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INTEGRATED WASTE MANAGEMENT SYSTEM FOR SPENT NUCLEAR FUEL AND HIGH-LEVEL WASTE

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Until recently the United States has not considered long-term storage as part of its waste management policy. Furthermore, the current policy does not emphasize integration between storage and disposal. Yet, the United States has (1) planning experience with multi-purpose handling canisters that integrate storage, transportation, and disposal functions, (2) use of vastly different waste thermal loads that required integration at the repository, and (3) the lack of off-site storage that created orphan waste at decommissioned reactors and reduced the buffer capacity of the system. These situations provide insight on the development and implementation of an integrated nuclear waste program for other countries starting to develop their nuclear waste management system.

I. INTRODUCTION

The pre-disposal aspects of the waste management system—storage, transportation, and waste packaging and handling—involve significant challenges because of the large scale of operations required to manage spent nuclear fuel (SNF) and high level radioactive waste (HLW). While a repository is under development, it is useful to consider pre-disposal issues. These issues can become much more important if long-term storage is an important part of a country's waste management policy.[1]

Without a clear long term plan, a repository program could reach a situation similar to the United States (US), which includes: (1) little standardization of storage and transportation casks with many inner canister sizes optimized for each reactor site based on their own immediate needs; and (2) waste orphaned at decommission reactors with limited capability to repackage or transport it in the future.

The goal of this paper is to provide insights about waste management integration between storage transportation, and disposal that would be useful for a nuclear waste program at the early stages of development and implementation in other countries. The observations may not be particularly useful or applicable to a mature waste management program.

II. STORAGE OF RADIOACTIVE WASTE

II.A Current Storage in the US

The *Nuclear Waste Policy Act of 1982* (NWPA) provides that waste owners are responsible for storage of their waste until it is accepted by the Federal government, which is responsible for disposal. Hence, integration of storage and disposal functions is inherently difficult because of this separation of responsibilities. NWPA specified that a repository begin operating in the 1998, and therefore that storage needs would be limited to the spent fuel that accumulated until the repository began operation. With an assumed repository receipt rate of 3,000 MTHM/yr—about 50% higher than the annual rate of generation of SNF in the US—it was anticipated that operation of the repository would stop the buildup of spent fuel in storage and begin working off the backlog that had accumulated prior to 1998.

Dry storage casks were first licensed for use in 1986, as a result of a dry storage demonstration program authorized by §218 of NWPA. Since then, dry storage systems are the preferred choice for additional on-site storage at reactor sites once initially cooled in wet storage.[2] Most of the canisters in use are dual-purpose, designed for storage and subsequent transportation, but some fuel is contained in single-purpose storage canisters. Many of the current storage casks use an inner canister that is welded rather than bolted shut. Hence, the inner canister may need to be cut open later for either reprocessing or disposal of the SNF.

In the absence of guidance from the Department of Energy (DOE) to standardize waste management, each

[1] The period for long-term storage will vary with each country. Here we mean beyond the 60 yr period for which US Nuclear Regulatory Commission (NRC) would currently license a storage facility (i.e., initial 20 yr license with 2 extensions).

[2] Rather than enlarge wet storage, most US utilities have adopted dry storage for the long term, but new waste management programs in other countries may wish to revisit the decision to use long-term dry storage versus long-term wet storage.

utility made incremental decisions about what storage system would be best for their particular circumstances. Utilities understandably sought the most cost effective storage systems for their SNF. Simple economic considerations provided an incentive for vendors to develop casks with large capacity.

The Electric Power Research Institute (EPRI) recently described the current storage situation as follows (Ref. 1): At the end of 2009, the utilities had ~63,000 metric tons of heavy metal (MTHM) stored at their sites as follows: (1) 170,000 assemblies in wet pool storage, and (2) 52,000 assemblies in 1,200 dry storage casks. Over 20 different dry storage cask designs were in use, most of which would require re-opening for disposal.

The proposed surface facility designs for the Yucca Mountain repository include a Wet Handling Facility (WHF) with a pool in which these casks could be cut open to allow the fuel to be transferred to a Transportation-Aging-Disposal (TAD) handling canister, however, throughput would have been limited.

