Recognising interdependencies in design of nuclear fuel cycle and transportation of SNF and HLW

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Spent nuclear fuel (SNF) discharged from a nuclear power plant and high level radioactive waste (HLW) generated during reprocessing SNF are typically stored at the sites where they are generated, often for prolonged periods of time. Eventually, however, these materials must be transported off-site to an interim storage facility, a reprocessing plant, or directly to a deep geologic repository. This paper considers the interdependencies between nuclear fuel cycle options and the transportation system, and argues that both must be addressed as part of an integrated system. Two examples are presented to illustrate why this is important. The first draws from experience gained during development of the US Department of Energy's (DOE) program for disposing of SNF and HLW in a proposed repository. In particular, decisions DOE made with regard to waste package design had profound implications on the viability of the transportation system. The second example relates to operational changes now underway at nuclear power plants. The impact on fuel integrity of storage over long time periods and subsequently in transportation is not known, particularly for high burn-up fuel that is rapidly becoming the industry norm. Absent consideration of storage and transport interdependencies, this could become problematic in terms of future handling operations, especially if it results in repackaging being required before transport. The present paper emphasises the need to recognise and address interdependencies in the design of the nuclear fuel cycle and the transportation of SNF and HLW as a proactive part of the planning process, rather than as a problem that is addressed as an afterthought. It also identifies an opportunity for this to be taken into account in preparing for future operations, offering the potential to achieve benefits for the industry overall, including for transportation of SNF and HLW.

Keywords: Transport, Interface with repository and NPP, Storage, Package design

Introduction

When the fuel is no longer reactive enough for continued reactor operation, it is considered to be spent nuclear fuel (SNF) and is removed from the reactor core. It is initially stored in the reactor cooling pool and, at many nuclear power plant sites, is subsequently packaged into dry storage containers while awaiting its ultimate disposition. If the fuel is to be disposed of directly in a geologic repository, the SNF in its storage container may also be the final form in which the fuel will be emplaced in the repository. Alternatively, if the storage container is not suitable for disposal, the SNF will need to be repackaged into a specifically designed disposal container, or the storage container will need to be loaded into an overpack designed for emplacement in the repository.

If the fuel is destined for reprocessing, the uranium and plutonium contained in the SNF is separated for use in the fabrication of recycled uranium and mixed oxide fuel respectively. This reduces the volume of SNF that requires disposal, but results in the production of high level radioactive waste (HLW), together with large volumes of other waste forms that are generated during reprocessing and the production of recycled uranium and mixed oxide fuels.

There is international consensus that emplacement in a deep geologic repository is the preferred option for final disposal of SNF and HLW, in order to provide the necessary protection for human health and the environment for many thousands of years. The approach adopted for disposal of other waste forms varies for different countries. However, in all cases, unless the

