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MANAGING AGING EFFECTS ON DRY CASK STORAGE SYSTEMS FOR EXTENDED LONG-TERM STORAGE AND TRANSPORTATION OF USED FUEL

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ABSTRACT

There is currently no designated disposal site for used nuclear fuel in the United States, which raises the prospect of extended long-term storage (i.e., >120 years) and deferred transportation of used fuel at operating and decommissioned nuclear power plant sites. Under U.S. federal regulations contained in Title 10 of the *Code of Federal Regulations* 72.42, the initial license term for an independent spent fuel storage installation (ISFSI) must not exceed 40 years from the date of issuance. Licenses may be renewed by the U.S. Nuclear Regulatory Commission at the expiration of the license term upon application by the licensee for a period not to exceed 40 years. Applications for ISFSI license renewals must include (1) time-limited aging analyses that demonstrate that structures, systems, and components (SSCs) important to safety will continue to perform their intended function for the requested period of extended operation and (2) a description of the aging management program for managing issues associated with aging that could adversely affect SSCs important to safety. This paper highlights issues related to managing aging effects on dry cask storage systems and ISFSIs for extended long-term storage and transportation of used nuclear fuel. In particular, it focuses on aging management issues related to the confinement boundary of bolted-closure and welded-closure storage casks and canisters. These highlights were largely extracted from a report prepared by Argonne for the U.S. Department of Energy's Used Fuel Disposition Campaign for research and development on extended storage and transportation.

INTRODUCTION

As part of the U.S. Department of Energy (DOE) Used Fuel Disposition Campaign's research and development (R&D) program, Argonne National Laboratory prepared a report titled *Managing Aging Effects on Dry Cask Storage Systems for Extended Long-Term Storage and Transportation of Used Fuel, Rev. 0* [1]. This report, referred to herewith as "the Rev. 0" report, examines issues related to managing aging effects on the structures, systems, and components (SSCs) in dry cask storage systems (DCSSs) and independent spent fuel storage installations (ISFSIs) for extended long-term storage and transportation of used fuels, following an approach similar to that of *the Generic Aging Lessons Learned (GALL) Report* [2] on managing the aging of and the license renewal of nuclear power plants. The Rev. 0 report contains five chapters: (I) an introduction that contains an overview of the license renewal process based on Title 10, Part 72 of the *Code of Federal Regulations* (10 CFR Part 72) [3] and the guidance provided in the U.S. Nuclear Regulatory Commission (NRC) report, *Standard Review Plan for Renewal of Used Fuel Dry Cask Storage System License and Certificate of Compliance,* NUREG-1927 [4]; (II) definitions and terms for structures, components, materials, environments, aging effects, and aging mechanisms; (III) time-limited aging analyses (TLAAs); (IV) descriptions and evaluations of aging management programs (AMPs); and (V) information related to the aging management review and application of AMPs, consisting of tabulations from evaluations of AMPs and TLAAs for the SSCs that are important to safety in the DCSS designs (i.e., NUHOMS®, HI-STORM 100, Transnuclear [TN] metal cask, NAC International S/T storage cask, ventilated storage cask [VSC-24], and Westinghouse MC-10 metal dry storage cask) that have been and continue to be used by utilities for the dry storage of used fuel. In addition, the Rev. 0 report contains an appendix on quality assurance.

Chapter IV of the Rev. 0 report includes two AMPs related to structural components and five AMPs dealing with mechanical components. The present paper focuses on two of the mechanical component AMPs, namely those concerned with confinement boundary integrity and leakage monitoring of bolted-closure casks and welded-closure canisters. These two AMPs are discussed in some detail here.

CASK AND CANISTER DESIGNS AND REGULATORY REQUIREMENTS

DCSSs are of two general types: (1) self-contained shielded metallic casks without an overpack and (2) metallic canisters with a separate overpack to provide radiation shielding and physical protection. The systems presently in common use in the U.S. are summarized in Table 1.

Table 1. Summary of Dry Cask Storage Systems Currently in Use in the U.S.

