Preliminary Concept of Operations for the Spent Fuel Management System[+] — 17134

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ABSTRACT

The Nuclear Fuels Storage and Transportation Planning Project (NFST) within the US Department of Energy's Office of Nuclear Energy is tasked with identifying, planning, and conducting activities for developing interim storage and transportation capabilities in support of an integrated waste management system (IWMS). The IWMS is expected to transport Spent Nuclear Fuel (SNF) from a reactor and deliver it to a repository in a suitable container, with the possibility of interim storage. The system will be composed of multiple subsystems including possible interim storage facilities (ISFs), one or more repositories, facilities to package and/or repackage SNF, and transportation.

The project team is analyzing options for an IWMS to identify viable options. To support analysis, the project team has developed a concept of operations framework for SNF related components of the potential integrated system and the interdependencies between those components. A goal of this work is to aid system analysts in developing consistent models across the project. The concept of operations framework will be updated periodically as new developments emerge.

At a high level, SNF is expected to be transported from reactor sites to a repository. Initially, SNF is unloaded from reactors and placed in spent fuel pools (SFPs) for wet storage at utility sites. To maintain space in SFPs, SNF is placed in containers at reactor sites for storage and/or transportation only after the SNF has cooled enough to satisfy loading limits. Once transportation requirements are met, the SNF may be transported to an ISF, where it is stored until a repository is developed, or it is transported directly to a repository if one is available.

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This technical paper reflects concepts which could support future decision-making by DOE. No inferences should be drawn from this paper regarding future actions by DOE. To the extent this technical paper conflicts with the provisions of the Standard Contract, the Standard Contract provisions prevail.

While the high level operation of the system is straightforward, analysts must evaluate numerous alternatives, such as the number of ISFs (if any), ISF design, the stage at which SNF repackaging occurs (if needed), repackaging technology, types of containers used, repository design, component sizing, and timing of events. These alternatives arise due to technological, economic, or policy considerations. This paper provides an overview of the potential alternatives identified in the concept of operations framework at a conceptual level.

INTRODUCTION

The Nuclear Fuels Storage and Transportation (NFST) Planning Project is laying the groundwork for a US Integrated Waste Management System (IWMS). As part of this work, analysts are evaluating system alternatives. To support development of baseline scenarios and provide a point of reference across the project, a concept of operations framework is maintained to describe components of the potential IWMS, regularly taking into account new and more detailed information. This paper summarizes the current concept of operations framework.

The concept of operations framework for the spent fuel management system lists the equipment and procedures used to remove SNF from reactor sites, possibly store the SNF, and ultimately deliver the SNF produced by the current reactor fleet to a repository for final emplacement. The preliminary systems in the concept of operations framework are intended to be part of an overall IWMS that is flexible and adaptable to future changes. A high level diagram of concepts listed in the framework is shown in Figure 1.

In this work, the current trends in SNF container selection and usage are discussed to introduce terminology and provide background. Next, SNF management at utility sites is discussed, followed by transportation and ISF systems. Finally the paper concludes with a very brief mention of repository surface operations.