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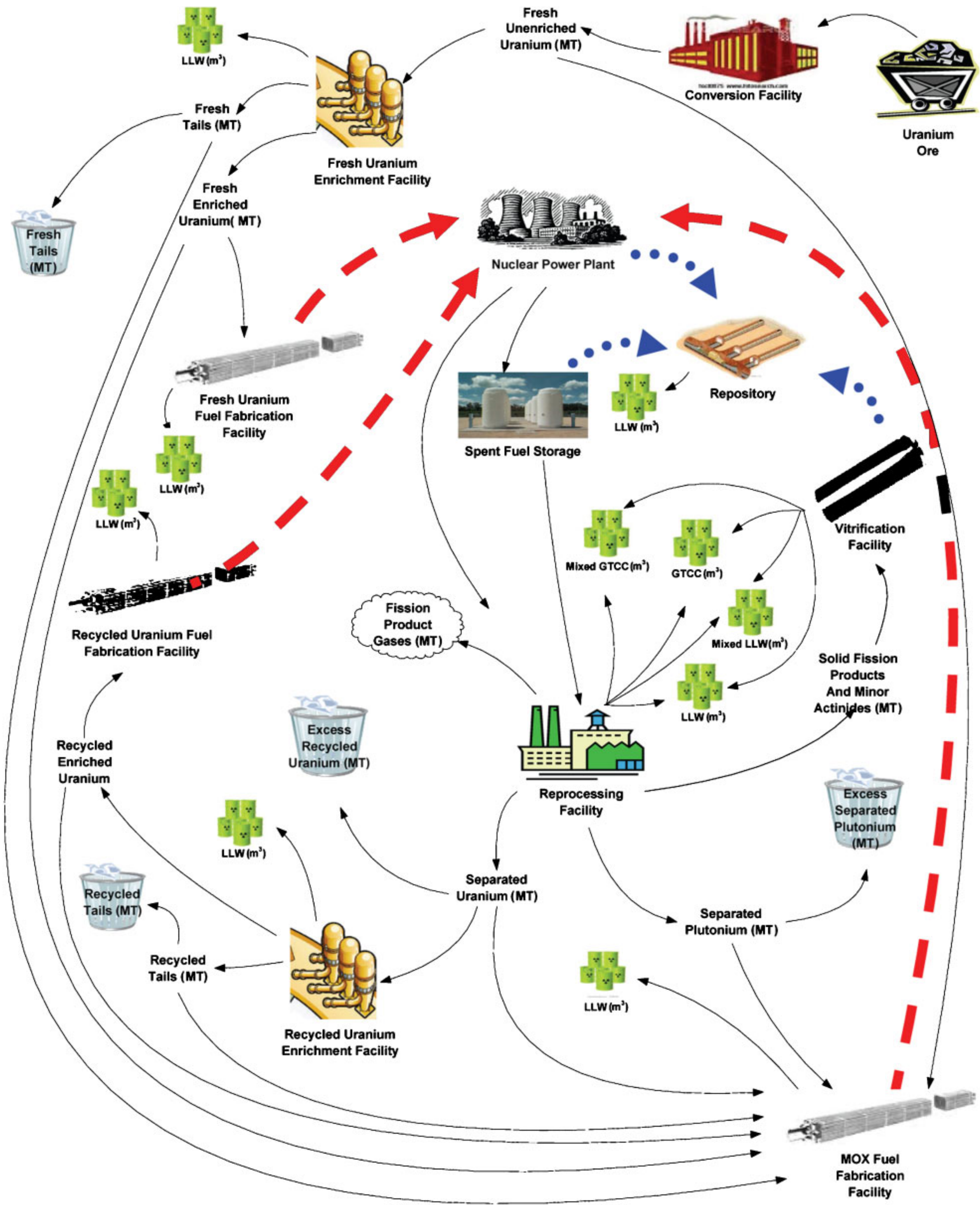

1 Nuclear fuel cycle process flow options

reprocessing and recycled fuel fabrication facilities are co-located with the necessary waste disposal facilities, all of the SNF, HLW and other waste forms will need to be transported for processing and/or disposal.

Figure 1 presents a schematic showing the operations included in the nuclear fuel cycle for both the once-through and the reprocessing/recycle options. The figure clearly illustrates why the nuclear fuel cycle is the archetypical complex system, being comprised of many elements that are connected by an extensive set of interdependencies. Note in particular the range of processes involved, each of which produces different types and volumes of wastes, and that any fuel cycle option will result in generation of SNF and/or HLW. Transportation links the production of new fuel and the management of SNF and HLW. Consequently attempts to design and operate a complex nuclear fuel cycle system without properly integrating transportation operations run the risk of creating a structure whose pieces fail to fit together effectively.

Past experience suggests that this risk is not a theoretical one. Moreover, the potential exists for this risk to continue to arise as a result of operational changes that are currently taking place in the nuclear industry. In the discussion to follow, two cases are examined, one retrospectively and the other prospectively, to elaborate on these observations. The first case focuses on HLW and all types of SNF, whether generated commercially or as part of a nuclear-defense program. The second case is limited to consideration of commercial SNF (CSNF) generated during operation of nuclear power plants.

Transportation interdependencies

The two cases illustrate the significance of the interdependencies of transportation and other system elements.The first, the US repository program experience, is a retrospective one. It details the challenges that arise when a complex and interdependent system is not analysed and managed in an integrated fashion. This case is represented by the blue dotted arrows in Fig. 1.The second case presents an argument for early recognition of such interdependencies and discusses how a conscious decision to address them can avoid the kinds of problems that occurred in the first case. This case is represented by the red dashed arrows in Fig. 1.

US repository program experience

In 1977, US Department of Energy (DOE) began studying a site at Yucca Mountain in Nevada, as one of several candidates, to determine whether it would be suitable for the nation's first deep geologic repository for disposal of the SNF and HLW being stored at over 100 facilities around the nation (DOE 1986). In 1987, the US Congress directed DOE to study only Yucca Mountain (US Congress 1987). In July 2002, Congress gave DOE the authority to prepare and submit a license application to construct a repository at Yucca Mountain (US Congress 2002).The license application was submitted in June 2008 and is presently under review by the US Nuclear Regulatory Commission (NRC) (DOE 2008a; NRC 2008). Since submission of the license application, DOE has declared its intent to withdraw the application, with prejudice. Whether or not this can be done is the subject of current litigation.