Vendor	System	Cask/Canister	Type[a]	Closure
Energy*Solutions*	Fuel*Solutions*	VSC-24, W150	C/O	Welded
General Nuclear Systems, Inc.	CASTOR	V/21, X/33	Cask	Bolted
Holtec International	HI-STAR-100	MPC-68, MPC-80	C/O	Welded
	HI-STORM-100	MPC-24, MPC-32, MPC-68	C/O	Welded
NAC International, Inc.	S/T	NAC-I28	Cask	Bolted
	MPC	MPC-26, MPC-36	C/O	Welded
	UMS	UMS-24	C/O	Welded
	MAGNASTOR	MAGNASTOR	C/O	Welded
Transnuclear, Inc.	NUHOMS	52B, 61BT, 61BTH, 7P, 24P, 24PHB, 24PT, 24PTH, 24PT1, 32P, 32PT, 32PTH, 12T, HD	C/O	Welded
	TN Metal Casks	TN-24, TN-32, TN-40, TN-68	Cask	Bolted
Westinghouse	MC-10	MC-10	Cask	Bolted

[a] C/O = metallic canister with overpack; Cask = self-contained metallic cask without overpack.

All of the self-contained cask designs listed in the table incorporate bolted top enclosures with O-ring seals, whereas the canister plus overpack configurations, which are generally of more recent design, use a welded top closure. The TN-68 cask, an example of a bolted cask design, is shown in Figure 1. Figures 2 and 3 show the HI-STORM 100 vertical dry cask storage system and the NUHOMS horizontal dry cask storage system, respectively, both of which are examples of welded canister plus overpack designs.

Both the bolted cask and welded canister plus overpack DCSSs are subject to a number of regulatory requirements. The 10 CFR Part 72 requirements related to aging management review for renewal of ISFSI license and Certificate of Compliance for DCSS designs are described in Section 3.3 of NUREG-1927. The significant regulatory requirements include the following:

Redundant Sealing. NRC Interim Staff Guidance (ISG)-5 [5] and 10 CFR 72.236(e) specify that both bolted- and welded-closure casks and canisters provide redundant sealing of the confinement boundary. Accordingly, bolted-closure casks have inner and outer lids, each with redundant metallic or elastomer O-ring seals. Welded-closure canisters likewise have inner and outer cover plates sealed by separate, redundant closure welds.

