Considerations for Dry Transfer Systems for Used Nuclear Fuel

Fuel Cycle Research & Development

Prepared for
U.S. Department of Energy
Used Fuel Disposition
Campaign

Christine Stockman
Eric Lindgren
Sandia National Laboratories
Halim Alsaed
Idaho National Laboratory

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☒ Technical Review	☐ Peer Review
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Review Documentation Provided	**Review Documentation Provided**
☐ Signed TR Report or,	☐ Signed PR Report or,
☐ Signed TR Concurrence Sheet or,	☐ Signed PR Concurrence Sheet or,
☒ Signature of TR Reviewer(s) below	☐ Signature of PR Reviewer(s) below

Name and Signature of Reviewers
Steven C. Marschman
Steven C Marschman

NOTE 1: *Appendix E should be filled out and submitted with the deliverable. Or, if the PICS:NE system permits, completely enter all applicable information in the PICS:NE Deliverable Form. The requirement is to ensure that all applicable information is entered either in the PICS:NE system or by using the FCT Document Cover Sheet.*

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SUMMARY

This report fulfills the milestone M3FT-14SN0802052, "Dry Transfer Needs", under the Work Package Number FT-14SN080205. This report builds on the dry transfer system report by Carlsen and BradyRaap (2012), focusing on the need for, and system requirements of, a dry transfer system (DTS) at independent spent fuel storage installations (ISFSIs).

This report reviews 1) the regulatory and technical drivers for repackaging UNF at ISFSI sites, 2) the transportability of canisters at ISFSI-only sites and of casks and canisters at all ISFSI sites, 3) the alternatives to an ISFSI Site DTS, and 4) the high-level functional and operational requirements for a DTS.

The regulatory drivers for repackaging at ISFSI sites include the requirements for retrievability during storage [10 CFR 72.122(l)], and subcriticality and geometry control for transportation [10 CFR 71.55(b) and 71.55(d)(2)]. If the degradation state of the cask/canister and internals becomes unknown, repackaging may be necessary depending on the interpretation of these requirements and the associated guidance. Regulatory engagement is needed regarding: any change in the level to which retrievability is required (assembly or canister), whether 10 CFR 71.55(b) only requires compliance in the "as loaded" configuration, and whether the conditions from which the geometry cannot be substantially altered are those when loaded or those used in the criticality, shielding, and thermal calculations (i.e., performance-based). Regulatory engagement has started with DOE and industry response to the NRC call for comments on retrievability, cladding integrity and the safe handling of spent fuel.

A technical driver for repackaging at ISFSI sites is the need to transport UNF that is currently in storage-only containers to its final destination. Storage-only casks would be required to be repackaged prior to transportation. For storage-only canisters, repackaging may be avoided if a specially designed transportation cask is licensed on the basis of the moderator exclusion exception in 10 CFR 71.55(c), and if geometry control requirements are met or are considered to be performance-based. The moderator exclusion exception in 10 CFR 71.55(c) has yet to be successfully used in licensing. If repackaging is required at a site without a pool, a DTS would be needed.

There are licensed transportation casks designed for all the canisters currently at ISFSI-only sites, however the same is not true at all ISFSI sites. As of July 2013, there were over 500 casks/canisters at ISFSI sites that did not have a licensed transportation cask. Of these, 27 casks and 297 canisters were intended as single purpose storage-only containers.

A number of alternatives to an ISFSI site DTS have been proposed. These include: 1) using damaged fuel cans for fuel of unknown condition such as high burnup fuel after extended storage, 2) over packing if a canister is breached, 3) performing any required repackaging in pools while the pools are still present, 4) transporting UNF to its final destination before degradation occurs, 5) and regulatory engagement. If some or all alternatives are pursued, an ISFSI site DTS may not be needed.

This report also reviews the regulations in 10 CFR 72 for fuel handling systems, summarizes the high-level functional and operational requirements, and provides a listing of the primary structures, systems, and components of a DTS.

Given the anticipated the large cost of a standalone DTS and the uncertainty in the interpretation of the regulations and guidance that may drive the need for an ISFSI-site DTS, the authors recommend that at this time greater priority be given to pursuing the alternatives to a DTS than to development of an ISFSI-

site DTS. Recommended in particular are: performing any required repackaging in pools while the pools are still present, transporting UNF to its final destination before degradation occurs, and regulatory engagement. If in the future, these alternatives are unavailable or prove to be ineffective, then greater emphasis can be placed on developing a DTS specific to the needs at that time.

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CONTENTS

TABLES

ACRONYMS

ADAMS	The NRC Agencywide Documents Access and Management System
BSC	Bechtel SAIC Co. LLC
BWR	boiling water reactor
CFR	Code of Federal Regulations
CoC	Certificate of Compliance
CSF	consolidated storage facility
DECON	NRC designation for reactor sites undergoing decommissioning
DOE	U.S. Department of Energy
DTS	dry transfer system
EPRI	Electric Power Research Institute
FF-DSC	failed fuel dry shielded canisters
GTCC	greater than Class C
GWd	gigawatt-day
HAC	hypothetical accident conditions
HI-STAR	Holtec International Storage, Transport, and Repository Cask System
HVAC	heating, ventilation, and air-conditioning
INL	Idaho National Laboratory
ISFSI	independent spent fuel storage installation
ISG	interim staff guidance
JAPC	Japan Atomic Power Company
LWT	legal weight truck
MPC	multipurpose canister/cask
MTU	metric tons (Tonnes) of uranium
NAC	NAC International, Inc.
NCT	normal conditions of transport
NE	Office of Nuclear Energy
NEI	Nuclear Energy Institute
NRC	U.S. Nuclear Regulatory Commission
NUHOMS®	Nutech horizontal modular storage

NUREG	publication prepared by staff of the U.S. Nuclear Regulatory Commission
NWTRB	United States Nuclear Waste Technical Review Board
PWR	pressurized water reactor
R&D	research and development
SFST	Spent Fuel Storage and Transportation (a division of the NRC)
SSC	structure, system, and component
TEPCO	Tokyo Electric Power Company
TN	Transnuclear, Inc.
UFDC	Used Fuel Disposition Campaign
UMS	Universal MPC System
UNF	used nuclear fuel
U.S.	United States
VSC	ventilated storage cask

USED FUEL DISPOSITION CAMPAIGN Considerations for Dry Transfer Systems for Used Nuclear Fuel

1. INTRODUCTION

The U.S. Department of Energy Office of Nuclear Energy (DOE-NE), Office of Fuel Cycle Technology has established the Used Fuel Disposition Campaign (UFDC) to conduct the research and development (R&D) activities related to storage, transportation, and disposal of used nuclear fuel (UNF) and high-level radioactive waste. Within the UFDC, the Storage and Transportation task has been created to address issues of extended or long-term storage and transportation. For this task, an analysis was performed to identify data gaps in the technical basis for long-term storage of UNF and to prioritize the R&D needed to close those gaps (Hanson et al. 2012). One identified high priority activity consisted of determining the need for dry transfer of UNF. Consequently, an analysis was performed to define the potential uses and needs for a dry transfer system (DTS) and to review available options and alternatives for addressing these needs (Carlsen and BradyRaap 2012). This report builds on that analysis, and provides more details on the need for, and system requirements for, a DTS at independent spent fuel storage installation (ISFSI) sites.

The objective of this report is to review the technical and regulatory drivers for a DTS, and provide the high-level functional and operation requirements. In order to fulfill this objective, the following information is discussed in this report:

- Dry Transfer Needs (Section 2)
- Review of Regulatory and Technical Drivers for Repackaging (Section 3)
- Dry Repackaging at ISFSI-only Sites (Section 4)
- Alternatives to an ISFSI Site DTS (Section 5)
- High-Level Functional and Operational Requirements for a DTS (Section 6)

2. Dry Transfer Needs

A DTS may be needed to repackage UNF at a centralized facility or repackage UNF at the independent spent fuel storage installation (ISFSI) sites.