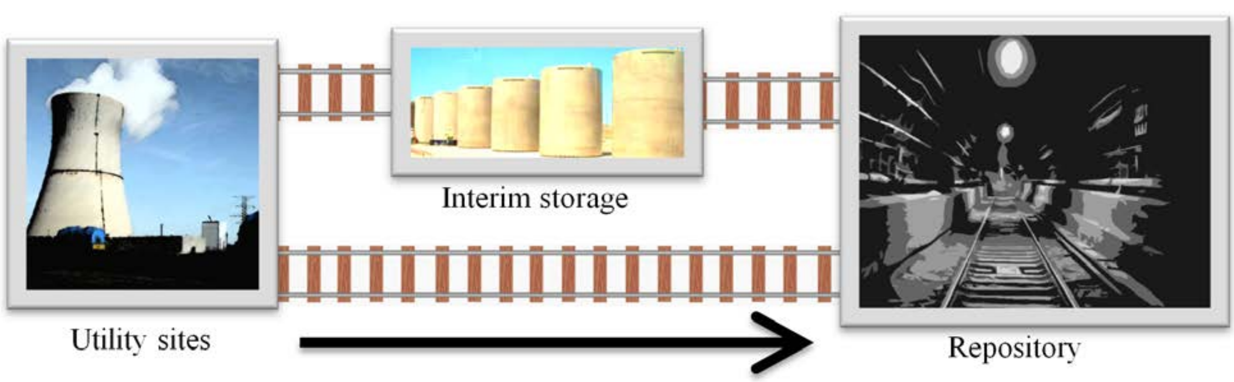

Figure 1. High level diagram of SNF flow in an integrated waste management system.

SNF CONTAINERS

Currently, SNF containers are classified into two broad categories: bolted lid casks and welded canisters. Bolted lid casks are thick, single walled containers not frequently used for dry storage due to economic considerations. Bolted lid casks predate welded canister systems, so most bolted lid casks are located at older dry storage installations. In some limited cases, bolted lid casks may provide benefits in the transportation of SNF since they can easily be reused. Currently, SNF is primarily stored in welded canisters housed in vertical concrete storage overpacks or horizontal concrete storage modules. Vertical storage overpacks and horizontal storage modules are designed to cool the sealed canisters by facilitating airflow. Canisters have the advantage of being substantially less expensive and more versatile than bolted lid casks, and in some cases have the capability to be used as part of the waste package in a repository. For shipment, canisters are transferred into transportation overpacks designed to isolate and protect the canister during hypothetical accident conditions. Because they are sealed, transportation overpacks often have lower, more constraining thermal limits than storage overpacks. Upon arrival to a repository, canisters are transferred to an emplacement overpack if they are compatible with the repository, or they are repackaged into repository compatible canisters and then loaded into emplacement overpacks. At utility sites and waste management facilities, canisters can be transported using a transfer overpack, which is a lighter version of a transportation overpack, often with a bottom lid that facilitates canister transfer between overpacks.

SNF casks began to be loaded in the late 1980s as spent fuel pools (SFPs) at utilities reached capacity. Early on, bolted lid packages were more common, but utilities came to overwhelmingly favor loading canister systems. Processing time, dose and loading cost are typically driven by the number of canisters handled, so over the past two decades, canister capacities have increased from around 24 to approximately 37 pressurized water reactor (PWR) assemblies. Canister capacities for boiling water reactor (BWR) assemblies have shown a proportional increase in size. While the larger canister sizes reduce handling costs at reactor sites, they are not likely to be disposable in a repository.

The high capacity canisters being loaded by utilities may not be compatible with any known repository design. While it is unclear what the specific requirements of an SNF emplacement overpack will be, some bounding values are available. To prepare for a wide range of possible repository requirements and to reduce complexity in the IWMS, concepts for canisters capable of being placed in a repository are being examined with hopes of standardizing canisters in the IWMS [1]. One of these standardized canister concepts is shown on the right side of Figure 2. Individual canisters are small, so any repository emplacement criteria should be met. Further, the canisters are loaded into a multicanister carrier, allowing parallelized canister loading and parallelized transfer of canisters between overpacks, thereby reducing handling costs prior to emplacement in a repository.

Another possible approach to reducing handling costs at utilities is to load reusable bolted lid casks at utilities and then package the assemblies into a repository-compatible canister system at a packaging facility.