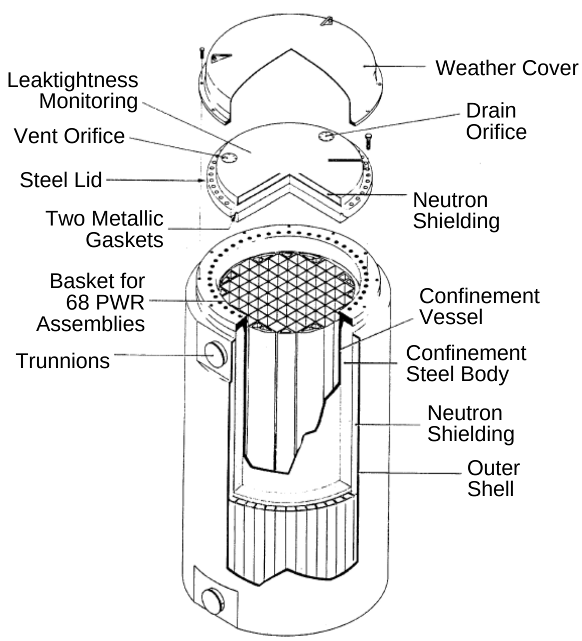

Figure 1. TN-68 dry shielded bolted cask

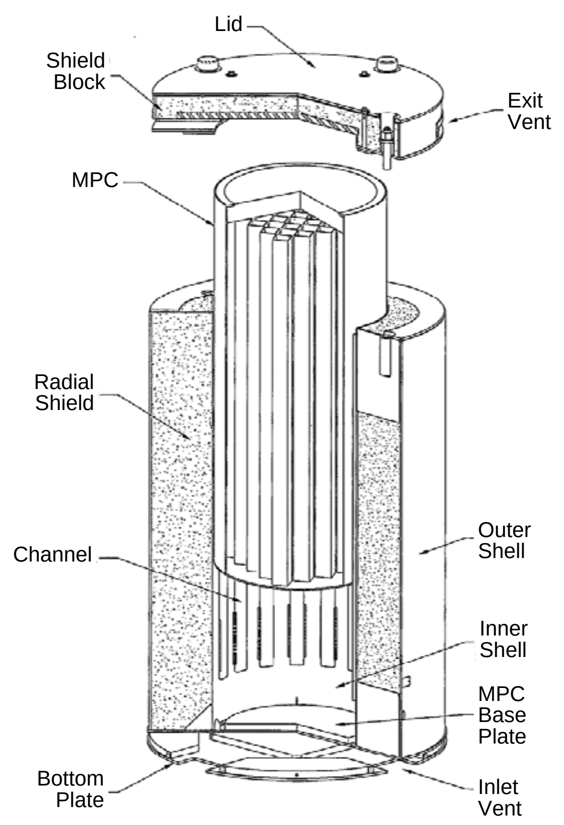

Figure 2. HI-STORM 100 vertical dry canister storage system with the 100S Version B overpack

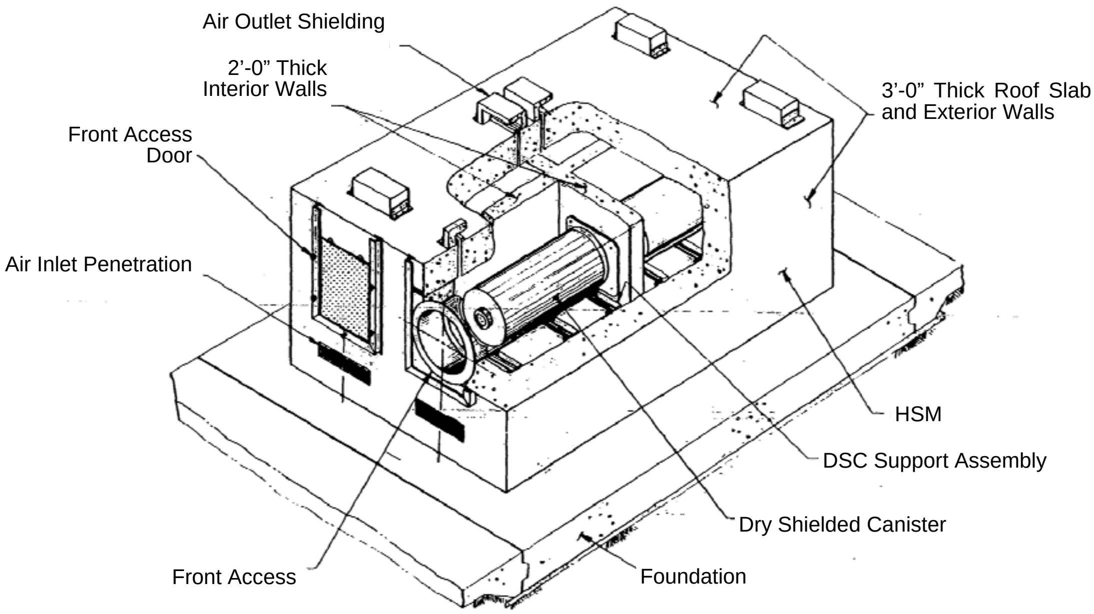

Figure 3. NUHOMS horizontal dry canister storage system with concrete storage module

Leakage Monitoring. NRC ISG-5 and 10 CFR 72.122(h)(4) specify that storage systems must have the capability for continuous monitoring such that the licensee is able to take appropriate corrective actions to maintain safe storage conditions. Bolted-closure cask systems incorporate an overpressure leakage monitoring system. This system monitors the pressure between the inner and outer lid seal assemblies in the TN metal, NAC-I28, and CASTOR casks and inside the cask cavity in the MC-10 casks. A low-pressure alarm is triggered when the pressure reaches a predetermined threshold. The continuous pressure monitoring ensures timely detection of aging effects in the confinement boundary so that appropriate corrective actions can be taken to maintain safe storage conditions for the dry cask storage systems.

ISG-5 states that seal monitoring is not required for canisters enclosed entirely by welding, since monitoring of other welded joints in both bolted casks and welded canisters is not required. However, the licensee and cask vendor must demonstrate that the seal welds have been sufficiently tested and inspected to ensure that the weld will behave similarly to the adjacent parent metal of the canister. In addition, ISG-5 states that the lack of a closure monitoring system in welded canisters is typically coupled with a periodic surveillance program designed to ensure timely detection of closure degradation.

