Integrated Solutions for Interim Used Fuel Management: From Pool Unloading to Safe Delivery to Recycling or Repository Facilities – 17235

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ABSTRACT

Safe management of used nuclear fuel (UNF) is key to the survival of the nuclear industry. That is why it is more important than ever to have a consent-based, practical, credible, and sustainable roadmap for managing the back-end of the nuclear cycle.

Worldwide UNF Light Water Reactors (LWR) inventories are currently around 200,000 tons and are estimated to grow to more than 350,000 tons by 2030, and operating nuclear reactors in the U.S. continue to discharge UNF every 18 to 24 months. International experience has demonstrated that the development of a permanent geological repository can be a multi-decade process, especially in the face of public acceptance challenges.

Meanwhile, the solution for permanent disposal of UNF in the U.S. is moving at a glacial pace. As a result, industrial stakeholders have been forced to find practical interim UNF storage solutions in order to continue safely operating their reactors.

Among those interim solutions are the cask- or canister-based dry storage systems that have dramatically increased in the last 10 years as they provide flexibility for expansion with a low up-front investment.

With interim dry storage in place for more than 30 years, our industry is entering a new phase as we are forced to prepare for a few more decades before geological repositories begin operating. Consequently, interim dry storage has to be extended for 80 years or more.

Thus, new considerations have to be taken into account to ensure the safety of this stored used fuel:

- Interim storage systems are aging
- High burn-up fuel behavior overtime is uncertain
- Used fuel is losing its self-protection
- The number of shutdown sites without a fuel transfer facility, such as a pool, is increasing
- Some owners of Independent Spent Fuel Storage installation (ISFSI) at shutdown sites are not nuclear operators anymore.

With increasing uncertainties, AREVA TN -- based on its long expertise with used fuel transportation and interim storage systems -- is adapting its portfolio to develop integrated and flexible solutions that will remove the burden of interim used fuel management from nuclear operators.

AREVA TN is developing comprehensive solutions to reduce risks including the

continued supply of proven safe high-performance dry storage systems; on-site services to safely transfer used fuel from pool to pad; the optimization of fuel heat load in the storage pool and pad; innovative aging management services including inspection, monitoring and repair; a realistic solution for consolidated interim storage with a priority to remove Used Nuclear Fuel stored in dry storage systems from shutdown sites; world-class transport and logistics services to safely move the used fuel from nuclear reactor sites to consolidated storage and repository or recycling as applicable, and turnkey management of shutdown ISFSIs.

Due to the lack of an available path for transporting used fuel away from reactors, nuclear operators are faced with many challenges and growing uncertainties. Our presentation will describe the practical solutions developed and being developed in order to manage used fuel on behalf of nuclear operators and allows them to continue focusing on the important job of producing carbon-free clean energy.

INTRODUCTION

Our industry has to embrace a reality: implementing a responsible disposal of nuclear waste project is far more complex than anticipated. Different factors including political agendas and underestimating the importance of public acceptance -- in a world driven by social media -- have created major delays in the implementation of geological repositories. While interim storage of final waste arising from treatment has been demonstrated to be safe for several centuries, there is still uncertainty. It is clear, the road will not be smooth and interim steps need to be defined to bridge the gap.

Nuclear energy is among the best options for carbon free clean energy on the planet. To remain sustainable, our industry must demonstrate that nuclear is a cost-competitive source of energy. This means removing all uncertainties linked to fuel back-end management. Consequently, most efficient back-end management costs are part of the equation for the successful continuation of our industry. Drawing the roadmap from departure to the destination point, while facing the realities, is the best way to succeed in optimizing the costs and also obtaining required public acceptance. This presentation will describe integrated solutions from reactor pool to repository or reprocessing.

NUCLEAR CAPACITY, SPENT FUEL INVENTORIES GROWTH AND STATUS OF GEOLOGICAL REPOSITORIES

Nuclear Capacity and Used Fuel Inventories

Nuclear power capacity worldwide is increasing steadily, with over 60 reactors under construction in 15 countries as shown in figure 1. There is a geographical shift as most of reactors on order or planned are located in the Asian region. In addition, further capacity is being created by plant upgrading. Plant life extension programs are maintaining capacity, particularly in the U.S.