In submitting its Yucca Mountain license application, DOE was required to demonstrate that the waste management system design meets specific safety standards. Development of the system design was, from the outset, heavily focused on the underground repository, along with consideration of the configuration of the surface facilities where inbound shipments of SNF and HLW would be received and handled before emplacement. Owing to concerns about the need to minimise the handling and re-packaging of SNF at the repository surface facility, DOE in 2005 adopted the transportation, aging and disposal (TAD) waste package concept (DOE 2007). In theory, the TAD would enable SNF to be loaded at a reactor site and remain in this packaging through its final emplacement in a repository drift. However, the weight of the TAD configuration meant that DOE could only move loaded TADs to Yucca Mountain by rail.

Although the decision to develop a TAD might have seemed appropriate based on satisfying requirements for disposal, other considerations, particularly those involving transportation, were discounted. What follows is a discussion of how the TAD decision and other Yucca Mountain system design elements made the transportation system component problematic as well as threatening to the viability of the entire system operation.

Shipment origin: lifting capacity

Loading of TADs at a commercial reactor site would require a handling system with a minimum of 100 ton lifting capacity. However, the current equipment configurations at many sites would not meet this threshold (TriVis 2005). Therefore, each of these sites would require an upgrade to its crane lifting capacity, requiring regulatory action, incurring significant expense and possibly creating operational downtime. Moreover, at some facilities, the extent of the upgrade required might be cost prohibitive, requiring other operations to be arranged, including possibly transportation of SNF from the facility for loading into TADs at another location.

Access/egress: modal access options

At many sites, short line (locally and regionally owned) railroads would likely have been relied upon for transporting TADs to transfer points where they would connect with the mainline railroad network. Many of these short-line railroads would require significant upgrades to allow transport of SNF in TADs based on DOE's minimum track quality standards (Federal Railroad Administration 2008). If these short-line railroads could not be upgraded – perhaps because of the expense involved – other, more logistically complicated, routes would have to be used.

Line-haul: moving waste from the proposed caliente railhead to yucca mountain

Perhaps the major issue, however, is that the Yucca Mountain site is not presently connected to the national railroad infrastructure. To do so would require construction of a new 330-mile rail line connecting the Caliente, Nevada mainline railhead to Yucca Mountain, at an estimated cost of $3 billion (DOE 2008b). Significant delays could have been incurred in constructing this new line, due to the need to obtain water permits, availability of financial resources, and the resolution of environmental impacts. This would have reduced the efficiency of the repository construction project, delayed the start of repository operations, and potentially changed the characteristics of the waste stream arriving at the repository. Moreover, if the new line was never constructed, the feasibility of the entire Yucca Mountain project would have been at risk. However, there is little evidence that any contingency plan had been considered or developed to cover this eventuality.

Shipment destination: surface facility interface

In its surface facility design and throughput analysis of the Yucca Mountain receipt facility, DOE assumed that 90% of the CSNF would arrive at the repository site packaged in TADs, although this assumption was acknowledged to be questionable. The 10 percent of the CSNF not packaged in TADs would also arrive by rail at the waste handling facility (WHF) on the repository site, where the fuel assemblies would be transferred to TADs. However, the WHF was designed with limited capacity, and if more than 10% of the

CSNF did not arrive in TADs, backlogs would have been created, forcing additional amounts of CSNF to be placed on aging pads. Alternatively, it would require construction of additional WHFs.

This requirement for repackaging SNF into TADs at the repository site may not, at first sight, appear to be an issue that had a particular bearing on the requirements of the transportation system. However, any difference between the quantities of SNF assumed to be loaded in TADs at the nuclear power plant sites and what will happen in practice would change the numbers and types of casks needed for fuel storage, as well as the requirement for cask handling equipment, maintenance and other transportation logistics. Consequently, this underscores the need to account for the interdependencies of the design of the fuel cycle and the program for transportation of SNF and HLW.

Operational changes now underway at nuclear power plants

Before 2000, most fuel discharged from nuclear power plants in the US had burn-ups below 45 GWd/tU, which is considered to be the threshold for high burn-up (HBU) fuel. Currently, fuel burn-ups of 45–50 GWd/MtU are typical, and it is expected that burn-ups of over 60 GWd/MtU will be routine in the future. Consequently, while there is considerable experience with storage of SNF, both in reactor pools and at dry storage facilities, there is little experience with storing HBU fuel that will be the dominant fuel form requiring future storage.