2.1 Dry Transfer Need at Central Storage or Disposal Sites

Repackaging at a central storage or disposal site may be needed to replace containers that are compromised by age, natural phenomena or accidents, or to meet the acceptance criteria at future disposal site(s). Such repackaging may be performed dry as originally proposed for Yucca Mountain (Bechtel SAIC Co. LLC (BSC) 2005), or wet in a large water pool as finally proposed for Yucca Mountain (DOE 2008). Following the Blue Ribbon Commission recommendation for one or more consolidated storage facilities (CSFs), DOE supports the goal of siting, designing, licensing, constructing and commencing operations at a CSF by 2025 (DOE 2013a). A pilot CSF would be operational by 2021 and a geologic repository by 2048. Due to heat limitations for the repository concepts under investigation, direct disposal of current storage casks would not be possible without decades to centuries of ventilation or decay time (Hardin et al. 2012). Disposal in the 2048 time frame would require much smaller waste packages than currently used for dry storage, and thus a major repackaging campaign would be needed. For repository concepts that rely on waste package performance, a standard high performance waste package may be imposed, also necessitating a major repackaging campaign.

Any centralized facility would receive a diverse range of packages. There are 27 welded canister types and 7 bare fuel dry storage cask types in use today. There are 10 large rail/intermodal transportation casks and two legal weight truck casks licensed today that can transport light water reactor assemblies. Thus any facility used to repackage fuel would need to have the capability to be flexible.

There are benefits and drawbacks to using either wet or dry facilities for repackaging. Some advantages of wet facilities include the industry experience and cool fuel temperatures during repackaging. Some advantages of dry facilities include the ability to avoid the thermal shock that occurs when the fuel is rewetted and the need to redry the fuel. Experience with retrieving fuel from storage either wet or dry is quite limited. There has been limited retrieval of the UNF since dry storage has started, with the exception of the need to remediate leaking casks (Peach Bottom inspection report (Nuclear Regulatory Commission [NRC] 2011a) and a couple of research projects in the United States (Electric Power Research Institute [EPRI] 2002) and Japan (Aida et al. 2010, Yamamoto 2010, and TEPCO 2013). Only the U.S. demonstration project used dry facilities to retrieve the used fuel; the other used a fuel pool to open the cask. One potential problem using a pool is the thermal shock on rewetting. The fuel in dry storage will be relatively hot and will experience a rapid quenching when the cask is filled with water, unless measures are taken to reduce the extent of (but not eliminate) thermal shock, such as forced helium cooling (DOE 2008, Section 1.2.5.3.4.2). The quenching may induce undesirable high stresses in the cladding that potentially lead to fuel rod failure especially with high burnup fuel. Furthermore, the long-term degradation effects of rewetting the fuel are presently unknown (United States Nuclear Waste Technical Review Board [NWTRB] 2010, p. 80). Section 6.5.1.2 of NUREG-1567 (NRC 2000a) requires that the thermal shock from the rapid cool down be evaluated to show that the fuel and components are not damaged during the rewetting process. MacKinnon et al. (1998, p. 6-18) state that the thermal shock from rewetting low burnup fuel is insufficient to cause any permanent damage however significant amounts of crud spallation may occur. This conclusion has been corroborated by research that has been done in Japan, where a number of bolted casks have been opened and a limited number of fuel assemblies were removed and inspected. Tokyo Electric Power Company (TEPCO) performed inspections in 2000, 2005 on low burnup fuel (Aida et al. 2010), and most recently in 2013 (burnup not given) (TEPCO 2013). At least one cask containing low burnup fuel was also opened and inspected by the Japan Atomic Power Company (JAPC) in 2009 (Yamamoto, 2010). In all cases the cask was returned to the pool for inspection. The cask was purged with helium and the effluent analyzed for Kr-85. For the JAPC inspection, the gas effluent during water flooding was also analyzed for Kr-85 as a means to detect rod failure due to the thermal stress of re-flooding. In no case was any Kr-85 detected. The lids were leak tested, removed, and the seals and sealing surfaces visually inspected. No serious issues were detected. The only noted abnormality was a white discoloration of gasket surfaces caused by residual water. Two assemblies (three in the 2013 inspection) were removed for visual inspection. No issues were detected. Flaking of some crud from the cladding of one of the three assemblies inspected in 2013 was detected. Similar research using high burnup fuel would help determine the importance of thermal shock in the decision to repackage wet or dry.

2.2 Dry Transfer Need at ISFSI Sites

Repacking at the ISFSI sites may be necessary to replace containers that are not transportable and those containers and their internals that are compromised by age, natural phenomena or accidents. There are over 500 casks/canisters at ISFSI sites that currently do not have a licensed transportation cask, and 27 of the casks and 297 of the canisters were intended as single purpose storage only containers. The transportability of containers is discussed in Section 4. Compromised containers and their internals include those that cannot be demonstrated to meet the storage and/or transportation requirements provided in 10 CFR 72 and 10 CFR 71 (Code of Federal Regulations) because the degradation states of the container and internals are unknown. Section 3 discusses the implications of the storage and transportation regulations for such containers. Besides providing a means for mitigation and recovery from an unplanned event or the discovery of an unforeseen condition, provision of a dry transfer capability may be required as part of the safety basis for extended storage and may also address public concerns.

3. Regulatory and Technical Drivers for Repackaging

Repackaging of UNF that is in dry storage may be needed for continued storage or for transportation if the dry cask storage system cannot be demonstrated to meet the storage and/or transportation requirements provided in 10 CFR 72 and 10 CFR 71, respectively. This may occur if degradation of the cask/canister and/or its internals occurs during storage. In particular, if the cask/canister is breached allowing air to enter, the internals may undergo degradation. Also, high burnup cladding may become brittle if the UNF cools below the ductile-brittle transition temperature. In either of these cases, the material properties of the internals become uncertain such that retrievability during storage or subcriticality and geometry control under normal conditions of transport (NCT) and transportation hypothetical accident conditions (HAC) may not be demonstrable. Because the integrity of the components internal to the cask/canister cannot be physically verified without opening the cask/canister, demonstrating compliance with the regulations becomes problematic and action may be required. Repackaging, with emplacing damaged fuel assemblies into damaged fuel cans within the canister or cask, is one action that would solve the regulatory compliance issues associated with cladding. Other actions, such as emplacing any suspect canister inside an overpack, have been proposed, but it is not clear if this would address all regulatory requirements. This section reviews some degradation mechanisms that may act on the cask/canister internals and the regulations and regulatory guidance that have implications pertinent to the potential need for repackaging UNF of unknown degradation state.

3.1 Degradation of Cask/Canister Internals

A demonstration project has shown that when intact low burnup fuel was stored for almost 15 years within a confinement boundary that maintained an inert helium atmosphere, the cask and internals remained undegraded. (EPRI 2002) However, the fuel in this demonstration project was dried before being loaded into the cask and did not experience a drying process prototypic of large storage casks, primarily those that could result in high temperature (e.g., approaching 400^{o}C) that could promote some degradation mechanisms (e.g., hydride reorientation). Mechanisms have been identified that may breach the confinement barrier and expose the cask/canister internals to air and moisture (Hanson et al. 2012). Once exposed to the air and moisture, cask/canister internals such as the fuel, cladding, baskets, and neutron poisons may undergo oxidation and corrosion. Intact cladding will protect the fuel from these effects, but not all fuel that was classified as “undamaged” during loading is unbreached (NRC 2007a). Once confinement is breached, fuel within breached cladding will might oxidize and eventually swell, causing the cladding to split open. The rate of oxidation is highly temperature dependent. If the breach of confinement is not detected before significant degradation has taken place, the material properties of the cask internals will become unknown.