The more different-sized canisters there are, the more transportation overpacks have to be designed, certified, and constructed, and the more complex is the front-end design for repositories or reprocessing plants that have to accept, open, and unload them—with concomitant impacts on the total cost and complexity of waste management.

II.B Future Storage Situation in the US

Protection of public health and safety during storage, transportation, and eventually final disposition through direct disposal or reprocessing/disposal will always be the primary goal of the waste management system. An important question, however, is the cost to provide the required level of safety. In concept, retrieval of SNF from long term storage after 100 years or more could involve constructing a new handling facility at each reactor and long-term storage site to process the storage canisters such that the SNF is safe for transport to, and disposition at, some other location. Although this could be a planned option, it would be somewhat similar to the situation currently occurring at the Hanford storage site in the US.

Because there could be unforeseen problems with removing the SNF from storage containers for reprocessing or disposal, planning and developing storage systems with features that avoid the need to construct new retrieval process facilities at each storage site might provide future generations more flexibility by making retrieval easier and more economical.

EPRI projected on-site spent fuel storage in the US by the end of this century under three scenarios, all assuming no centralized storage (Ref. 1): (1) No new nuclear plants, 60-year plant lifetime: 133,000 MTHM at ~70 sites in ~11,000 dry storage casks with SNF orphaned at decommissioned sites; (2) Limited nuclear expansion to add 1000 MW/yr starting in 2015: ~180,000 MTHM in ~12,000 dry storage casks; and (3) Extensive nuclear expansion with growth of 3% per year starting in 2015: ~750,000 MTHM in ~47,000 dry storage casks.

Along with retrieval of SNF after long-term storage, an important policy question is where long-term storage should occur—at current sites, regional sites, or one centralized site. A 2009 GAO Report evaluated centralized and regional storage compared to on-site storage and concluded that centralized storage was favorable (Ref. 2). However, the long history of resistance to efforts to site centralized storage facilities beginning with the unsuccessful Atomic Energy Commission (AEC) proposal for a Repository Surface Storage Facility (RSSF) in 1970, the unsuccessful Away from Reactor (AFR) Facility proposal by President Carter in 1977, the unsuccessful siting of the Monitored Retrieval Storage (MRS) facility in 1987, and the volunteer siting process for the MRS between 1988 and 1995, strongly suggests that gaining acceptance of a facility solely for storage will be difficult in the US (Ref. 3). Public opinion on whether one centralized storage site, several regional sites, or continued on-site storage is preferred is discussed in a companion paper (Ref. 4).

Articulation of a clear rationale for the eventual movement of SNF from existing sites to other facilities for long-term or permanent disposition is an important need. An objection that was raised to the Yucca Mountain repository was that no compelling reason had been given for moving SNF from existing sites any time soon, in view of the safety of continued onsite storage. On the other hand, it is clear that permanent surface storage at current and former reactor sites is not a preferred solution.

Long term storage raises issues concerning self protection and security. Radiation from SNF falls below that which will rapidly disable a potential thief or saboteur, the "self protecting" level, after approximately 100 years of storage, and this period is only slightly longer (120 yr) for high-burnup fuel. Under current US regulations, this situation could require more stringent and expensive provisions for safeguards and security. This might affect calculations about when it is cost-effective to remove fuel from reactor sites. Obviously, however, the use of massive storage casks, mitigates against easy diversion and, to some extent, sabotage. Hence, adoption of some form of "attractiveness" rankings may be needed as discussed further in this conference in sessions on security.

So called "orphan" sites (i.e., sites that no longer have an operating reactor and often have no facilities at all other than dry cask storage for SNF) raise special issues with respect to the rationale for movement of stored SNF. Fuel/canister degradation and decreasing self-protection could provide sufficient motivation for moving fuel from such sites. With no operating reactor at a site, the full costs of security are attributable to the continued presence of SNF onsite. Also, if any technical difficulties arise during storage that necessitated reopening and recovering fuel from storage containers, new handling facilities will have to be built and licensed at each orphan site.