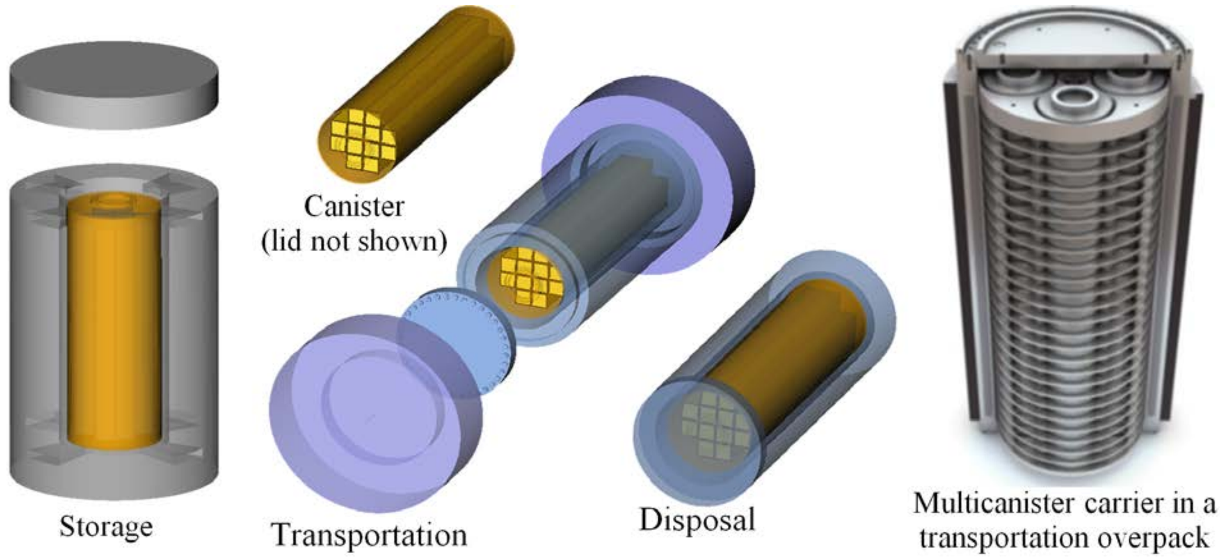

Figure 2. A generic canister system and a multicanister carrier concept (far right) [2].

SNF MANAGEMENT AT UTILITIES

At a high level, utility sites manage SNF according to the flowchart shown in Figure 3. Following discharge, SNF is placed in wet storage. To maintain space in the SFP, utilities may place SNF in dry storage once the SNF has cooled enough to meet NRC enforced thermal and dose limits. Criticality limits must also be met when loading SNF containers. Cooling typically takes on the order of five years. In the future, utilities will load casks to transport SNF offsite. For loading, canisters are placed in a transfer or transportation overpack, immersed in a SFP, and loaded. After loading, canisters are removed from the pool, welded, drained, dried, and decontaminated. Canisters are loaded and transported onsite in transfer overpacks and then placed within ventilated concrete storage overpacks. To a limited extent, some loaded storage overpacks can be transported around the site. The final step in managing SNF at utilities is shipment. Canisters are transferred from pools or dry storage to transportation overpacks. Typically, reactor sites handle casks using cask transporters, cranes, and air skids. It is expected that utilities will load railcars with cranes already at the siding, or mobile cranes may be used.

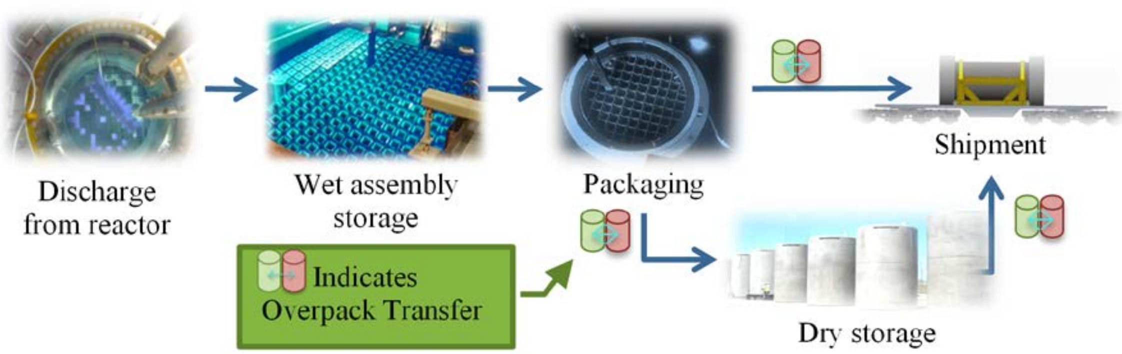

Figure 3. Utility site flowchart.