Other mechanisms have been identified that could render the material properties of the cask internals unknown including thermal aging of aluminum alloys, creep and fission product attack on cladding

(Hanson et al. 2012). However, the degradation mechanisms of greatest concern today are those associated with the effects of hydrogen within high burnup cladding. These include hydride embrittlement, hydride reorientation, and delayed hydride cracking (Hanson et al. 2012). During reactor irradiation, hydrogen is produced as the zirconium-based cladding reacts with the cooling water, and some of this hydrogen is absorbed into the cladding. The longer the fuel burns in the reactor, the higher the amount of absorbed hydrogen. The solubility of hydrogen in zirconium-based cladding is very temperature dependent and when the solubility is exceeded, zirconium hydrides form. High burnup cladding is discharged from the reactor with hydrides that are mainly circumferential and mainly in a rim under the outer surface oxide corrosion layer. When the dry storage cask is vacuum dried, the cladding temperatures may approach 400ºC and many of the hydrides may dissolve into the Zircaloy. As the cask cools during storage, hydrides re-precipitate, with precipitation essentially complete by 200ºC. These hydrides are brittle, and if their concentration throughout the cladding is high, or if the hydrides re-precipitate in the radial direction, the cladding may become brittle and susceptible to failure. This is seen in an increase in the ductile-brittle transition temperature from below room temperature to as high as 150ºC under some experimental conditions (Burtseva et al. 2010). As the cladding cools during extended storage, the effects of hydride embrittlement are an increasing concern. If the cladding temperature falls below the ductile-brittle transition temperature (which is uncertain), the material properties may be degraded by an uncertain amount.

3.2 Storage Retrievability Requirements and Guidance

10 CFR 72.122(h)(1) states: “The spent fuel cladding must be protected during storage against degradation that leads to gross ruptures or the fuel must be otherwise confined such that degradation of the fuel during storage will not pose operational safety problems with respect to its removal from storage. This may be accomplished by canning of consolidated fuel rods or unconsolidated assemblies or other means as appropriate.” 10 CFR 72.122(l) states: “Retrievability. Storage systems must be designed to allow ready retrieval of spent fuel, high-level radioactive waste, and reactor-related GTCC [greater than Class C] waste for further processing or disposal.”

Regulatory guidance pertinent to repackaging includes interim staff guidance (ISG): ISG-2 (NRC 2010a) and ISG-1 (NRC 2007a).

ISG-2 (NRC 2010a) defines ready retrieval: “The staff considers a fuel assembly to be “ready retrievable” if it remains structurally sound (i.e., no gross degradation) and could be handled by normal means (i.e., does not pose operational safety problems during removal) or, in the case of a structurally unsound assembly or an assembly that has rods with breaches greater than a pinhole or a hairline crack that could release fuel particulate, if the assembly is placed inside a secondary container (described in ISG-1 as a “can for damaged fuel”) that confines the fuel particulate to a known volume and, that container can be handled by normal means.”

ISG-1 (NRC 2007a) provides guidance on classifying fuel as damaged, undamaged, or intact, for purposes of storage or transportation. It states that the ISG is not a regulation or requirement; however it also states that fuel “must be classified as damaged or undamaged after the storage or transportation system has been designated.” The definitions for damaged, undamaged, or intact are given relative to the ability of the fuel to fulfill its fuel-specific or system-related functions. These functions are design specific and different for storage versus transportation, which is why the fuel cannot be classified before the system is designed. Intact fuel is defined as that which can fulfill all its functions and also is unbreached. Undamaged fuel is fuel that can fulfill its functions, and damaged fuel is fuel that cannot. Undamaged fuel may be breached and may have assembly defects. Grossly breached fuel is not readily retrievable and thus must be considered damaged for storage purposes. Such fuel can be made retrievable by placing it in a damaged fuel can as specified in 10 CFR 72.122(h)(1).

3.2.1 Implications for Storage

Under current regulations and guidance, fuel that is classified as undamaged and loaded into a storage cask/canister without a secondary assembly container (damaged fuel can), must remain undamaged during storage. In particular, it must remain retrievable and not become grossly breached so as to allow release of fuel particulates from the fuel rods. If the fuel cannot be demonstrated to be retrievable, then the fuel must be repackaged or removed from storage. If transported to another site, the fuel could not be put into storage without repackaging.

An example where retrievability may be hard to demonstrate is where a storage canister has been breached. One proposed solution is to overpack the breached canister. This would restore the storage confinement safety function. However, if the canister internals have degraded, it may be difficult to demonstrate retrievability, and thus continued storage of the canister could be precluded. Arguments could be made that the degradation of internals is insignificant based on the estimated time of breach and the temperature dependent degradation rates, however it is not clear how likely such arguments would be to succeed.

Another example where retrievability may be hard to demonstrate is systems containing high burnup fuel whose temperatures drop below the cladding ductile-brittle transition temperature. One solution is to place all high burnup fuel assemblies into damaged fuel cans during loading. This approach is not one favored by industry but was employed at the Maine Yankee ISFSI.

With current guidance, retrievability must be maintained at the assembly level, however the NRC is reconsidering this interpretation as it considers integration of the storage and transportation regulations (NRC 2013a). If guidance or regulations are changed, repackaging for the purposes of maintaining assembly retrievability may become unnecessary. The NRC has requested comments on retrievability**,** cladding integrity and the safe handling of spent fuel: “The NRC would like external stakeholders to provide an assessment of (1) whether ready-retrieval of individual spent fuel assemblies during storage should be maintained, or (2) whether retrievability should be canister-based.” In addition, the NRC has asked several questions. “Should the spent fuel cladding continue to be protected from degradation that leads to gross rupture, or otherwise confine the spent fuel, during storage such that it will not pose operational safety problems with respect to its removal from storage?” “Should each high burnup spent fuel assembly be canned to ensure individual fuel assembly retrievability? Additionally, should spent fuel assemblies classified as damaged prior to loading continue to be individually canned prior to placement in a storage cask?” (NRC 2013a)

In their response to the NRC, the Nuclear Energy Institute (NEI) states industry’s preference is to avoid repackaging at the ISFSI sites (NEI 2013). They do not recommend defining retrievability as either "Fuel Assembly-Based" or "Canister-Based," but instead recommend retrievability be defined as the ability to remove spent fuel from the ISFSI and to transport it to a destination facility. They recommend that the requirements in 10 CFR 72.122(h)(1) remain, but that interpretation of the provision to "otherwise confine" fuel be clarified to credit the dry storage system’s confinement boundary. They do not believe that high burnup fuel should be canned to ensure individual fuel assembly retrievability. They do believe that assemblies classified as "damaged" prior to being placed into dry storage should continue to be placed into individual cans prior to placement in the dry storage system. NEI illustrated the impacts of the current and recommended interpretations of the regulations with two scenarios: fuel in extended storage and high burnup fuel. In both these scenarios, if the retrievability of assemblies or cladding integrity could not be fully demonstrated, NEI indicates that under current guidance the fuel would need to be placed in individual fuel cans prior to being repackaged for renewed storage or transportation. In contrast, under their proposed regulatory framework, the fuel would not need to be repackaged at the reactor facility site. It could continue to be safely stored and then transported to a destination facility, where if repackaging is required, the cost and worker dose would be substantially less.

The NRC request for comments shows some willingness to reconsider the definition of retrievability. If industry recommendations are adopted, the regulatory driver for repackaging casks whose internals have unknown material properties for continued storage would be removed; however, repackaging or data on the degraded material properties would still be required to meet transportation requirements as discussed in the following sections.