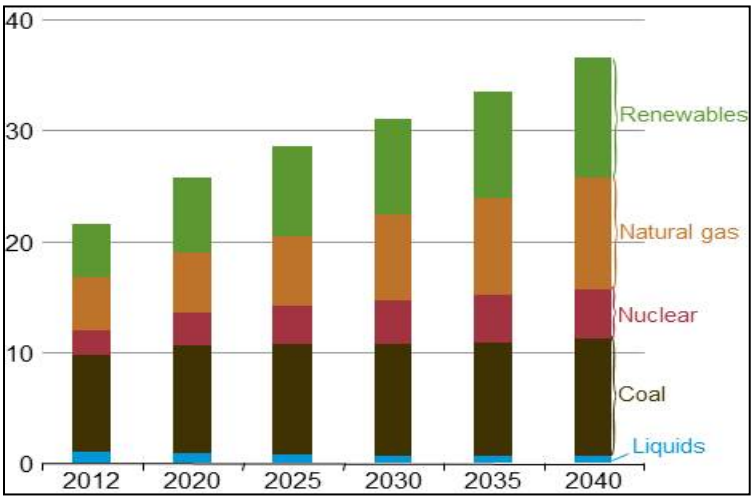
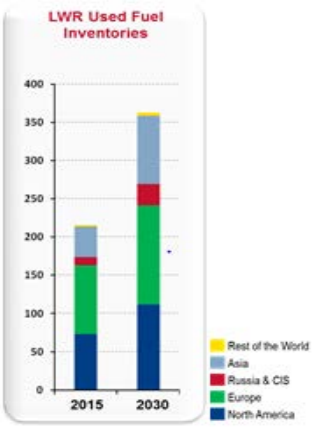


Fig. 1. World net electricity generation by energy source, 2010-40 (trillion kilowatt-hours)/source DOE/EIA-0484(2016) - May 2016

Some more optimistic scenarios forecast that global nuclear power will almost double with a capacity of 373GWe in 2012 to 645GWe in 2040. China Nuclear Power generation will be multiplied by a factor of 13 with ~ 12GWe in 2012 to 173GWe in 2040. In any case, we can predict a growth of capacity that will drive an increase of used fuel inventories. Worldwide UNF Light Weight Reactor (LWR) inventories are currently around 200,000 tons, estimated to grow to more than 350,000 tons by 2030 as shown in figure 2 (Source AREVA). A few countries have a national policy to recycle the spent fuel. However, even if we forecast an increase in the future, -recycling facilities remain scarce resources. Less than 1/3 of the cumulative inventory of used fuel has been recycled today.



Geological Repositories

Designing and licensing a geological repository is not only a technical and engineering project, it is a far more complex project. Political controversy and public acceptance have affected the schedule of all the projects worldwide. As a reminder, in the U.S., the first geological repository was expected to start operations in 1998; the latest forecast is for a 2050 start.

The most advanced projects are with Finland, Sweden and France with a forecast to start operation around 2025. Finland is expected to be operational in 2022, becoming the first permanent repository for spent nuclear fuel disposal. It will serve as a reference for other projects.

INTERIM STORAGE SOLUTIONS

Because of scarce resources for used fuel management, nuclear operators have to manage and reduce risks related to pool saturation. Except for those countries that have deployed recycling, reactor operators need to implement interim solutions to continue producing and selling electricity.

Deployed and proven alternate interim storage solutions consist of wet storage in pools and dry storage in vaults or casks and canister systems. On-site dry storage in casks and canister systems has increased significantly in the last 20 years. This solution offers proven safety and flexibility, thus avoiding the need for a significant cash flow up-front. In an economically stressed environment, the modularity of dry casks is attractive. In the U.S., dry casks and canisters systems have been operating on reactor sites for more than 30 years.

AREVA TN's portfolio of interim solutions includes those alternate technologies as highlighted in the pictures below. Figure 3 is a picture of concrete/canister system deployed in the United States. Figure 4 shows a metallic dual purpose cask technology deployed in Western Europe.

View of NUHOMS dry storage in USA

View of TN-24 casks in Switzerland

CHANGING ENVIRONMENT

As the establishment of geological repositories is delayed, our industry has to consider new factors.
We can consider two main groups of nuclear operators:

1. The mature fleet that has already implemented dry storage solutions (mainly in North America and Europe) ;
2. The youngest fleet that is about to face pool saturation.