III. INTEGRATED STORAGE, TRANSPORTATION AND DISPOSAL CANISTERS

If long-term SNF storage at reactor sites is going to play an important role in the waste management system for the foreseeable future, it is important to determine whether standardization of storage systems could reduce the total life-cycle costs and the technical impacts of storage. One important area of investigation concerns the possible use of SNF canisters that can be used for storage, transportation, and ultimate disposal if the SNF is disposed of directly. The US experience with this issue is as follows.

III.A Proposed Multipurpose Handling Canister

In the early 1990s, the concept of a multi-purpose handling canister (MPC) was considered by DOE. An MPC was to be loaded at the reactors and then placed in an appropriate overpack vessel for storage, moved to another overpack for transportation, and finally placed in a corrosion resistant overpack (waste package) for disposal. An MPC system minimized the handling of bare spent fuel, and, thereby, simplified the operation of the waste management system, and facilitated overall system integration.

The MPC concept met with a favorable reaction by some utilities and the Edison Electric Institute (EEI) was a leading supporter. Proponents also believed a MPC system would simplify repository facilities. The Nuclear Waste Technical Review Board (NWTRB) spoke favorably about the MPC concept (Ref. 5):

> If developed properly, the MPC has the potential of (1) enhancing safety in the waste management system by substantially reducing handling, (2) fostering a systems approach to the management of the nation's spent fuel and high-level waste, and (3) introducing a level of standardization into a system that currently is evolving in an *ad hoc* fashion.

In 1994, the DOE issued the Multi-Purpose Canister System Evaluation (Ref. 6). The evaluation compared a bare-fuel system with three canister options: an MPC, transportable-storage casks, and a multi-purpose unit that could serve as the disposal package without an overpack. Findings and recommendations of that report included:

1. The MPC system was the most suitable alternative because it provided a triple-purpose function at lower cost than the other canister systems, with a cost comparable to the individual-assembly handling system.
2. The MPC system would simplify operations throughout the waste management system, and would standardize SNF storage and introduce overall system compatibility at utility sites. It would also decouple the utility operations for retrieving SNF from the on-site dry storage from operations in the spent fuel pools, potentially allowing earlier decommissioning of pools.
3. The MPC system was projected to reduce overall SNF management costs for both DOE and the utilities by $550 million compared to the reference case with no MPC. Although a positive savings the value was small enough to be within the uncertainty in the analysis. The net reduction resulted from an estimated $1.45 billion increase in the system (a $5 billion increase in container costs and a $3 billion decrease in repository costs), that was offset by a $2 billion reduction in utility costs from a reduction in storage costs.

Because utilities had concerns about costs for purchasing, handling, and transportation of the new canisters and how these costs would be recouped and because vendors thought selecting one vender was unfair, Congress eliminated funding for the MPC in 1996 (Ref. 7).[3] However, the Navy chose to proceed with a dual-purpose canister system for the management of naval SNF and the management of naval special case low-level radioactive waste. The primary benefits identified were standardization for container manufacturing, efficiency in fuel unloading at shipyards, and reduction in radiation exposure (Ref. 8). Naval SNF has been loaded into these large dual-purpose canisters for dry storage at Idaho National Laboratory. These dual purpose canisters could be used for transportation to a repository and were to be used for direct disposal using a waste package overpack at Yucca Mountain,

III.B Transportation, Aging, and Disposal Handling Canister

In 2005, the Nuclear Waste Technical Review Board reiterated its interest in multi-purpose canisters (Ref. 9):

> …the Board recommends that the DOE evaluate the costs and benefits of using dual-purpose (transportation and storage) or multipurpose (transportation, storage, and

[3] In the US, all costs of storage, transportation, and disposal are paid for by the utility rate payers. However, disposal costs are paid as a 0.01¢/kWh fee on power produced, as mandated by federal government, which are placed in a trust fund then appropriated by Congress, while storage costs are subject to utility rate adjustments overseen by the states.

