of hot cell facilities that are adaptable to many different designs of incoming used fuel casks and canisters, both bolted and welded.

- **Dual purpose casks**

Dual purpose casks are designed and licensed for dry storage and transport functions. AREVA has developed metallic dual purpose casks with more than 200 casks ordered. Dual purpose casks are in operation in USA, Japan, Belgium, Switzerland, Germany and Italy. The capacity reaches 40 PWR FA or 97 BWR FA, and maximum 65 to 70 GWd/t burn up, cooling times 5 to 7 years.

TN NOVA™ system is the latest system designed by AREVA for this market and consists of a canister system that is transported horizontally and transferred horizontally into a ventilated metal storage overpack which can be tilted vertically for storage on site. The system thus combines the advantages of closely packed indoor storage of metal casks with the advantages of a canister-based system, in particular the separation of the transport and the storage licenses. The canister used in the TN NOVA™ is licensed for both storage and transportation, but the transportation cask is not part of the storage system.

Dual purpose casks provide flexibility with respect to storage location as they may be stored in a protected building with passive cooling (Japan and Europe) or on an outdoor storage pad (USA) at site depending upon specific country requirements. They may also be stored horizontally, as in the cask of the TN-24 casks (Fig. 4) that survived the tsunami at Fukushima Daichi.

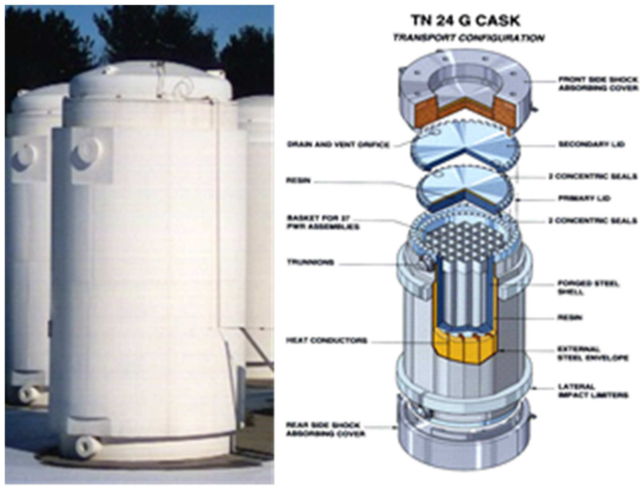

Fig. 4. Example Dual Purpose Cask System

The advantages of the dual purpose cask are modularity, passive cooling, easy end of life retrieval and transport, and the capability for re-use.

In addition the possibility exists for monitoring the long term behaviour of UNF with a specific lid that allows for the implementation of sensors. This is the approach that was used for the original EPRI-DOE demonstration program [2], and the proposed approach for the demonstration of high burn up UNF in the USA with AREVA TN-32 casks.

- **Centralized pool storage**

Wet storage is a required step after fuel discharge to allow sufficient cooling time period for the decay heat and gamma source terms to decrease. Centralized wet storage is also an interim solution while a final UNF management approach is being implemented. It is a proven solution based on up to 60 years of experience in some countries including in the US.

The advantages of pool storage (Fig. 5) are that most of the mechanisms which could affect fuel cladding integrity do not occur at pool temperatures and that fuel behaviour can be easily monitored due to accessibility to the fuel. Consequently, the major advantage of this solution is to ensure retrievability of the UNF in the long term because with low temperature (<45℃) the fuel is not subject to thermally activated phenomena which could affect the integrity of the fuel. It can also limit the number of fuel handling operations as the fuel can go directly from wet storage in a pool to the selected UNF disposition path. Consequently, pool storage reduces risks, dose rate and complexity related to fuel transfer. For the reactor operator, fuel handling in the pool is part of their normal operations, unlike the transfer to dry storage. It is worth noting that prior to moving to dry storage, most US reactors first re-racked their pools to increase capacity. For the construction of new reactors in countries without geologic storage or recycling on the horizon, pools with a capacity for the full life of the plant, including life extension, may be the preferred option, as in the case of Hinkley Point [3].

After the Fukushima event, many countries have been performing additional analysis taking into account Fukushima to ensure of the safety of wet storage conditions. In the United States, the US Nuclear Regulatory Commission (NRC) issued in early October 2013 a report of a study on the consequences of a beyond-design basis earthquake on a US spent fuel pool. The study shows that pools provide adequate protection and expedited removal from the pools does not bring substantial safety enhancements.