3.3 Transportation Subcriticality and Geometry Control Requirements and Guidance

The general requirements for fissile material transportation packages are found in 10 CFR 71.55. These regulations include three criticality safety requirements described in paragraphs (b), (d), and (e) along with paragraph (c) that provides a discretionary exemption from (b) that allows moderator exclusion.

10 CFR 71.55(b) outlines the requirements for the design, construction and content limits for fissile material transportation packages and requires subcriticality of the contents in their “most reactive credible configuration”, including configurations “moderated by water to the most reactive credible extent” and “fully reflected by water on all sides.” The NRC staff states in SECY-07-185 (NRC 2007b) “The requirement that water be assumed within the containment system is not explicitly tied to the ability of the package to limit water in-leakage under the regulatory tests and conditions that simulate normal conditions of transport and accident conditions. Instead, it is a general design requirement that is intended to ensure that no criticality accident could occur in transportation, considering analytical uncertainties and uncertainties in the transportation environment...For spent fuel casks, this requirement also ensures safety during underwater loading and unloading operations.” Note that, unlike 10 CFR 71.55(d) and (e) discussed below, 10 CFR 71.55(b) does not specify any tests for determining the most reactive credible configuration. Therefore, demonstrating subcriticality for as-loaded conditions may assure compliance with this requirement as discussed in more detail below.

10 CFR 71.55(c) provides a discretionary exemption from (b): “The Commission may approve exceptions to the requirements of paragraph (b) of this section if the package incorporates special design features that ensure that no single packaging error would permit leakage, and if appropriate measures are taken before each shipment to ensure that the containment system does not leak.”

10 CFR 71.55(d) describes the transportation package performance requirements under NCT which include (1) subcriticality (without a water moderation requirement), (2) no substantial alteration of geometric form, (3) no leakage of water into the containment and (4) no substantial reduction in the effectiveness of the package. Note that in determining the most reactive credible configuration for NCT, the tests specified in 10 CFR 71.71, which include, among others, vibration, free drop (from a 1-foot height for heavy [over 15,000 kg] transportation packages), corner drop (from a 1-foot height), compression, and penetration must be considered.

10 CFR 71.55(e) describes the transportation package performance requirements under HAC and requires subcriticality assuming (1) the most reactive credible fuel rearrangement consistent with the damaged condition of the package and the chemical and physical form of the contents; (2) water moderation to the

most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents; and (3) full reflection by water on all sides, as close as is consistent with the damaged condition of the package. Note that in determining the most reactive credible configuration for HAC, the tests specified in 10 CFR 71.73, which include, among others, free drop (from a 9-m height), crush, puncture, thermal stress, and immersion must be considered.

There are numerous NRC guidance documents that apply to transportation subcriticality and geometry control including:

- NUREG-1617 "Standard Review Plan for Transportation Packages for Spent Nuclear Fuel" (NRC 2000b),
- NUREG/CR-5661 "Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages" (Dyer and Parks 1997),
- ISG-1 "Classifying the Condition of Spent Nuclear Fuel for Interim Storage and Transportation Based on Function" (NRC 2007a),
- ISG-11 "Cladding Considerations for the Transportation and Storage of Nuclear Fuel" (NRC 2003a), and
- ISG-19 "Moderator Exclusion under Hypothetical Accident Conditions and Demonstrating Subcriticality in Spent Fuel under Requirements of 10 CFR 71.55(e)" (NRC 2003b).

3.3.1 Implications for Transportation

UNF may be transported immediately after being loaded into a transportable canister/cask or it may be placed in dry storage for several decades prior to transportation, which could have implications on demonstrating compliance with the criticality safety and geometry control requirements specified in 10 CFR 71.55(b), (c), (d)(2) and (e). The implications of significance in determining the need for a DTS are discussed below.

Compliance with 10 CFR 71.55(b)

The Acceptance Criterion for compliance with the criticality requirements for a single package in the standard review plan for UNF transportation applications is provided in Section 6.4.4 of NUREG-1617, which states "…the analysis pursuant to 10 CFR 71.55 (b) should consider the packaging and contents to be in their most reactive condition, as determined by the tests in 10 CFR 71.71 (NCT) and 10 CFR 71.73 (HAC)". Based on this Acceptance Criterion, the NRC staff considers demonstrating subcriticality under the tests of NCT and HAC to be an acceptable means for demonstrating compliance with 10 CFR 71.55(b).

However, although ISG-19 is "intended to clarify the review of the criticality safety evaluation for a single package under hypothetical accident conditions", the NRC staff provides additional guidance in this ISG for compliance with 10 CFR 71.55(b), stating:

> "Spent fuel that is intact and undamaged <u>when loaded into a transportation cask</u> can be assumed to be in its intact, "as loaded" configuration when showing compliance with the general design requirements in 10 CFR 71.55(b)" (emphasis added)

The above quote from ISG-19 implies that the "most reactive credible condition" required in 10 CFR 71.55(b)(1) is the "as loaded" configuration of the fuel when loaded into a transportation cask. This is further supported by Section 6.1 of NUREG/CR-5661, which states:

> "The single-package series of calculations must consider a model of the single containment vessel fully reflected by water…The containment vessel should be optimally moderated with the fissile content in its most reactive credible configuration. This water-reflected, optimally moderated containment vessel analysis should be compared with one where the water reflector is replaced by the package material (including water flooding in voids) that surrounds the containment system...
> Demonstration that these two single, undamaged cases are adequately subcritical satisfies the requirements of 10 CFR § 71.55(b)."

Based on the above quotes from ISG-19 and NUREG/CR-5661 as well as the fact that, unlike 10 CFR 71.55 (d) and (e), 10 CFR 71.55(b) does not specify any tests for determining the most reactive credible configuration, it is possible to conclude that an analysis of as-loaded conditions is sufficient to demonstrate compliance with 10 CFR 71.55(b), without the need to take into account loads due to NCT and HAC. Such an analysis would be significantly easier than that suggested in NUREG-1617. However, it is important to note that since 10 CFR 71.55(b) refers to subcriticality for transportation, the as loaded configuration must be considered the configuration just prior to transportation. Any degradation during dry storage that could result in changes important to criticality safety (e.g., neutron poison efficacy) or reclassification of the UNF due to degradation during storage or changes in regulatory definitions (e.g., when the definition of damaged fuel changed, the NRC staff required Rancho Seco to re-evaluate UNF classification (NRC 2009b)) must be considered in determining the "as loaded" configuration for transportation.

Compliance with 10 CFR 71.55(b) for casks/canisters containing UNF with cladding whose material properties may have degraded from high burnup and/or extended storage, may be challenging, potentially requiring re-evaluation of fuel classification for determining the "as loaded" configuration. Additionally, the analysis could be more complicated if compliance with 10 CFR 71.55(b) must include consideration of NCT and HAC (per NUREG-1617), possibly requiring the exception described in 10 CFR 71.55(c) (see below); alternatively, repackaging of these casks may be necessary prior to transportation.

Therefore, given the significance associated with the interpretation of the 10 CFR 71.55(b) requirements, engagement with the NRC and industry is prudent for consistent clarification and application.