While similar at a high level, utility sites have a variety of configurations, so site-specific SNF management plans are being examined. This includes identification of site-specific limitations that may impact various storage and transportation options, such as crane capacity limits, SFP structural limits, the ability to maintain a full core reserve, floor loading capacities, and transportation infrastructure. Not all utilities may be able to handle the larger SNF casks in use today, and this may constrain standardized canister concepts.

TRANSPORTATION

Due to the size and weight of SNF casks (~100 metric tons), rail is the preferred transportation method. Utility sites without rail access will require packages to be transported to the nearest available rail terminal. This may be accomplished using a heavy haul truck, barge, or small canisters shipped individually by legal weight truck.

During the first years of transportation system operation, dedicated rail consists (trains) are expected to transport casks from reactor sites to an ISF as part of a larger cycling of transportation assets shown in Figure 4. As the IWMS matures, other destinations will be added, such as geologic repositories and SNF packaging facilities. It is anticipated that an ISF will either be the principal destination for consists or the principal point of departure, so it is often assumed that transportation facilities will be co-located with the ISF. These include an end-of-line railyard, a rail maintenance facility (RMF), and a cask maintenance facility (CMF).

Starting at the end-of-line railyard, consists are assembled (Figure 4, step I) and delivered to origin sites (step II), where the casks would be removed from the railcars and loaded with SNF (step III). Alternatively, empty cask railcars may be shipped to SNF origin sites individually via normal rail service, in which case the consist would be assembled at the origin site. Because the escort car is a high value asset, it may arrive to origin sites immediately prior to departure. Following transfer of SNF and a final preshipment inspection, the consist will depart to the destination. This destination is anticipated to initially be an ISF (step IV). Loading and unloading operations are the responsibility of the origin and destination sites. If the origin site does not have rail access, casks will be transported between the origin site and a nearby transfer terminal, where they will be loaded onto railcars.

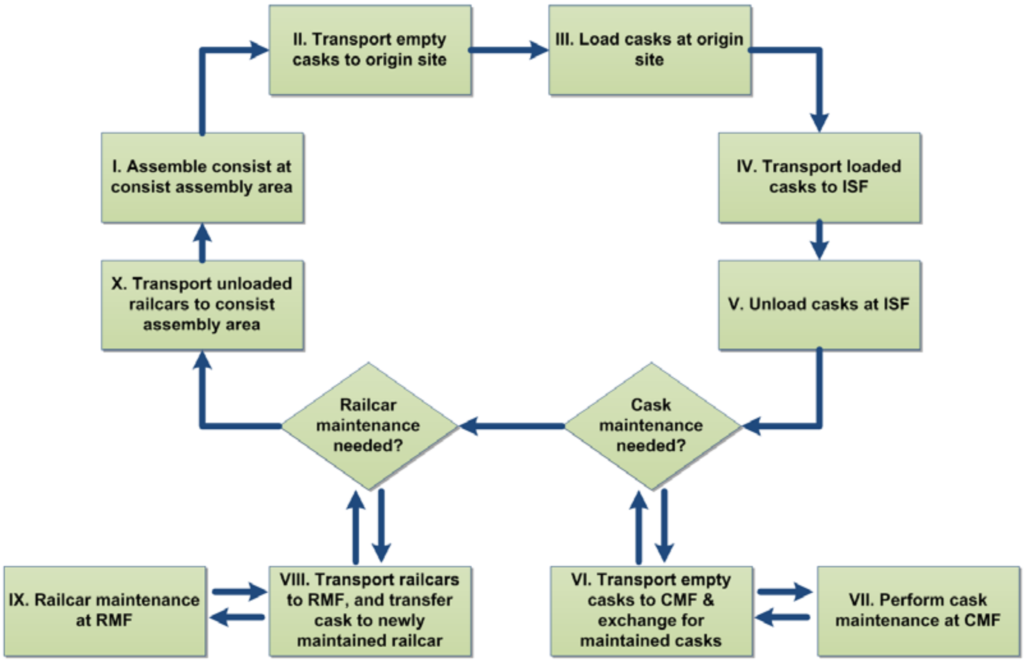

Figure 4. Transportation system summary flowchart[1].