> disposal) casks for transporting, storing, and disposing of spent fuel at Yucca Mountain. The use of such casks has the potential to limit the number of times that spent-fuel assemblies must be handled and, thus, the risks and radiation exposures associated with such handling.

Also in 2005, the challenges of designing the receiving and waste packaging buildings at Yucca Mountain that would handle bare fuel at very high rates led to a DOE decision to use a multipurpose transport, aging, and disposal (TAD) handling canister loaded at the reactor and never opened again. Similar to the early MPC concept, the same TAD was to be used for transportation, aging (or storage), and disposal. A TAD was to be placed inside overpacks that provided shielding, heat dissipation, and structural strength for storage and transportation. For the repository, the disposal overpack for the TAD was the corrosion resistant waste package. The relatively small amount of uncanistered SNF that was anticipated to be transported would be packaged into TADs at the repository.

The TAD system includes the TAD canister, aging overpack, site transporter, shielded transfer cask, transportation overpack, transportation shipping skid, and transportation ancillary equipment. The TAD system was intended to (Ref. 10) (1) support the standardization of SNF storage, transport, aging and disposal packaging to allow integration of SNF handling operations; (2) use utility fuel handling experience in packaging SNF; (3) simplify repository operations and minimize redundant handling of bare SNF assemblies at the repository, leading to cleaner facilities; (4) reduce the production of low-level waste (LLW) and worker radiation exposure at the repository; and (5) reduce complexity and cost at the repository.

The TAD canister system was to comply with technical requirements of 10 CFR 71 for Transport, 10 CFR 72 for Storage, and 10 CFR 63 for Disposal. Rather than select one vendor as with the MPC, DOE chose a market driven approach to develop and deploy the TAD system. This approach allowed any number of vendors to participate provided they met the performance specifications. Development of the TAD system specifications received substantial input from industry and from the transportation and repository components of the waste management program. DOE issued the TAD system performance specifications in November 2006 (Ref. 11).

The use of the TAD for 90% to 95% of the 63,000 MTHM of commercial SNF necessitated a fundamental change in the previous repository design used for the site recommendation. The new design included three principal facility modules for handling SNF and HLW on the surface and is reviewed in a companion paper (Ref. 12). The modules were a Canister Receipt and Closure Facility (CRCF) that loaded TADs into waste packages for disposal, a Wet Handling Facility (WHF) with a spent fuel pool for handling bare SNF assemblies and loading them into TADs, and a Receipt Facility (RF) that received TADs and Naval dual-purpose canisters and sent them to the on-site aging facility, the WHF, or the CRCF. The surface facilities also included a relatively small, Initial Handling Facility (IHF) that processed only HLW canisters and Naval dual-purpose canisters.

The TAD was large. The standard SNF waste package in the license application submitted to the Nuclear Regulatory Commission (NRC) in 2008 held 21 intact pressurized water reactor (PWR) assemblies or 44 intact boiling water reactor (BWR) assemblies. The disposal overpack had an outside diameter of 1.88 m and length of 5.85 m. The total number of SNF packages in the license application was 7796 (Ref. 13, Table 6.3.7-1).

The TAD was much larger than waste packages being considered in other countries for repositories in different media. The large emplacement drifts and gently-sloped access ramps at Yucca Mountain allowed use of large waste packages and was consistent with the desire of utilities to use large containers for storage and transportation of SNF.

Other repository sites and designs could require use of smaller handling canisters if a similar integrated waste management system design was desired. There is currently no assurance that canisters of the weight of the TAD can be lowered safely down vertical shafts.[4] The equipment does not exist and standard mining practices do not necessitate its development. Similarly, borehole disposal would have a diameter constraint.

A small canister design was under consideration in the US in the early 1980s; it was intended for use in salt, shale, granite, or tuff (Ref. 14). The initial package for Yucca Mountain held up to 3 intact PWR assemblies or 6 intact BWR assemblies and was 0.66 m in diameter and 4.76 m long (Ref. 15). In comparison, the Swedish and Swiss designs for crystalline rock repositories contain 4 PWR assemblies. The German shielded disposal package contains 12 PWR assemblies and weights ~65 tonnes (the largest package being considered for a repository in which the packages are lowered vertically to the disposal horizon).