Closure Weld Design. The welded canister cover plate-to-shell welds are partial penetration welds designed in accordance with the American Society of Mechanical Engineers (ASME) Code, Section III, Division 1, Subsection NB [6]. The closure welds are multiple-pass welds, which consist of three or more layers of weld metal. Each layer may be composed of a single weld bead or several adjacent weld beads of common thickness. The minimum of three layers minimizes the probability of a weld flaw propagating through the weld layers and resulting in a leakage path. This effectively eliminates a pinhole leak, which might occur in a single-layer weld, since the chance of pinholes being in alignment on successive weld layers is not credible.

Inspection and Leak Testing. 10 CFR 72.236(j) states that the spent fuel storage cask must be inspected to ascertain that there are no cracks, pinholes, uncontrolled voids, or other defects that could significantly reduce its confinement effectiveness. NRC ISG-25 [7] further states all the canister/cask confinement boundary welds are to be inspected and pressure and helium leak tested in accordance with the appropriate articles of the ASME Code, Subsection NB or NC, and ANSI 14.5 [8]. For bolted-closure casks, the entire confinement boundary is to be helium leak tested and pressure tested. The confinement boundary should be tested at the fabrication shop, with only a leakage test performed on the bolted lid closure seals (including drain and vent port seals) by the DCSS user in the field. For welded-closure canisters, if the entire confinement boundary is tested to be leak tight in accordance with American National Standards Institute (ANSI)-N14.5 (i.e., 1.0×10^{-7} ref. cm^3/sec) and the canister lid-to-shell weld conforms with the criteria of ISG-18 [9], then leakage is not considered credible and effluents are not required to be considered in confinement dose analyses. NRC ISG-18 further states that helium leak testing is not required for the multi-pass lid weld, provided the weld is executed and examined in accordance with NRC ISG-15 [10].

Other Regulatory Requirements. Other applicable regulatory requirements include those of 10 CFR 72.236(l), which requires that the DCSSs be evaluated to ensure that the confinement of the radioactive material is reasonably maintained under normal, off-normal, and credible accident conditions. Furthermore, 10 CFR 72.122(h)(5) requires that the used fuel be packaged in a manner that allows handling and retrievability without the release of radioactive materials to the environment. One aspect of retrievability is the ability to remove the used fuel assemblies from the DCSS and repackage them in a new container without releasing radioactive materials. Used fuel is likely to be retrievable if the fuel rods as well as the assemblies are not warped, the cladding is intact, and the confinement boundary has not been breached. Any ingress of air and moisture into the dry cask storage canister can lead to degradation of the used fuel assemblies due to oxidation, particularly if fuel temperatures are sufficiently high.

In addition, 10 CFR 72.128(a)(1) specifies that used-fuel storage systems must be designed with a capability to test and monitor components important to safety, and 10 CFR 72.122(i) specifies that instrumentation systems for dry storage casks must be provided in accordance with cask design requirements to monitor conditions that are important to safety over anticipated ranges for normal and off-normal conditions. Finally, 10 CFR 71.55 describes the general requirements for packaging used for the shipment of fissile materials, including spent nuclear fuel.

AGING MANAGEMENT OF BOLTED-CLOSURE CASKS

The Bolted Cask Seal and Leakage Monitoring Program in the Rev. 0 report is an AMP that manages the effects of aging on the integrity of the confinement boundary to ensure that timely and appropriate corrective actions can be taken to maintain safe storage conditions of the cask. The aging effects managed include loss of material due to corrosion, loss of sealing forces due to stress relaxation and creep of the O-rings, loss of preload of the closure bolts, and stress corrosion cracking (SCC) of welded plugs for sealing the inter-seal passageway in the TN casks. The specific components and systems that are typically managed by this program include the shield lid, primary lid, closure lid, protective covers, O-ring assemblies, and associated bolts and welds.