Use of the Exception in 10 CFR 71.55(c) for Compliance with 10 CFR 71.55(b)

10 CFR 71.55(c) provides an exception to 10 CFR 71.55(b) in the form of moderator exclusion. However this exception has not been used for the general approval of a cask design. In their letter to the NRC commissioners, the NRC staff note that "[t]he provisions of 10 CFR 71.55(c) allow the Commission to approve an exception to the requirement that the package must be subcritical with water in the containment system. The staff's long-term practice has been to consider this exception to be appropriate only for limited shipments and not for general approval of a design… Using the moderator-exclusion provision of 10 CFR 71.55(c) for the general approval of a spent fuel cask design has not been considered appropriate in the past, because it would lead to the routine use of an exception that has important safety implications." (NRC 2007b). In their reply to the NRC staff, the commission reaffirms that "[t]he staff should continue to consider moderator exclusion on a case-by-case basis." (NRC 2007c). The implication of this position, is that this exception is hard to obtain, therefore, it cannot be relied upon to address the subcriticality requirement for all the UNF that has unknown material properties. 10 CFR 71.55(c) and

associated guidance does not currently provide a path for a general exception (e.g., exception for all high burnup UNF or more a general exception for all UNF with unknown material properties); consequently, some UNF (high burnup UNF or low burnup UNF after extended storage) may need to be repackaged before transportation.

Compliance with 10 CFR 71.55(d)(2)

10 CFR 71.55(d)(2) specifies that under normal conditions of transport "The geometric form of the package contents would not be substantially altered". When material properties of the package contents are unknown, it is difficult to show compliance with 10 CFR 71.55(d)(2). For the transportation of canisters that were breached prior to shipment, it may be possible to demonstrate compliance if the temperature and time of exposure of the internals to air were low. For high burnup fuel, it may be possible to demonstrate compliance if the fuel is transported after only short storage times, so that the temperature is above the cladding ductile-brittle transition temperature. If the time of a canister breach is unknown or after high burnup fuel has cooled during extended storage, demonstration of compliance with 10 CFR 71.55(d)(2) is more difficult. However, it is not clear how to interpret the language of 10 CFR 71.55(d)(2). A literal interpretation would be that the contents could not be substantially altered from that when the package was loaded. However, 10 CFR 71.55(d)(2) lies within a section dealing with criticality and it is possible that it should be interpreted in that context – that is that the geometric form of the package contents could not be substantially altered <u>from that used in the criticality analyses</u>. In its review of Revision 58 of the NAC International, Inc., legal weight truck (NAC-LWT) Certificate of Compliance (CoC), the NRC staff seem to be using this second interpretation: "…NRC staff is satisfied that the intent of 10 CFR 71.55(d)(2) is met, in that there is no substantially altered configuration that challenges the criticality analyses, or that poses an undue risk to health and/or safety during operations." (NRC 2013c). Similarly, in its review of Revision 6 of the RH-TRU 72-B CoC, the NRC staff stated "Since the applicant performed the criticality evaluations using reasonably bounding geometry, the staff verified that the geometry could not be altered so as to affect the conclusions of the criticality safety analysis. The staff finds that the applicant meets 10 CFR 71.55(d)(2)." (NRC 2011b). The second interpretation is also recommended by NEI in their response to the NRC request for comment (NEI 2013). "As long as analyses can demonstrate that the transportation package will maintain the safety functions of sub-criticality, containment and shielding, then the contents would not be "substantially altered."" (NEI 2013). Thus, depending on the interpretation of 10 CFR 71.55(d)(2), repackaging of casks with internals of unknown material properties may or may not be needed.

Compliance with 10 CFR 71.55(e)

ISG-19 provides two options for demonstrating compliance with 10 CFR 71.55(e): 1) perform criticality calculations assuming water in-leakage and reconfigured UNF geometries based on (a) either bounding assumptions or (b) actual structural UNF and cladding properties, or 2) demonstrate moderator exclusion with physical testing of the water exclusion boundary. ISG-19 indicates that there is insufficient material property information for high burnup fuel to perform structural evaluations to determine credible reconfigured fuel geometries, so applications for transportation casks for high burnup fuel may not be able to rely on Option 1(b) without additional data. To date, the only transportation cask that has been approved by the NRC using provisions contained in ISG-19 is the Holtec International Storage, Transport, and Repository Cask System (HI-STAR) 180 (Morton et al. 2011). The HI-STAR 180 is approved for high burnup fuel, up to 66 gigawatt-day per metric tons of uranium (GWd/MTU). In their application, Holtec used Option 2, moderator exclusion, as their primary means for showing compliance with 10 CFR 71.55(e) but also provided some Option 1 calculations for defense in depth (NRC 2009a). However, Holtec did not use the 10 CFR 71.55(c) moderator exclusion exemption for compliance with 10 CFR 71.55(b), but provided calculations showing subcriticality for flooded as-loaded, intact pressurized water reactor (PWR) UNF. Note that applicant for HI-STAR 180 demonstrated that the double lid design meets the intent of ISG-19 and that the integrity of both the inner and outer lids is demonstrated through an analysis in lieu of physical tests.

3.4 Summary of Regulatory and Technical Drivers for Repackaging

Under current regulations and guidance, repackaging may be required if the degradation state of the canister internals becomes unknown, such as if a canister is breached or after extended storage of high burnup fuel. In particular, compliance with 10 CFR 72.122(l), 71.55(b), 71.55(d)(2), and 71.55(e) would be challenging under these circumstances and may drive the need for repackaging. However, based on the discussion for regulatory drivers above, the following guidance and interpretation of applicable regulatory requirements could reduce the need for repackaging:

- A canister-based as opposed to assembly-based retrievability for compliance with 10 CFR 72.122(l),
- For 10 CFR 71.55(b), the regulatory requirement could be interpreted to apply to "as-loaded" configurations only,
- A performance-based interpretation of the geometry control requirement specified in 10 CFR 71.55(d)(2),
- ISG-19 provides achievable alternatives for compliance with 10 CFR 71.55(e) if the transportation cask design can be relied upon to demonstrate moderator exclusion.

In addition, these key regulations and guidance are currently under review by the NRC. If the regulations or guidance are changed in a manner consistent with industry recommendations, the regulatory need for repackaging may be eliminated.

4. Dry Repackaging at ISFSI-only Sites

As discussed in Section 3, repackaging may be required for continued storage or transportation if the degradation state of the cask/canister internals becomes unknown, such as if a cask/canister is breached or after extended storage of high burnup fuel. In addition, repackaging of storage-only casks would be required prior to transportation. For storage-only canisters, repackaging may be avoided if a specially designed transportation cask is licensed on the basis of the moderator exclusion exception in 10 CFR 71.55(c), and if geometry control requirements are met or are considered to be performance-based. If such canisters/casks needing repackaging are at sites without a working pool, the transfer would need to be conducted dry. For this reason, the transportability of canisters/casks at sites that have undergone or are undergoing pool decommissioning is reviewed here. In addition, because eventually all pools will be decommissioned, the transportability of canisters/casks at all ISFSI sites is reviewed.

4.1.1 Transportability of Canisters at ISFSI-only Sites

From the NRC's list of shut down power reactors (NRC 2013b), 14 are light water reactors with fuel onsite. Table 1 lists the 10 sites that have been decommissioned or are undergoing decommissioning. Those undergoing decommissioning are identified by the NRC as "DECON" and those where the license has been reduced to include only the ISFSI are called "ISFSI-only" (NRC 2013b). Four other reactors with fuel on site have been permanently shut down and put into "SAFSTOR" where the nuclear facility is maintained and monitored. The most recent reactor shutdown, which was announced on June 7, 2013, is that of the San Onofre Units 2 and 3. The San Onofre ISFSI currently uses the (Nutech horizontal modular storage) NUHOMS®-24PT storage system with 24PT1 and 24PT4 canisters which may be transported in MP-187 and MP-197 transportation casks, respectively.