They both have to deal with new constraints in the management of their used fuel:

Mature Fleet

The mature fleet has been able to deploy on-site dry storage without major public concerns; it is now a “routine” operational activity linked to the reactor operation. However, with time, uncertainties around aging are surfacing thus driving the new initiatives to ensure continuous safety and security.

Uncertainties include:

- Aging of deployed systems
- Fuel behavior overtime with possible alteration of the licensed fuel content for transportation
- Increasing number of secluded shutdown sites with new challenges:
    - No pool in case of need to transfer the fuel into another system prior to transportation
    - Handling and transport infrastructure around those sites is deteriorating
    - Expertise is diminishing as experienced staff are retiring
- Aging used fuel is no longer self-protected

Another factor affecting the mature fleet relates to economic viability forcing some plants to prematurely shutdown. Plant operator needs to reduce costs of their shutdown sites and quickly eliminate storage pool operating costs.

In order to mitigate the problem of aging systems and fuel behavior, the industry is proactively working on aging management programs including inspections, monitoring and repair. Fuel behavior analyses are also ongoing with several national and international initiatives underway.

As a designer and owner of dry storage systems, AREVA TN is innovating new technologies to inspect, monitor and repair systems.

TN Aging Management

- High Burn-up demonstration project: AREVA TN and AREVA Federal Services are supporting a DOE effort to study high burn-up fuel. This project is designed to answer questions about long-term storage by placing irradiated

fuel into a storage cask and monitoring behavior over many years.
- Corrosion inspection in vulnerable location: In the U.S., dry storage canisters are welded. Over time, especially in a marine environment, corrosion risk must be monitored and mitigated. AREVA TN is developing an inspection tool that will allow a thorough inspection of canister surfaces.
- Tools and processes: we are at the birth of aging management. Consequently aging management plans are not only new requirements from the NRC but are also evolving as the industry learns more with inspections and feedback from operators. AREVA TN is working with the US NRC and customers in developing appropriate tools and processes to address this need.

Youngest Fleet

The youngest plants in the fleet will need interim storage solutions too. They will not be able to implement a final disposal solution in time to transfer their used fuel from their site to recycling or a repository. Furthermore, there is also a consensus that prior to disposal, used fuel need to be cooled for at least 40 years to reduce constraints on a repository.

In addition, with our new world of instantaneous communications and events such as Fukushima, it is important to be ready to address public concerns that would not have surfaced 20 years ago. For example in China and in S. Korea, the spent fuel nuclear programs are also under high scrutiny of the public and local communities as various protests have already taken place.

Meanwhile, as implementation of used fuel management solutions are questioned more frequently by the concerned public, used fuel pools are reaching saturation in some of those countries. Development of on-site interim solutions must be carefully administered to ensure public consent is considered and the public and local communities are educated.

However, we have to acknowledge that all those necessary additional activities for both mature and youngest nuclear fleets have an incremental cost. Optimizing this cost is crucial for demonstrating the economic viability of the nuclear industry in a competitive energy source environment.

THE REALISTIC AND MOST EFFICIENT ROUTES FROM NUCLEAR REACTOR POOLS TO REPOSITORIES

As a reminder, there are two main paths for nuclear waste final disposal:
- Used fuel is disposed into a geological repository
- Used fuel is recycled, allowing 95 percent of materials to be re-used in the fuel cycle, with only the remaining five percent to be disposed in a geological repository.

The latter scenario accounts for less than 1/3 of the spent fuel inventories, yet

offers a responsible and efficient path. Used fuel is moved from reactor pools to recycling facilities. Interim dry storage prior to recycling may be used for additional flexibility. After recycling, ultimate wastes will be disposed at the geological repository. With current unavailability of repositories, they are currently stored in dedicated interim storage facilities that are licensed for at least 100 years pending opening of final disposal.

In the first scenario -- in an idealistic world -- the spent fuel is moved from the reactor pools to centralized storage at the repository site for the necessary cooling period pending disposal. As we have learned over the past decade, with the complexity of geological repository projects, this is not a realistic option.

Interim storage is an essential element of a back-end management roadmap. However, a strategic planning that will include the complete solution with interim steps is needed in order to minimize costs and maintain a competitive edge. A strategic planning to cover fuel management from pool to repository will allow developing smooth and cost effective transitions during different phases. A fragmented and short-term approach also called “wait and see” approach is not a practical or cost-effective roadmap that will demonstrate our nuclear energy price competitiveness. Consolidation enables the concentration of fixed costs and expertise until a repository is available. It will reduce cost uncertainty and will address public concerns by demonstrating safe and secure transport and consolidated interim storage facility operations.