If canisters smaller than the TAD are adopted by a country's waste management program, multiple handling canisters could be placed in overpacks for storage and transportation to reduce costs and maintain the current approximate dimensions of dry storage casks.

It is worth noting that Private Fuel Storage (PFS), the multi-utility enterprise that obtained a license from NRC for a 40,000 MTHM dry storage facility on land owned

[4] The 10 bundled drums of TRU waste disposed upright at WIPP have a similar diameter to a TAD (~1.8 m vs. 1.9 m), but the bundle is only 1.8 m high and weighs ~3 tonnes, which is far less than the ~54 tonnes for a TAD canister when loaded and ~150 tonnes when placed in the 5.8 m long, horizontal disposal package.

by the Goshute tribe in Utah, specified a single cask system for use at the facility, although the member utilities were using a variety of storage systems (Ref. 17).[5]

The successful development of a specification for a TAD canisters for storage and eventual disposal at a Yucca Mountain repository, through interactions with the utilities and vendor community, suggests that development of a standardized storage system might be achievable through a similar interactive and cooperative approach.

IV. WASTE STREAM INTEGRATION

IV.A Integrated Disposal of Radioactive Waste

Currently the statutory and regulatory basis for radioactive waste disposal in the United States anticipates separate disposal pathways for different wastes: (1) HLW/SNF in a mined geologic disposal facility; (2) LLW for classes A,B, and C in shallow land burial; and (3) greater-than-class-C (GTCC) waste (which is somewhat similar to TRU Waste from defense programs in the US and intermediate radioactive waste in classification schemes adopted by some countries) using mined geologic disposal unless another method is approved by NRC, as noted in a companion paper (Ref. 18). These disposal pathways were based on the length of time the waste is hazardous, type of waste stability, and intruder protection required (e.g. LLW requires the lowest degree of isolation). In general, the highest degree of isolation results in the highest cost of disposal.

Experience with design of repositories for HLW and SNF suggests that opportunities might exist for cost-effective, co-disposal of these waste forms in a single repository as being considered in other countries.[6] For example, the flexibility to dispose of LLW generated during HLW/SNF repository operations in the repository rather than shipping the LLW off site might be advantageous.

The design of HLW/SNF repositories, specifically the density at which waste can be disposed, will likely be constrained by thermal limits. Generally the final layouts have a fairly low areal heat loading resulting in disposal rooms or drifts being spaced relatively far apart. The total excavated underground area is therefore dictated by the heat generating waste. Integrated waste disposal concepts could take advantage of the large excavated volume required thermally for emplacing the HLW/SNF by emplacing GTCC (and possibly low volumes of other classes of LLW) in these areas. For example, it may be possible to utilize rooms or drifts constructed to provide access to the HLW/SNF disposal areas for low- or non-heat generating wastes (LLW or GTCC) without requiring significant additional underground excavation, provided the chemical characteristics of the LLW or GTCC do not compromise the isolation capability of the repository. Such integrated disposal concepts could reduce total fuel cycle waste disposal costs, since the front-end costs of developing a high-level waste repository will have to be borne in any event and the incremental cost of disposing of other wastes in the unused areas may be low. Integration of the LLW and HLW regulations in a country would facilitate implementation.[7]

IV.B Co-Disposal of Defense and Commercial HLW/SNF

NWPA presumed that radioactive waste from atomic energy defense activities would go to a civilian repository NWPA did not preclude a defense-only repository, but made no provisions for siting one and made it clear that such a repository would be subject to NRC licensing. NWPA placed the responsibility on the President to justify a separate defense waste repository. In 1985, President Reagan determined that a separate repository was not needed, based on analysis that showed that there would be large cost savings (~$1.5 billion) to using the civilian repository for the defense wastes, and that no other factors distinguished significantly between the options (Ref. 19). Since then the DOE has planned for disposal of the relatively cool SNF and HLW from defense nuclear activities in a repository developed for commercial SNF.