The AMP for bolted-closure casks consists of a leakage monitoring activity and a visual inspection activity. The leakage monitoring activity provides for continuous monitoring of the pressure between the two seal assemblies or inside the cask cavity. In the TN, NAC-I28, and CASTOR metal casks, an overpressure leakage monitoring system provides continuous monitoring of pressure in the region between the redundant metallic seal assemblies, which is pressurized with a nonreactive gas to a pressure greater than the helium pressure in the cask cavity. A decrease in pressure indicates that the nonreactive gas is leaking, either into the atmosphere due to a degraded outer metallic seal assembly or into the cask cavity due to a degraded inner metallic seal assembly. As discussed above, a breach of the cask confinement boundary from causes other than degradation of the inner metallic seal is not considered credible. Therefore, for the TN, NAC-I28, and CASTOR casks, the licensee does not have to specify the maximum allowed leakage rate, because leakage of radioactive contents through both seals is not a credible event. An overpressure leakage monitoring system in the MC-10 casks provides continuous monitoring of pressure inside the cask cavity, and a decrease in pressure indicates a leakage from the cask cavity through the seals or lid welds. For this cask design, the licensee should specify the maximum allowed leakage rate, as recommended by ISG-5, Rev. 1. For the MC-10 casks, leakage rates greater than the specified maximum leakage rate indicate degradation of both the inner and outer metallic seals. For all bolted-closure cask systems, the overpressure monitoring panel should be checked at least daily to verify that no alarms are indicated.

The inspection activity under the AMP for bolted-closure casks provides for periodic visual inspections of the closure seal components and maintenance of the overpressure leakage monitoring system and associated instrumentation. The closure lid (or neutron shield lid) on the MC-10 cask is held in place by fasteners, and elastomer O-rings are compressed to form a seal against the outside atmosphere. Similarly, the protective environmental cover on the TN and CASTOR casks is secured to the cask flange with studs and nuts. The potential for loss of material from the closure seal components beneath the closure or protective cover is managed by visual inspection (after removal of the protective cover) that verifies the absence of corrosion and water intrusion in the area below the cover. The inspection interval and the sample size should be based on an engineering assessment, taking into account the length of time in service, decay heat load, maintenance history, and service environment. The visual inspection interval for the seal area under the closure cover should not exceed 20 years, as recommended in Appendix E of NUREG-1927. However, ISFSI sites exposed to aggressive environments may require a visual inspection of the seal area at shorter intervals based on an engineering assessment. Note that the closure lid on the MC-10 cask is often welded over the primary lid to provide seal redundancy; therefore, the area under the closure lid may not be accessible in such casks.

In conjunction with periodic visual inspections of the accessible closure seal components, the O-ring associated with the cask outer protective environmental cover may be replaced as a preventive action. The replacement frequency is based on test data for the O-ring materials and determined by correlating loss of sealing forces over time with leakage tightness, as recommended in NUREG/CR-7116 [11].

If the low-pressure alarm is triggered, the AMP for the bolted-closure casks states that a root cause analysis of the pressure leakage should be performed and an engineering evaluation should be conducted to determine whether the degradation of the seal assemblies requires immediate correction. Any detected conditions that do not satisfy the visual examination acceptance criteria are required to be dispositioned through an approved site corrective action program. Corrective actions include repair or replacement of the defective metallic seals, which may require equipment and facilities for evacuating, drying, and backfilling the cask cavity with helium. In addition, dispositioning of flaws in vent cover welds may require analytical evaluation in accordance with a methodology comparable to ASME Code Section XI [12] to determine whether the flaw is acceptable for continued service until the next inspection.

Helium leakage was detected in two of the TN-68 bolted-closure casks at Peach Bottom in October 2010 (NRC Information Notice [IN] 2013-07 [13]). In both cases, there was no loss of confinement capability. The root cause analyses indicated that the leakage in one cask was caused by a material defect in the weld plug that provides sealing of the drilled inter-seal passageway associated with the drain port penetration of the cask lid. The defective welds were repaired in accordance with the ASME Code and cask design requirements. In the other cask, leakage occurred in the cask main lid outer closure seal.

Corrosion of the outer metallic lid seals and TN-32 lid bolts has been observed in the Surry ISFSI owing to external water intrusion near the lid bolts and outer metallic seals, resulting in five seal replacements [14]. One seal on a CASTOR X/33 cask has also been replaced at Surry. In addition, an inspection of an MC-10 cask was performed after about 20 years in service at Surry; 12 knurled nuts that fasten the closure cover to the cask were removed for inspection. While there was some oxidation of the outer O-ring edge, the O-ring seal surface and the areas underneath the closure cover had no cracks or indications of degradation [15].