In the U.S, with its large fuel inventory, a lack of anticipation, planning and integration will affect the final costs. The breakdown of responsibilities between nuclear operators who are asking for cheaper interim solutions has resulted in larger systems. Meanwhile, the Department of Energy has not defined any specifications to ensure smooth and cost-efficient compatibility of transport and storage thus amplifying the risk of cost increase. Many cost uncertainties will remain until used fuel is moved and a geological repository is designed and licensed.

There are successful examples of consolidated interim storage facilities in operation worldwide such as:

- In Sweden: SKB (owned by Swedish nuclear operators) is the Nuclear Fuel and Waste Management Company operating a wet storage facility named Clab. This central interim storage facility accommodates spent nuclear fuel for Swedish nuclear reactors while waiting for the final repository to begin operating. It is located north of Oskarshamn along the coast. Today, there is an inventory of about 6,300 tons of used nuclear fuel in the Clab facility. A picture of the entrance view of Clab facility is shown in figure 5. In early 2000, the facility was extended and today it has a permit for the interim storage of a total of 8,000 tons. At the beginning of 2015, SKB applied for a permit from the authorities to store up to 11,000 tons due to risk of delay with the geological Repository at Forsmark. Transportation operations from

nuclear power plants are mainly performed by sea. SKB also owns and operates the transportation assets. Guided tours are offered to visitors to be educated on the nuclear industry and used fuel management (Source SKB).

- In Switzerland: Zwilag facility, shown in figure 6, is the Swiss centralized dry interim storage facility for used fuel and wastes. It is owned by Swiss nuclear power plants. It is licensed to store used fuel and high-level waste. It is an indoor facility with dual-purpose metal casks. Transportation operations are performed by rail and truck. The facility is also equipped with a hot cell should it be necessary to examine the spent fuel or transfer it into another cask. The facility is also open for public visits. The Swiss government is responsible for defining the spent fuel management policies and the nuclear operators are responsible for the interim solutions regarding waste and spent fuel.

Entrance view of Clab, Sweden – Fig 5

Aerial view of Zwilag, Switzerland Fig. 6

In the United States, AREVA TN is actively working to license a first Consolidated Interim Storage facility that in a first phase will enable and accommodate the removal of spent fuel from the majority of existing shutdown sites. AREVA TN is collaborating with Waste Control Specialists (WCS) to start operations of the first US CIS facility. NAC International is also associated with this effort; AREVA TN being the technical integrator.

The WCS site is currently operating a low-level radioactive waste (LLRW) disposal facility licensed by Texas as an US Nuclear Regulatory Commission (NRC) Agreement State. The plan is to accommodate spent fuel for interim storage in additional to LLRW disposal.

The license application for the CIS facility was submitted to the NRC in April, 2016. It covers an initial 40-year license for the consolidated interim storage facility, which is designed to store 40,000 metric tons of spent fuel. The NRC is reviewing the application for acceptance. Once NRC is ready for review, they will docket it for technical review and begin public meetings.

In line with the report issued by the U.S. Department of Energy's Blue Ribbon

Commission, the first phase of the facility includes space for more than 300 dry storage systems comprised of 17 different systems (12 sites, 7 Stranded). The NRC license for the WCS CIS facility is anticipated for 2019. Construction will begin in 2019 and operations are planned for in 2021.

CONCLUSION

A practical and realistic back-end management roadmap must include interim storage phases. On site, wet and dry storage and consolidated storage facilities are the key building blocks of a comprehensive and certain back-end management roadmap. Consolidation is even more effective in countries with shutdown sites and aging dry storage systems.

However, to reduce the additional costs as well as the cost uncertainty associated with these additional phases, it is critical to have an integrated strategic planning. Fragmentation of operations and short-term vision will bring complexity and cost burdens.

Finally, with governments playing a pivotal role in the development of policies that impact a used disposal solution, nuclear operators and waste management organizations need to be actively engaged in advocating for practical cost effective solutions to limit risk exposure. Without such engagement, the ultimate danger is that we are left with an uncompetitive nuclear energy industry that is not sustainable for the long-term With so much at stake – global warming, safety of the environment and people – it is incumbent upon global leaders, our industry and on the next generation to step forward and ensure the safe and cost-effective management of used nuclear fuel.