To minimize travel time, fleet and cask maintenance facilities would ideally be at a location where rail consists frequently travel. This location could be along a rail spur leading to an ISF, or at an ISF. Cask maintenance facilities would be equipped to store casks in use, would maintain campaign kits for loading casks, and may perform minor maintenance such as annual leak testing and periodic replacement of minor components. It is unclear which tasks are more efficiently accomplished during cask turnaround at an ISF or repository when the cask lid is removed. The cask maintenance facility may also include facilities for larger maintenance tasks such as cask recoating and/or basket repair and replacement.

The RMF is expected to perform storage, cleaning, and maintenance of railcars to ensure that they are compliant with appropriate standards such as American Association of Railroads Standard S-2043. The facility is tentatively expected to include railcar storage areas, cleaning facilities, light and heavy maintenance shops, and other supporting buildings.

[1] Diagram developed based on image generously provided by our fellow IWMS investigators Kevin Connolly, Matthew Feldman, William Reich, Steven Maheras, and Ralph Best.

INTERIM STORAGE FACILITY

It is possible that one or multiple ISFs may be implemented in the IWMS. In the baseline case, a pilot ISF would operate during a ramp-up period, accepting fuel from shutdown reactor sites. The SNF receipt rate would increase to nominal throughput capacity as ISF receipt capability is built out. Initially, transportation package unloading and canister transfer may be performed using methods similar to those now used at utility sites. However, a full-scale facility is expected to include a concrete structure to facilitate handling and to reduce worker dose from the levels that occur with current cask handling practices. Additionally, a repackaging facility may be included.

The operation of an ISF is illustrated in Figure 5. After SNF is received at a rail siding, it will likely be placed in dry storage. Wet storage may be used, although it is unlikely due to increased cost and thermal cycling of SNF cladding. If the SNF is not already in a welded canister, it may be packaged into one after arriving at the ISF. SNF will be shipped offsite when a repository becomes operational. Canister transfer between overpacks is required for almost every step in the process.

It is anticipated that the current trend of storing SNF in concrete overpacks and storage modules will continue at an ISF. If wet storage were to be implemented, it may only be on a small-scale and would only be used for shuffling fuel and handling off-normal situations in an SNF packaging facility. In order to reuse bolted lid casks, they need to be unloaded, so SNF packaging capability and associated assembly storage capacity would be required if SNF is received in reusable transportation casks with bolted lids. A packaging capability would also be needed for any large scale wet assembly storage at the ISF.

To transfer canisters between overpacks, a variety of options may be implemented. Canister transfer facilities may initially consist of a pair of pits in which transfer overpacks can be stacked atop transportation and storage overpacks for canister transfer. It is anticipated that a handling facility will ultimately be built to facilitate efficient canister transfer between overpacks, thus increasing throughput and reducing worker dose.