Based on President Reagan's decision, the DOE established a policy to allocate 90% of the first repository capacity (in MTHM) to civilian SNF and 10% of the repository capacity to DOE-owned SNF and HLW. (NWPA does not specify any allocation.) As a result, 63,000 MTHM of the 70,000 MTHM statutory limit is allocated to civilian waste and the remaining 7,000 MTHM is allocated to national defense waste.

The reference plan for operation of the Yucca Mountain repository synchronized co-emplacement of defense and commercial waste packages in the same disposal drifts, as part of the thermal management strategy to use the lower heat output of interspersed

[5] The PFS is another example of the difficulty of building a storage facility in the US (Ref. 16). The PFS storage facility received a license from NRC but construction of the facility was blocked by rulings on needed permits by the US Department of Interior. The rulings have recently been remanded by the courts, but future of the site remains uncertain.

[6] The *Low-Level Radioactive Waste Policy Act of 1980* (LLWPA) (§4 (a)(1)) states that disposal of LLW produced within its border is the responsibility of the states unless produced by DOE for defense activities or, as amended in 1986, GTCC LLW.

[7] In response to a congressional request in 2005, DOE studied options for geologic disposal of GTCC. One option was disposal of GTCC with thermally cool defense TRU waste at WIPP.

defense waste packages to dilute the higher heat output of the commercial SNF packages. Hence, while current US statutes and regulations do not anticipate co-mingling of most classes of LLW and HLW, and the repository did not plan for receipt of GTCC LLW, the Yucca Mountain repository did employ co-mingling thermally hot commercial SNF with thermally cool defense SNF and HLW.

For other countries that might want to contemplate co-mingling small amounts of radioactive waste categories, the US experience, however, does point out a complication that need to be addressed. For the current license design in the US, the placement of commercial SNF and defense SNF and HLW in drifts required careful synchronization of the co-emplacement. Placement in boreholes within drifts may offer some flexibility by allowing some boreholes to be skipped and filled later. Another approach is to provide buffer storage capacity to provide flexibility as discussed below.

IV.C Role of Storage in Providing Flexibility

The National Academy of Sciences (NAS) noted that a flexible staged development approach for a repository, as discussed further in a companion paper (Ref. 12), has significant implications for buffer storage requirements (Ref. 20):

> Adaptive Staging's flexibility and reversibility may require a higher buffer storage capability located at or near the repository site to keep open various options for emplacement schedules. Sufficient buffer storage provides the flexibility to choose among waste types (thermal blending), for managing emplacement and for ensuring a place to which waste can be credibly retrieved, should the need arise. Such buffer storage also provides a flexible mechanism to separate waste acceptance from waste disposal. Increased buffer storage allows for flexibility in the system, and affects the need for at-reactor storage and transportation capacity. A cost- and schedule-driven Linear Staging approach tends to minimize buffer storage and aims for 'just-in-time' delivery of waste.

The report went on to note:

> In many programs there is reluctance to implement a high-capacity buffer storage, especially if the storage facility operates before the repository is functional, out of societal fears that the buffer storage facility could become a permanent surface storage facility. This concern can be alleviated if the regulator grants the repository construction authorization before the surface facility is built and if the regulator grants the licenses to receive and emplace waste in the repository before the buffer storage facility is operational.

The tension between the desire to include substantial storage capacity as a way to provide system flexibility for decision makers and the concern that such capacity would reduce the national urgency for a repository and delay availability of permanent disposal capability has been a constant theme in the US waste program since before NWPA was passed. The AEC proposal in the1970 for a RSSF to allow a more deliberate pace for development of repositories, as noted at the beginning of this paper, was rejected because of this concern. The US has not been able to resolve this tension, but ideas to reduce this tension are presented in a companion paper on US public attitudes (Ref. 4).

Although not resolved in the US, some centralized storage capacity—whether at an independent storage site or at a repository—is likely needed in waste management program in other countries to provide a variety of functions that are integral to the logistics of waste handling prior to emplacement in a repository. As described by NAS above, storage capacity within the waste management system can enable receipt of waste to be decoupled from emplacement in a repository, facilitating a more deliberate, slow repository development process. Flexibility for the waste management system could be enhanced if legislation and regulations explicitly facilitate co-location of needed storage capacity at a repository site once it has been selected and approved.