AGING MANAGEMENT OF WELDED-CLOSURE CANISTERS

A major difference between bolted-closure casks and welded-closure canisters is the absence of a continuous pressure monitoring system in the latter design. Attachment 1 to ISG-5 states the following:

> *"In instances involving welded closures, the staff has previously accepted that no closure monitoring is required. This practice is consistent with the fact that other welded joints in the confinement system are not monitored. However, the lack of a closure monitoring system has typically been coupled with a periodic surveillance program that would enable the licensee to take timely and appropriate corrective actions to maintain safe storage conditions if closure degradation occurred."*

The importance of an effective periodic surveillance program is underscored by recent experimental results on the susceptibility of Types 304, 304L, and 316L stainless steels to chloride-induced SCC. Studies conducted at Southwest Research Institute found that the chloride-induced SCC of these alloys is strongly dependent on the concentration of salt deposits, residual stress, cask temperature, and relative humidity of the surrounding environment [16]. The results of salt fog tests, although they are considered conservative because of the high absolute humidity used in these tests, do demonstrate that the deliquescence of dry salt deposits can lead to SCC of austenitic stainless steels at temperatures that are only slightly greater than ambient temperatures [e.g., 43°C (109°F)]. Isolated corrosion pits and general corrosion were also observed at these temperatures, particularly in the heat-affected zone (HAZ), because of chromium depletion from the matrix. Cracking was primarily transgranular with sections of intergranular branching, and it occurred in regions where tensile stresses are the greatest or near the pits in the HAZ of the welds. None of the specimens exposed to the salt fog at 85 and 120 °C (185 and 248 °F) exhibited cracking because of the inability of salt deposits to deliquesce at high temperatures. Subsequent research [17] has indicated that the deliquescence relative humidity for sea salt is close to that of $MgCl_2$ pure salt. SCC was observed between 35 and 80 °C (95 and 176 °F), when the ambient relative humidity was close to or higher than this level, even for surface salt concentrations as low as 0.1 g/m^2. In addition, NRC IN 2012-20 [18] cites several other examples of chloride-induced SCC of austenitic stainless steel components in nuclear applications.

These findings have important implications for welded-closure canisters, since the alloys studied are commonly used to fabricate spent fuel storage canisters, and the deposition of airborne chlorides on canister surfaces may be anticipated at ISFSIs near marine environments or at locations where winter road salting is commonly practiced. In addition, the closure welds, as well as the other fabrication welds in the canisters, produce regions of SCC susceptibility because of the presence of residual stresses and sensitized microstructures in the weld heat-affected zone.

As a result of these findings, the NRC has proposed a research program with industry to determine the minimum conditions for potential initiation of chloride-induced SCC of spent fuel canisters and to determine the time scale in which it may be expected to occur in realistic service environments [19]. Concurrently, the Electric Power Research Institute has developed an R&D roadmap to identify canisters potentially susceptible to SCC [20]. This phenomenon (SCC) has historically not been the subject of NRC review of applications for renewals of license and certificates of compliance of DCSSs, but it has been the subject of some requests for additional information (RAIs) issued since 2012, including RAIs for the license renewal application for the Calvert Cliffs ISFSI [21].

The AMP Welded Canister Seal and Leakage Monitoring Program in the Rev. 0 report consists of examining and/or monitoring the top lid and vent cover welds of the confinement boundary to ensure that timely and appropriate corrective actions can be taken to maintain safe storage conditions of the canister. The program considers SCC induced by chlorides or other species to be the major threat to canister integrity and includes the following site-specific elements:

1. Determine the criteria by which the canister top lid and vent cover welds were designed, fabricated, erected, and tested. Based on the design and fabrication records, establish the stress conditions of the canister welds.

2. Examine the environmental conditions of the used-fuel storage canisters to establish the surface temperature and deposits (e.g., chlorides) on the storage canister welds. If the surface temperatures are below 85 °C (185 °F), indicating that deliquescence of dry salt deposits and subsequent SCC can occur, establish the humidity at the canister surface to determine the likelihood of wet surface conditions for the canister/cask welds. The possibility of moisture being introduced from other sources (e.g., rainwater or cooling tower water intrusion) should also be considered. Evaluate

the susceptibility of the storage canister welds to SCC under the environmental conditions prevalent at the used-fuel storage site.