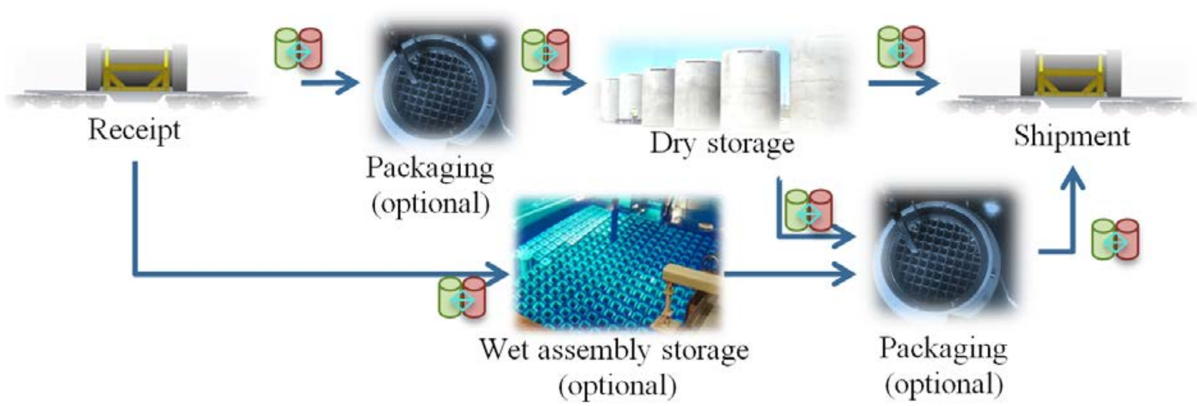

Figure 5. ISF flowchart.

Dry Storage Systems

Dry storage facilities at an ISF may be composed of vertical storage overpacks, horizontal storage modules (HSMs) or vault storage systems. Canisters stored in vertical and horizontal overpacks are currently the most common dry storage systems at utility sites. Due to economy of scale and the modular nature of these systems, they are expected to continue to be the primary means of storing SNF well into the future. Vault storage systems would require capital outlays in larger amounts and would require longer lead times than vertical overpacks and HSMs, so they are not expected to be deployed on a large scale.

Recently loaded canisters and canisters arriving to an ISF from offsite would be transferred to dry storage using procedures that vary according to the type of canister system employed for dry storage. If a horizontal storage module will be used, then the canister will be pushed from its transportation or transfer overpack into the storage module with a hydraulic piston. If a vertical storage overpack will be used, the canister in a transfer overpack will be placed atop the storage overpack, the lower lid of the transfer overpack would be removed, and the canister would be lowered slowly into the storage overpack.

Any ISF or repository site that stores a significant quantity of SNF will require systems to fabricate storage overpacks and HSMs. These large concrete components often cannot be shipped as a single component, so concrete is added to complete the overpack manufacturing process at the storage location. Deployment of HSMs and overpacks will be an important function at the ISF, nominally requiring two years of lead time for fabrication. If offsite overpack fabrication is not feasible, overpack deployment requires some combination of the following subsystems: a fabrication area and shop, a fabrication team, a concrete batch plant, and supporting tools and equipment [3].

Figure 6. Horizontal storage module components in transit (left) [3]; vertical storage overpack fabrication (right) [3].

SNF Shipping and Receiving

Several options are available for shipping and receiving SNF packages at an ISF. At a most basic level, a crane could be used to remove SNF from railcars for storage. A more robust alternative is a carrier receipt/shipping bay that can accommodate rail tracks/roadways for passage of both rail and truck carriers. An example of such a facility can be seen in Figure 7. In one carrier receipt bay concept, rail/truck lines are separated by a dual function work platform and equipment laydown area, and a bridge crane, and a bridge-mounted manipulator are used to manipulate casks. The transportation carriers would enter and exit the facility through remotely operated roll-up doors [4]. A third option is to include a receipt/shipping area in a facility to transfer canisters between overpacks. Space used for receiving fuel could be used to ship fuel if conditions allow. For example, when casks are ready to be shipped to the repository and SNF shipments to the ISF are curtailed, the same facilities used to accept SNF shipments can be used for preparing carrier/casks, loading canisters into transportation overpacks, and placing them on railcars. All loaded canister shipments from the ISF to the repository will be made by rail.

Railcar unloading typically consists of accepting SNF and queuing the railcars on a siding. A radiation survey is performed upon acceptance to verify safe shipment. Impact limiters and tie-downs are removed from the railcar, and the cask is then upended, lifted, and transferred to onsite transportation equipment.