Table 1. ISFSI-only and DECON Sites

Reactor Site (Shutdown date)	Storage System (Canisters)	Transportation Cask Status (NRC Docket number)	UNF Casks	Site Status
Big Rock Point (8/97)	Fuel Solutions W150 (W74)	TS-125 (71-9276) Certificate expires 10/31/17 Never fabricated	7	ISFSI-only
Connecticut Yankee (Haddam Neck) (12/96)	NAC MPC (MPC-24 & MPC-26)	NAC STC (71-9235) Certificate expires 5/31/14 Foreign use versions fabricated	40	ISFSI-only
Humboldt Bay 3 (7/76)	HI-STAR 100 HB (MPC-80)	HI-STAR 100 HB (71-9261) Certificate expires 3/31/14 5 units in use	5	DECON
La Crosse (4/87)	NAC MPC (MPC-LACBWR)	NAC STC (71-9235) Certificate expires 5/31/14 Foreign use versions fabricated	5	DECON
Maine Yankee (12/96)	NAC UMS (UMS-24)	NAC UMS (71-9270) Certificate expires 10/31/17 Never Fabricated	60	ISFSI-only
Rancho Seco (6/89)	TN NUHOMS-24P (FO-DSC, FC-DSC, and FF-DSC)	NUHOMS MP-187 (71-9255) Certificate expires 10/30/18 One cask fabricated, at site	21	ISFSI-only
San Onofre 1 (11/92)	TN NUHOMS-24P (24PT1)	NUHOMS MP-187 (71-9255) Certificate expires 10/30/18 Unit fabricated, in use elsewhere	18	DECON[a]
Trojan (11/92)	TranStor Overpack (Holtec MPC-24E and MPC-24EF)	HI-STAR 100 (71-9261) Certificate expires 3/31/14 Units fabricated, in use elsewhere	34	ISFSI-only
Yankee Rowe (10/91)	NAC MPC (MPC-36)	NAC STC (71-9235) Certificate expires 5/31/14 Foreign use versions fabricated	15	ISFSI-only
Zion 1 and 2 (2/97, 9/96)	NAC MAGNASTOR (TSC-37)	MAGNATRAN (71-9356) Not licensed	61 not loaded	DECON

[a] The NRC (2013b) table lists San Onofre as in “SAFSTOR”, but the text indicates that DECON is in progress. StoreFUEL (2013) lists San Onofre as “DECON in Progress”.

Sources: NRC (2013b), StoreFUEL (2013), Maheras et al. (2013), and documents within the NRC Agencywide Documents Access and Management System (ADAMS) under the docket numbers listed.

Except for the Zion site, which has yet to load canisters, the canisters at the 10 sites have corresponding licensed transportation casks (Table 1). At the Zion site, the NAC MAGNASTOR storage casks and the MAGNATRAN transportation casks are planned for use. The MAGNATRAN license request has been submitted and NAC responded to the latest NRC request for information in April 2013, but it is unclear when a license may be issued. NAC has indicated to the NRC staff the desire to receive a MAGNATRAN license before it loads fuel into the MAGNASTOR casks (StoreFUEL 2013), thus ensuring the transportability of the canisters before loading.

Transportability of a canister is achieved when the canister has a licensed transportation cask and when the contents of that canister meet the conditions of that license. Two conditions of the contents that may affect the canisters transportability are the burnup and the condition of the fuel.

Two sites, Maine Yankee and Zion, have high burnup (>45 GWd/MTU) used nuclear fuel assemblies in storage (Maheras et al. 2013). For the Maine Yankee canisters, the CoC for the NAC-UMS (Universal multipurpose canister/cask (MPC) System) cask specifically includes Maine Yankee fuel with burnup up to 50 GWD/MTU. The CoC classifies otherwise intact high burnup fuel as “intact” or “damaged” based on the percentage of rods with oxide thickness greater than specified limits. All high burnup fuel at Maine Yankee has been placed in damaged fuel cans, so these canisters are transportable. For the Zion canisters, the MAGNATRAN submittal specifies burnups up to 60 GWD/MTU with the requirement that fuel with burnup greater than 45 GWD/MTU be placed in damaged fuel cans. Therefore, when the Zion high burnup fuel is loaded into canisters, it will be placed in damaged fuel cans in order to be transportable.

Most transportation CoCs that allow damaged fuel, have requirements to place the damaged fuel in damaged fuel cans or have specific canisters for that use. At the Rancho Seco site, the failed fuel dry shielded canisters (FF-DSC) were designated for storage and transportation of damaged fuel within damaged fuel cans. However, the definition of damaged fuel has changed since the fuel was loaded into canisters at the Rancho Seco site. As a result, six of the assemblies, then classified as intact and loaded into five DSCs designed for fuel assemblies with control components (FC-DSCs), are now classified as damaged. (Maheras et al. 2013) As stated in the Safety Evaluation Report for the Rancho Seco ISFSI: “The staff notes that under current guidance, visual examination alone is no longer a sufficient method for classifying assemblies as damaged or intact. Prior to transporting the fuel stored at Rancho Seco, fuel classification may need to be revisited, and the damaged fuel assemblies (and potentially the intact fuel assemblies) may need to be placed into damaged-fuel cans to be transportable.” (NRC 2009b). The need to repackage these canisters, which would require a DTS given that the pool has been decommissioned at this site, may be avoided if either of the following two approaches is implemented:

- Specially designed transportation cask is licensed on the basis of the moderator exclusion exception in 10 CFR 71.55(c), and geometry control requirements are met or are considered to be performance-based.
- Moderator exclusion based on the guidance in ISG-19 to meet 10 CFR 71.55(e), as loaded configuration to meet 10 CFR 71.55(b), and geometry control requirements are met or are considered to be performance-based. Although some fuel pins may have pinholes and cracks, an argument can be developed to support that the fuel assemblies have maintained their as loaded configuration and thus are considered undamaged per the performance-based definition of ISG-1 (i.e., the UNF remains in its as loaded configuration without the loads of NCT or HAC, however it may reconfigure during NCT or HAC).

It is important to note that the issue of changes in fuel classification during storage may not be isolated to Rancho Seco and may become more common once additional storage licenses are renewed, especially for high burnup UNF.

4.1.2 Transportability of Casks/Canisters at all Storage Sites

As additional reactors reach the end of their lifetimes, more sites will enter DECON and eventually become ISFSI-only, so currently licensed transportation casks were surveyed to see if all existing canisters at ISFSIs were covered. There are over 500 casks/canisters at ISFSI sites that currently do not have a licensed transportation cask, however many of these were designed to be transportable. For example, if Amendment 6 to the NUHOMS® MP-197 CoC is approved, an additional 185 canisters would become transportable. Table 2 lists the single purpose storage-only canisters (297) and casks (27). Of these, there are some canisters, such as the FuelSolutions ventilated storage cask (VSC)-24, which have impediments to transportation licensing. The VSC-24 lacks neutron poisons within its basket and thus demonstrating subcriticality when flooded is problematic. In 2006 Energy*Solutions* submitted an amendment to the TS-125 CoC to include the VSC-24 canister. After delays in Energy*Solutions'* response to 65 NRC questions, 36 of which were on criticality, the NRC closed the amendment request in 2008. The NUHOMS® 24P and 24PHB canisters also do not have neutron absorbing materials in their internal baskets, but rely on soluble boron for criticality safety during loading and unloading operations. It is not clear that these canisters could be licensed for transport without the use of the moderator exclusion exemption. For those casks/canisters for which a transportation license is not pursued/granted, repackaging will be required, and would be best done in the reactor pool before it is decommissioned.