Numerous fuel pool cooling systems operate reliably for decades and provide, if not just loaded with a full core inventory right after reactor shut down, considerable time for intervention is available in case of loss of power. Water treatment required depends on the frequency of refuelling operations and is insignificant for storage only operation. Intrinsic fuel pool safety is further enhanced when using passive fuel pool cooling combined with a hardened enclosure as developed by AREVA GmbH. Such passive system and protective design is successfully being implemented for more than 5 years operation of the external fuel pool at Goesgen NPP Switzerland.

Fig. 5. Example Pool Storage System

III. Research & development work needed

Integrity of UNF and dry storage systems has been demonstrated for existing licensed systems for low burn up fuel through the original 20 year storage license in the United States. As long as an inert atmosphere is maintained, fuel integrity is expected for low burnup fuel in dry systems. As the likelihood of much longer storage durations became apparent, various agencies have identified gaps in the knowledge necessary to assure the continued integrity of the storage system and the fuel [6 and 7].

The identified gaps concern the following issues especially for high burn up fuels:
- Thermal model for casks,
- Degradation process of fuel material,
- Cladding creep,

- Embrittlement of cladding,
- Pellet swelling,
- Technical basis for amount of residual water,
- Measurement of residual water,
- Corrosion
- Drying procedures and criteria
- Security features

In the United States, the greatest concern has centered on reduction in the ductility of high burnup cladding as it cools, and the possibility of stress corrosion cracking in stainless steel canisters stored due to chloride aerosols, for example at coastal storage sites.

To answer the needs for extending interim storage and for securing fuel retrievability in the future for disposal and/or recycling, additional studies must be performed to ensure safety and security of dry storage solutions due to the potential change in UNF behaviour over these timeframes, especially high burn up as well as the potential degradation of the components of the storage systems over time [3].

Aging and degradation of UNF are evaluated by many R&D national programs [4] in various countries facing the need to extend dry storage. Test methods and models are used to demonstrate the safety in storage conditions. R&D work has already been done to allow for licensing of low and high burn up UNF for current storage solutions and to help decision makers. Meanwhile, some storage systems and facilities are reaching the end of their initial license period, and are facing the need to extend the licenses, and to provide aging management programs before the results of the new research is available.

The challenge is to complete as soon as possible the research into the most important gaps identified, in order to demonstrate the safety of continued interim storage, and to provide the storage facilities with the tools, such as inspection techniques, needed for aging management. This is what is necessary for dry storage to continue to fulfil its objectives: first to provide safety and security protect the public and second to be an intermediate step to allow time to implement a long term and final UNF management solution. For the industry, this step is an additional cost burden, which is necessary in order to maintain the operation of its reactors but unnecessary had an approach to UNF management been established. Hence, the danger is that this step is transformed into an argument further supporting no decision regarding the approach to UNF management. Consequently, industry must ensure that pressure (and financial burden) is applied to all levels of government to further a complete approach to UNF management.

CONCLUSIONS

Interim storage solutions are needed. They give flexibility to the nuclear operators and ensure that nuclear reactors continue to operate. However, we need to keep in mind that they are also an easy way to defer a final decision for implementation of a UNF management approach (recycling or final disposal). In term of public perception, they can have a negative impact over time as it may appear that nuclear industry has significant issues to resolve. R&D work in the coming years will be crucial to demonstrate the safety and security of extended interim solutions but those solutions must not be considered without a time limit and the need for UNF management approach. We do have a general obligation to society to dispose of the material.

As awareness of the need for a sustainable fuel cycle grows, several initiatives have been launched in response to rising challenges associated with uncertain storage time that may go along extending used nuclear fuel interim storage until transport for reprocessing/recycling or Direct Disposal.

A European Directive [5] dated back in 2011 establishing a Community framework for the responsible and safe Management of used nuclear Fuel and radioactive Waste has taken effect since August 2013 within all European Union Member states.

More broadly, International Organizations such the IAEA and the WNA have also launched Working Groups to provide guidance to enable the development and implementation of informed policies and programs for ensuring safe, secure and effective used fuel management that do not endorse indefinite storage or continued storage of UNF without full commitment to a plan for its final disposition which may consequently result in unnecessary risks.

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