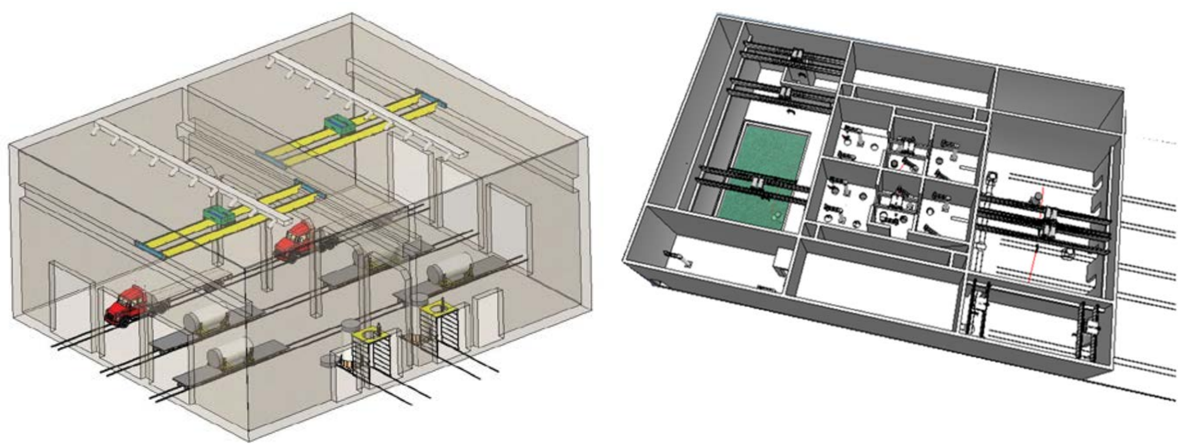

Figure 7. Carrier receipt facility concept illustration (left) [5] wet SNF packaging facility[2] (right).

[2] Thanks to our fellow IWMS investigators Young Soo Park and Mark Nutt for developing this image.

SNF Packaging Facility

An SNF packaging facility to remove SNF from reusable bolted lid transportation casks and place it into welded canisters may be included in an ISF design. The SNF packaging facility would include facilities for handling and short-term storage of individual SNF assemblies. Note that *packaging* refers to the initial placement of SNF into a welded canister from an SFP or a bolted cask, whereas *repackaging* refers to the placement of SNF into a welded canister from another welded canister. To reduce worker dose and improve reliability, semi-automated, remote SNF handling systems are expected to be employed at a repackaging facility. For example, automated lid welders (commonly used at utility sites) and lid openers will likely be used to seal and open canisters, and canisters would likely be transferred between overpacks within transfer cells.

At the facility, un-canistered commercial SNF in transportation casks, including transportable storage containers (if allowed), will be unloaded with an assembly handling system and placed in storage. SNF packaging systems can also repackage SNF from welded canisters that are not compatible with any repository into smaller, repository-compatible canisters. However this is expected to primarily be performed at a repository to reduce transportation costs and defer selection of a destination canister to a time when repository requirements are established. An SNF packaging facility will be needed somewhere in the IWMS unless all canister systems that are currently loaded become licensed for emplacement in a repository (in other words, direct disposal is feasible). It is likely that the SNF packaging facility will be a monolithic concrete structure as in recently developed SNF packaging facility concepts [6,7].

SNF will enter the packaging facility on a railcar, or it will be transferred from onsite dry storage. If SNF is received in a bolted lid cask, then the cask will be unsealed to prepare for unloading. If the SNF is in a canister, then the canister and its overpack will first be moved to a transfer cell, where the canister will be placed in a transfer overpack. The canister will then be unsealed. To prepare for unloading of SNF, casks and/or canisters will be gas sampled to ensure that fuel is in good condition. Cask closure bolts will be loosened and removed, or the canister lid welds will be cut. However, the lids will remain seated on the SNF container during its transfer to an SFP or hot cell for unloading. Assemblies will be unloaded and transferred to a repository-compatible canister and the shield plug and closure lid will be seated on the repository-compatible canister. This canister will be transferred to a decontamination area. Following any required decontamination, the lid will be welded and the canister drained and dried as needed. The loaded canister will then be transferred to the appropriate overpack in a transfer cell and released for storage or transportation. The empty canister will be decontaminated and prepared for shipment as low-level waste.