Table 2. Single Purpose Storage-Only Canisters/Casks

Reactor	**Storage System**	**Canister Type**	**Cask Type**	**Number 7/2013**
H.B. Robinson 2	NUHOMS®	7P		8
Calvert Cliffs 1, 2	NUHOMS®	24P, 32P		72
Davis-Besse	NUHOMS®	24P		3
Oconee	NUHOMS®	24P, 24PHB		129
Susquehanna	NUHOMS®	52B		27
Surry	Westinghouse		MC-10	1
Surry	Castor		V/21, X33	26
Arkansas Nuclear	FuelSolutions	VSC-24		24
Palisades	FuelSolutions	VSC-24		18
Point Beach	FuelSolutions	VSC-24		16

Source: Cask numbers from StoreFuel (2013)

5. Alternatives to an ISFSI Site Dry Transfer System

A number of alternatives to an ISFSI site DTS have been proposed. These include: the use of damaged fuel cans, over packing, repackaging while a pool is present, early transporting of UNF, and pursuit of alternative interpretations of regulation and guidance.

Damaged Fuel Cans: Damaged fuel cans were used by Maine Yankee for its high burnup fuel, thus avoiding any retrievability issues with its high burnup fuel. However, this practice is expensive and not advocated for general use for high burnup fuel by the industry (NEI 2013) or DOE (DOE 2013b). In addition, it does not address low burnup fuel that may undergo degradation during storage, or high burnup fuel already loaded into storage containers.

Over Packing: Morton et al. (2011) have proposed over packing of canisters to address the transportation requirements for subcriticality using the moderator exclusion exemption when the canisters and their internals may have degraded during storage. This concept calls for a separate watertight container, over packing the canister within the transportation cask. This container could be leak tested and thus satisfy the provisions in 10 CFR 71.55(c). Also, if used at an ISFSI site, this container could be used to reestablish confinement and an inert internal atmosphere for a breached canister. However, the overpack would not address the issues of retrievability and geometry control required by 10 CFR 72.122(l) and 71.55(d)(2).

Repackage While Pool is Present: The most cost efficient method of repackaging at ISFSI sites is to perform the repackaging in the reactor pool. Thus for sites that own storage-only casks or canisters, or have casks or canisters with unknown degradation states, it is important to do any repackaging prior to decommissioning the pool. This alternative is not available to the ISFSI-only sites.

Early Transporting of UNF: This alternative involves the transport all UNF while retrievability and geometry control can be demonstrated. It is consistent with the DOE goals of fielding a pilot CSF by 2021 and a larger CSF by 2025 (DOE 2013a). It remains to be seen if the CSF will be available soon enough for this alternative.

Pursue Alternative Interpretations of Regulation and Guidance: While this alternative could solve the issues of retrievability, subcriticality, and geometry control, it would be a risky proposition to rely on this course. There is no way to predict if, when, or how regulations and guidance may change. However, it is prudent to engage the NRC on these issues while pursuing other alternatives.

6. High-Level Functional and Operational Requirements of a DTS

In order to determine the functional and operational requirements of a DTS, the applicable regulatory requirements are reviewed in Section 6.1. The high-level functional requirements are summarized in Section 6.2, whereas the high-level operational requirements are summarized in Section 6.3. Section 6.4 provides a listing of the primary structures, systems, and components of a DTS.

6.1 Regulations and Guidance for a DTS

Dry transfer systems could be licensed under 10 CFR 50 if built within the buildings of a licensed reactor, however a DTS built at an ISFSI-only site would be licensed through 10 CFR 72. 10 CFR 72 does not specifically address dry transfer systems, but the regulations for handling systems would apply to a DTS built under 10 CFR 72. Under 10 CFR 72, handling systems must ensure subcriticality [§ 72.124(a)], radiation protection [§ 72.126], confinement [§ 72.128(a)(3)], and heat removal [§ 72.128(a)(4)] under normal and accident conditions. These systems must be designed with the means to minimize the quantity of radioactive wastes generated [§ 72.128(a)(5)] and facilities must be provided for radioactive waste treatment [§ 72.128(b)]. § 72.166 requires the control of handling so as to prevent damage or deterioration to materials and equipment.

The radiation protection requirements in 10 CFR 72.126 are reproduced here because they point to specific systems that must be present.

"§ 72.126 Criteria for radiological protection.

(a) *Exposure control*. Radiation protection systems must be provided for all areas and operations where onsite personnel may be exposed to radiation or airborne radioactive materials. Structures, systems, and components for which operation, maintenance, and required inspections may involve occupational exposure must be designed, fabricated, located, shielded, controlled, and tested so as to control external and internal radiation exposures to personnel…

(b) *Radiological alarm systems*…

(c) *Effluent and direct radiation monitoring*…

(d) *Effluent control*. The ISFSI or MRS must be designed to provide means to limit to levels as low as is reasonably achievable the release of radioactive materials in effluents during normal operations; and control the release of radioactive materials under accident conditions. Analyses must be made to show that releases to the general environment during normal operations and anticipated occurrences will be within the exposure limit given in § 72.104. Analyses of design basis accidents must be made to show that releases to the general environment will be within the exposure limits given in § 72.106. Systems designed to monitor the release of radioactive materials must have means for calibration and testing their operability."

NUREG-1567 (NRC 2000a) Section 6.5.1.4 states that "…the dry transfer system ensures that under normal, off-normal, and accident conditions that the fuel cladding temperature will not exceed 570ºC…"

Section 15.5.2.12 states that "A building that houses the SSCs (contains spent fuel casks, is used for transfer operations, or is used for temporary storage) must be designed to prevent massive collapse due to accident conditions…" including "…flood, fire and explosion, lightning, earthquake, tornado and tornado-generated missiles, and accidents at nearby sites."

6.2 Functional Requirements

The building and licensing of a DTS at an ISFSI-only site would not be trivial. The system would need to provide for the safety functions of subcriticality, radiation protection, confinement, and heat removal, for normal and accident conditions, and protection of materials. Demonstration of these functions would be required prior to receiving a license. These functional requirements and associated systems are summarized in the following sections.

6.2.1 Subcriticality

Subcriticality would be ensured by the absence of moderator during normal operating conditions. It must also be demonstrated that "before a nuclear criticality accident is possible, at least two unlikely, independent, and concurrent or sequential changes have occurred in the conditions essential to nuclear criticality safety". Unless the design of the DTS precludes the introduction of moderator (e.g., water from a fire suppression system, hydraulic fluid, external flooding) for normal operations, off-normal conditions, and accidents (including natural phenomena), criticality analysis of moderated configurations may be required.

6.2.2 Radiation Protection

The requirements in 10 CFR 72.126 account for areas that will contain radioactive materials with the potential for airborne contamination; in this case, the area where the assemblies are transferred. This area would be required to be within a confinement boundary with an effluent control system as specified in 10 CFR 72.126(c). Airlocks would be required for access to this controlled area, to prevent direct release of airborne radionuclides. Shielding must be used whenever the personnel are handling UNF. When the fuel is in the casks, shielding would be mostly provided by the transportation cask or storage transfer cask; a shielding design feature would be needed to reduce the shine from the top of the casks after removal and prior to placement of a lid/shield plug. Shielding when the assembly is outside either cask could be provided in one of two methods; (1) remotely perform the transfer within a large hot cell, with the hot cell providing the shielding, and (2) use a special shielded container into which an assembly is drawn, moved and then lowered into the new cask. The selection of shielding method has major implications on the design of the DTS.

6.2.3 Confinement

Confinement implies some type of enclosure between exposed radioactive materials and the environment with an effluent system that limits releases during normal operations and mitigates releases during accident conditions. An airlock would be required to move casks into and out of the confinement area where the transfer takes place. Confinement areas are normally maintained at a lower pressure than surrounding air so that any leaks will be into the confinement area and not out. In order to maintain negative pressure gradient, air is vented through a filtered effluent system. The confinement enclosure must be robust enough to maintain function during accident conditions.