In parallel with this, the length of time during which SNF will likely need to be stored before processing or disposal has been increasing, with storage periods of 100 years or more now foreseen. While the performance of advanced fuel designs in the reactor is well established, the impact on fuel integrity of storage over such long periods and subsequently in transportation is not known, particularly for HBU fuel.

Under the current US regulatory framework, a safety basis has been demonstrated by licensees for the storage of SNF in storage casks for 60 years. A safety basis has not been developed, however, beyond this period of time. Of particular concern are the potential impact of long term aging on SNF and the degradation of cask systems, structures and components, both of which have implications for cladding integrity, criticality safety, and offsite radiation dose limits for both normal and off-normal conditions. Complicating matters is the fact that the storage casks have varying contents, designs and applications, as well as being located at different facilities. Consequently, there is not yet adequate experience to give the necessary assurance that SNF, and the storage casks in which it is loaded, will be in a suitable condition for future transport operations after extended storage periods. Moreover, the extent to which the fuel may need to be repackaged before transport is also not yet known.

DOE, NRC and the nuclear industry have recognised the need to approach these considerations as an integrated system involving interdependencies among storage, transportation, disposal operations and, potentially, reprocessing. The goal of this effort is to also take these considerations into account as new fuel designs and transport packages are developed.

Steps are being taken to address this challenge in advance. A notable development has been the formation of the Extended Storage Collaboration Program, led by the Electric Power Research Institute and involving the participation of DOE, NRC, the Nuclear Waste Technical Review Board, utilities and cask vendors. One important component of this collaboration is the establishment of a long term cask demonstration program to monitor and evaluate aging effects.

Individual organisations are also developing their own initiatives. NRC is embarking on a seven-year plan for enhancing the technical and regulatory basis for extended storage and subsequent transportation (to a reprocessing, disposal or an away-from-reactor storage facility), taking both safety and security into consideration (NRC 2010). This activity includes performing a gap assessment, conducting research activities, participating in external research initiatives, and engaging other stakeholders, both domestic and international. DOE's Office of Nuclear Energy, now tasked with SNF and HLW management following the disbanding of the Office of Civilian Radioactive Waste Management, is similarly developing a strategic plan to guide its activities in this area. Importantly, outside organisations are being invited to help develop the program's focus and agenda. As part of its review function, the Nuclear Waste Technical Review Board is preparing a white paper on the technical basis for extended dry storage of SNF.

This raises another issue that has not yet become a focus of the nuclear industry, although there is increasing acceptance that it must be addressed. While the performance of advanced fuel designs in the reactor is well established, as noted above, the need to extend the periods during which SNF will require storage means that it is also important to take this into account in the design of new fuel types. If a small penalty in fuel performance in the reactor results in a major advantage during the storage, transport and disposition of SNF, this may have significant overall economic benefit for the nuclear power plant operator and warrants detailed assessment.

These developments, both individually and collectively, offer opportunities for transportation waste management system interdependencies to be fully recognised as part of the system design process, rather than as an afterthought that may come into focus only after a significant problem has been identified. Time will tell, of course, but early indications are that those involved in this process have taken note of the experience that was gained during development of the Yucca Mountain program.

Conclusions

Regardless of its design, the nuclear fuel cycle includes a waste management system that is comprised of many interrelated components, with transportation being the 'glue that holds the system together'. As noted in the previous discussion, it is imperative that the system be analysed and evaluated as an integrated whole. This enables one to examine system throughput, identify possible choke points, and recognise where various design and operational elements are incompatible. Understanding this, and taking it into account, is essential to harmonising cask design, fleet acquisition, handling, access/egress and line-haul operations, and other activities that must be carried out for the system to perform in a safe, secure and efficient manner.

When one has such a highly interdependent system, if it is treated in a piecemeal and segmented fashion, there is no guarantee that all of the elements will fit together effectively. Moreover, with respect to the management of SNF and HLW, it has typically been presumed that if the elements do not fit, the transportation component can always be adapted so as to make the rest of the system functional. That presumption is not necessarily the case.

In contrast, it appears that the lessons learned from the Yucca Mountain experience have had a positive impact on the manner in which extended long term storage and transport of high burn-up SNF is being addressed. Although in its early stages, the research and development plan appears to recognise the significance of the transportation function as an important and integrated component of any system design that emerges. While it is early in the process and the prognosis is good, transportation stakeholders must be vigilant in ensuring that those involved maintain an awareness of these interdependencies and take appropriate measures to address them effectively as part of the system design.

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