REPOSITORY SYSTEMS

Repository surface systems are expected to be similar to ISF systems, with the difference being that the goal is emplacement—rather than storage. Therefore, arriving SNF that is not in a repository-compatible container will be repackaged into a waste package. To meet repository emplacement thermal criteria, further SNF aging may be required. A flowchart of repository operations is shown in Figure 8.

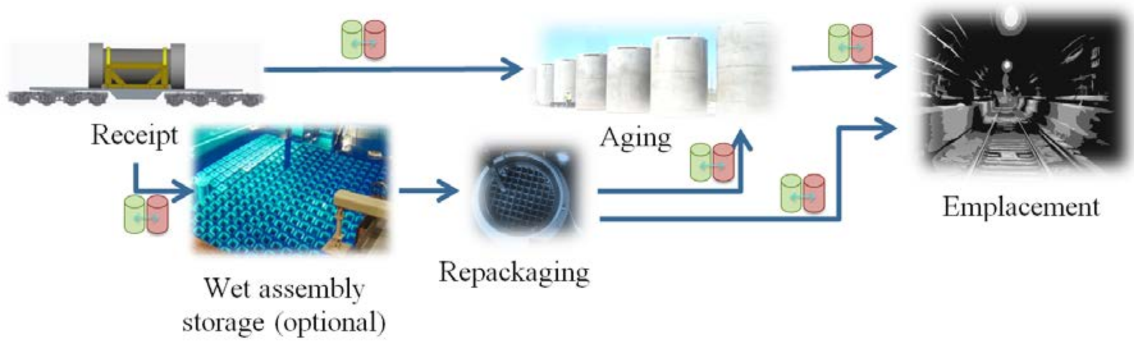

Figure 8. Repository flowchart.

CONCLUSION

The concept of operations provides an overview of how the SNF management system is anticipated to function from reactor to repository. Although the concepts described are straightforward at a high level, more detail is needed system wide to ensure that regulatory requirements are met, stakeholder concerns are addressed, utility site limitations are addressed, and the system is effective. The concept of operations description spans a range of conceivable SNF management systems while explicitly listing the systems being developed and providing context with regard to how each component may be used in the future. It has been useful to consult when beginning a new task to provide a starting point for investigators. It can also be used as a tool to support a systematic analysis of the SNF management system. For instance, it has been used to develop lift tallies as a metric of both risk and complexity of system configurations and operating schemes.

REFERENCES

[1] Joshaua Jarrell, Robert Joseph, Riley Cumberland, Rob Howard, and Mark Nutt, "A Proposed Path Forward for Standardization," in *Waste Management 2017*, Phoenix, AZ, 2017.

[2] EnergySolutions, NAC International, Exelon Nuclear Partners, Talisman International LLC, Petersen Inc., "DOE Advisory and Assistance Services Contract Task Order 18: Generic Design for Small Standardized Transportation, Aging and Disposal Canister Systems," 2015.

[3] Chicago Bridge and Iron Federal Services LLC, "Task Order 16: Generic Design Alternatives for Dry Storage of Used Nuclear Fuel.," 2015.

[4] TRW Environmental Safety Systems Inc., "Engineering Files for Site Recommendation," Las Vegas, NV, TDR-WHS-MD-000001 REV 00 2000.

[5] Mark Nutt et al., "Used Fuel Management System Architecture Evaluation," FCRD-NFST-2013-000020 2012.

[6] Bret van den Akker et al., "Wet Repackaging Facility Design Concept and Cost and Throughput Analysis," in *International High-Level Radioactive Waste Management*, Charlotte, NC, 2017.

[7] Abiodun Adeniyi et al., "Spent Nuclear Fuel Dry Packaging Facility – Modular Design, Dry Transfer Concept and Cost Estimate," in *International High-Level Radioactive Waste Management*, Charlotte, NC, 2017.