V. INTEGRATION OF AGREEMENTS

V.A Integration between Storage and Disposal Agreements

In the current US approach, the operator of the repository (i.e., DOE), has little control over the type and age of SNF sent to the repository. Instead the repository operations must plan for a variety of receipt scenarios. Although designing and constructing operations facilities with flexibility is desirable, the inability to plan an operating receipt schedule is challenging. Other countries may not want to follow this model. Planning at the storage/disposal facility would benefit greatly if the facility could manage the types and age of fuel received. The facility could combine fuel types and ages to maintain high radiation during transportation for enhanced security, and maintain more uniform heat loads within the repository without the need for extensive aging at the repository. Control of the age and type of fuels would also be desirable if the storage/disposal facility were combined with reprocessing facilities.

V.B Integration of Requirements between Storage and Disposal

Because of the separation of legislation and regulatory agencies in the US, there are separate legal and regulatory frameworks for reactors, storage, transportation, and disposal that were developed over time around the current once-through fuel cycle (Ref. 18).

Thus, a waste management system in the US must operate under multiple regulations (i.e., 10 CFR 71 for transportation, 10 CFR 72 for storage, and 10 CFR 63 for disposal) that highlight the different purposes.

Provided storage is short term, integration between the technical requirements in the regulations on facilities and components of the waste management system for storage and disposal may not be as important. However, as storage periods increase, requirements may need to be similar. Uncertainties about the likely state of SNF after an extended period of storage raise questions about whether the waste management system will be able to transport SNF loaded into a container today at the end of such a period without knowing the actual state of the fuel and the canister. In a few extreme cases, the SNF might be in the form of damaged assemblies with some rubble or granular fuel loose in the canister. Hence, a country's regulator will need to address the question as to how it will want a licensee to deal with extreme cases. Possibly, the waste management system should anticipate the development of long-term storage regulations that are similar to those developed for disposal and, thus, are probabilistic.

As an example in the US, the requirement to evaluate consequences of events with a frequency as low as 10^{-6}/yr in the 10 CFR 63 HLW disposal regulation for the Yucca Mountain repository[8] had an impact on the design of the TAD handling canister and the design of the surface facilities at the repository that were not otherwise required under 10 CFR 71 for transportation or 10 CFR 72 for storage at the reactor site, respectively. [9]

VI. INSIGHTS

Unless steps are taken to guide the process, a waste management system will evolve on its own, which if combined with long-term storage, could result in substantial quantities of orphaned waste with limited capability to repackage or transport if problems occur after 100 yr or more of storage. Better integration of the waste management system may avoid future difficulties.

Although the US has not considered long-term storage as part of its waste management policy, the US has had some experience in planning for an integrated handling canister that provides insights on the practical issues that need to be resolved. However, waste management programs in other countries will have the opportunity to analyze the implication of canisterization based on a range of alternative repository media, facility designs, canisters overpack designs for storage, transportation and disposal, and how much SNF might be reprocessed.

Although US does not currently co-mingle radioactive waste categories, the US has considered co-mingling waste of vastly different thermal loads which mimics some of the issues of co-mingling waste categories. One prominent issue is scheduling receipt of different waste types, which points to the desirability of buffer storage capacity within the waste management system to provide flexibility in order that both the desires of utilities to ship certain types of waste and the desires of a repository to receive various types of waste can be met within the waste management system.

When short-term storage is the national policy, integration of technical requirements may not be as essential important, but when long-term storage is the national policy, integration of technical requirements become more important since some of the requirements on storage will need to be similar to those of a disposal facility.

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[8] A companion paper discusses the different disposal regulations in the US, specifically the site specific disposal standard for HLW in 10 CFR 63 for Yucca Mountain and the generic HLW disposal standard in 10 CFR 60 (Ref. 18).

[9] NRC is currently undertaking an integrated review of its storage, transportation, and disposal regulations to determine if different requirements for each phase are still useful and necessary (Ref. 21).

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