6.2.4 Heat Removal

The cladding temperature limit of 570ºC provided in NUREG-1567 (NRC 2000a) is meant to protect the cladding from degradation. However even lower temperatures are required to limit oxidation of UO_2 exposed to air in breached fuel rods (see Section 3.3.5). Cooling of the fuel to meet temperature limits may be accomplished by one or more systems: a heating, ventilation, and air-conditioning (HVAC) system to cool the fuel transfer room, a cooling system for the exterior of the cask, and a cold inert gas system for cooling the interior of the cask.

6.2.5 Protection of Materials

10 CFR 72.166 requires control over handling that prevents damage or deterioration to materials and equipment. “When necessary for particular products, special protective environments, such as inert gas atmosphere, and specific moisture content and temperature levels must be specified and provided.” For the dry transfer of fuel with breached cladding, this requirement would apply to consideration of the atmosphere and temperatures under which exposed UO_2 could oxidize. At temperatures above 200°C, spent fuel oxidizes in air first to $UO_{2.4}$ which results in a slight volume reduction and then to U_3O_8 with an accompanied large volume increase (Hanson 1998). It is this second step that can result in the splitting of the cladding and release of fuel. The rate of this step is highly temperature dependent, so limiting the time and temperature of exposure to air may avoid significant oxidation. If temperatures are maintained

below 200°C, the time of exposure will not need to be limited. If higher temperature limits are used, then the exposure time will need to be limited to prevent oxidation to U_3O_8. For example, BSC calculations indicate that if the handling in air is limited to less than about 100 hours at temperatures below 350°C, oxidation should not progress significantly beyond $UO_{2.4}$ (BSC 2005). The other method of avoiding significant oxidation is to perform the transfer in an inert atmosphere. This may be accomplished by inerting the entire transfer room, or by providing an inert atmosphere to the assemblies while they are in the casks and during the transfer by inerting a transfer tube. Inerting the entire transfer room is quite expensive and has significant operational and safety considerations.

6.3 Operational Requirements

Based on the anticipated operations to repackage UNF from the various storage systems and configurations, the following is a list of high-level operational requirements and limitations for a DTS:

Operational Requirements:

- Load destination container onto the DTS conveyance and transfer through the airlock
- Unload source container from the transport vehicle (rail, truck or special purpose) remove impact limiters and position on DTS conveyance. Transfer through airlock. If the source container is a canister, it will be housed within a transportation cask or a storage transfer cask.
- For a source canister, test for leaks
- For a source canister, open transportation cask or storage transfer cask exposing top of canister
- For a source cask, inspect exterior
- Open ports and vent source cask/canister
- Unbolt cask lid(s) or cut open canister lids and remove
- Remove shield plug
- Retrieve UNF assembly from specified location in source cask/canister
- Provide for inspection of fuel assembly
- Place UNF into a damaged fuel can if necessary
- Place UNF into a staging area if it is not to be placed immediately into a destination cask/canister
- Place UNF into designated location in destination cask/canister
- Install shield plug
- Install lid(s) and bolt or weld in place, backfill with inert gas, leak test, and seal ports of destination cask/canister
- For a destination canister, place lid on transportation cask or storage transfer cask
- Decontaminate exterior of closed destination cask as necessary
- Transfer completed destination package through airlock and position on transport vehicle
- Decontaminate and disposition any casks, canisters, lids, or other package components that will not be reused
- Disposition any wastes generated during the operation

Operational Limitations

- Stage two casks, each up to 100 inches in diameter
- Space to store lids and damaged fuel cans during the transfer
- Small assembly staging area within the confinement area would aid in transferring assemblies between casks of different capacities and in balancing thermal loads in the destination containers
- The confinement area must have space and equipment to move 15-foot assemblies into and out-of 18-foot casks
- Outside the confinement area, facilities such as a heavy-load crane are needed to unload casks from an outside transport vehicle and position the cask on the DTS conveyance. Note that loaded transportation casks may weigh up to 125 tons without impact limiters.

6.4 Structures, System, and Components of a DTS

The essential structures, systems and components (SSCs) to meet the above mentioned functional and operational requirements are:

Confinement and Radiation Protection SSCs

- Confinement structure
- Airlocks
- Effluent control system
- HVAC system
- Shielding
- Radiation detection and alarm systems

Cooling and Temperature Control SSCs

- Temperature control systems, as needed
- Cask/canister/UNF cooling system

Cask/Canister/UNF Handling SSCs

- Conveyance systems (at least 125 ton capacity)
- Transport vehicle loading and unloading equipment (at least 125 ton capacity)
- Lid handling equipment
- Assembly and damaged fuel can handling equipment
- Assembly inspection system
- Canister opening and welding systems
- Cask/canister inert gas handling system (venting, flushing, filling, gas sampling and leak testing)
- Container decontamination system

Support SSCs

- Control room
- Video system
- Waste treatment facilities
- Utilities (Water, Electricity)

7. Conclusions

This report reviews 1) the regulatory and technical drivers for repackaging UNF at ISFSI sites, 2) the transportability of canisters at ISFSI-only sites and of casks and canisters at all ISFSI sites, 3) the alternatives to an ISFSI Site DTS, and 4) the high-level functional and operational requirements for a DTS.

The regulatory drivers for repackaging at ISFSI sites include the requirements for retrievability during storage [10 CFR 72.122(l)], and subcriticality and geometry control for transportation [10 CFR 71.55(b) and 71.55(d)(2)]. If the degradation state of the cask/canister and internals becomes unknown, repackaging may be necessary depending on the interpretation of these requirements and the associated guidance. Regulatory engagement is needed regarding: any change in the level to which retrievability is required (assembly or canister), whether 10 CFR 71.55(b) only requires compliance in the "as loaded" configuration, and whether the conditions from which the geometry cannot be substantially altered are those when loaded or those used in the criticality, shielding, and thermal calculations (i.e., performance-based). Regulatory engagement has started with DOE and industry response to the NRC call for comments on retrievability, cladding integrity and the safe handling of spent fuel.

A technical driver for repackaging at ISFSI sites is the need to transport UNF that is currently in storage-only containers to its final destination. Storage-only casks would be required to be repackaged prior to transportation. For storage-only canisters, repackaging may be avoided if a specially designed transportation cask is licensed on the basis of the moderator exclusion exception in 10 CFR 71.55(c), and if geometry control requirements are met or are considered to be performance-based. The moderator exclusion exception in 10 CFR 71.55(c) has yet to be successfully used in licensing. If repackaging is required at a site without a pool, a DTS would be needed.

There are licensed transportation casks designed for all the canisters currently at ISFSI-only sites, however the same is not true at all ISFSI sites. As of July 2013, there were over 500 casks/canisters at ISFSI sites that did not have a licensed transportation cask. Of these, 27 casks and 297 canisters were intended as single purpose storage-only containers.

A number of alternatives to an ISFSI site DTS have been proposed. These include: 1) using damaged fuel cans for fuel of unknown condition such as high burnup fuel after extended storage, 2) over packing if a canister is breached, 3) performing any required repackaging in pools while the pools are still present, 4) transporting UNF to its final destination before degradation occurs, 5) and regulatory engagement. If some or all alternatives are pursued, an ISFSI site DTS may not be needed.

This report also reviews the regulations in 10 CFR 72 for fuel handling systems, summarizes the high-level functional and operational requirements, and provides a listing of the primary structures, systems, and components of a DTS.

Given the anticipated large cost of a standalone DTS and the uncertainty in the interpretation of the regulations and guidance that may drive the need for an ISFSI-site DTS, the authors recommend that at this time greater priority be given to pursuing the alternatives to a DTS than to development of an ISFSI-site DTS. Recommended in particular are: performing any required repackaging in pools while the pools are still present, transporting UNF to its final destination before degradation occurs, and regulatory engagement. If in the future, these alternatives are unavailable or prove to be ineffective, then greater emphasis can be placed on developing a DTS specific to the needs at that time.

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