3. Based on the combination of material and fabrication conditions, applied and residual stress, and wet or moist surface conditions, identify the canister locations prone to potential SCC.

On the basis of the information established in the assessment of canister welds, a site-specific condition monitoring (i.e., inspection) program should be developed to manage the aging effects of cracking of the canister closure welds due to SCC or other degradation processes, including general corrosion and pitting, in an aggressive environment. As a part of the program, the method, extent, and frequency of the inspection program, as well as the sample size and the basis for selection, should be defined. Also, it should be determined whether access to the weld surface would require retrieval of the canister from the storage module or overpack. If remote inspection using a camera and/or fiber-optic technology through openings, such as air inlets and outlets, is proposed, the access path from the vents to the weld surface and the sensitivity and effectiveness of the technique must be demonstrated first on a site-specific basis.

The sample size of storage canisters to be inspected should be based on an assessment of compliance with the guidance in ISG-15 and ISG-18, the environment, the estimated stress state of the weld, the length of time in service, the design configuration, the decay heat load during normal operation, abnormal conditions during service, and operating experience. Canisters that were loaded before the publication of the relevant NRC ISGs (i.e., ISG-5, ISG-15, ISG-18, and ISG-25) should be included in the sample. For ISFSIs in marine environments (i.e., salty air), a larger sample size should be considered to ensure that the sample size is representative of the site environmental and DCSS material, design, and fabrication conditions. This consideration is particularly important if surface conditions are such that salt deposition (a function of surface location and orientation) and deliquescence (T <85 °C [185 °F]) is possible at or near the welds. The inspection interval and the number of canisters inspected should be based on a site-specific engineering assessment of possible crack growth rates for the specific conditions of that canister, not to exceed 20 years.

In situations where managing the effects of cracking is not feasible without significant additional effort, an alternative activity to inspection may rely on monitoring of leakage to ensure timely detection of a breach of the canister confinement boundary to prevent degradation of the contents of the storage canisters. One possible alternative approach is to continuously or periodically monitor the overpack vent outlets by using helium mass spectrometry techniques to detect helium leakage from a breached canister. Alternatively, the vents might be monitored to detect the presence of airborne radioisotopes indicative of canister leakage. The effectiveness and sensitivity of any such alternative monitoring technique must be demonstrated first on a site-specific basis.

Ensuring the integrity of welded canisters also extends back to the proper initial design, fabrication, and leak testing of the welds as well as the exercise of proper precautions during canister loading. NRC ISG-15 provides guidance on proper materials selection, and NRC ISG-18 provides guidance on the design and testing of the canister lid welds. For a welded canister design, the NRC has accepted closure designs employing redundant lids or covers, each with independent field welds. NRC ISG-25 states that all the canister/cask confinement boundary welds are to be inspected and pressure and helium leak tested in accordance with the appropriate articles of the ASME Code Subsection NB or NC and ANSI 14.5. However, helium leak testing is not required for the multipass lid weld, provided the weld is executed and examined in accordance with NRC ISG-15. Precautionary measures should also be taken to prevent contamination of the outer surface of the used fuel assemblies with boric acid during loading to avoid potential interaction of boric acid and the zinc coating applied to the fuel basket [22].

The inspection report for the Calvert Cliffs ISFSI [23] indicates the capabilities and limitations of visual inspection techniques for evaluating the conditions of the ISFSI components. Staff at Calvert Cliffs performed an inspection of the interior of two horizontal storage modules (HSMs) and the exterior of the dry shielded canisters (DSCs) they contained. The visual inspection was conducted by using a remote-controlled, high-definition pan-tilt-zoom camera system with a 100-mm head. A remote inspection was performed by lowering the camera through the rear outlet vent, which allowed for viewing of the majority portion of the DSC, its support structure, and the interior surfaces of the HSM. A direct inspection was performed through the partially open door by mounting the camera on a pole. This allowed for views of the bottom end of the DSC, the seismic restraint, the HSM doorway opening, and the backside of the HSM door. The resolution of the images obtained was not stated. On the upper shell of both casks**,** a thick coat of dust and small clumps of unknown material were observed. Near the outlet vent, there was evidence of water coming in contact with the DSC, apparently from wind-driven rainwater entering the module via the rear outlet vent. The center circumferential weld and longitudinal welds were found to be in good condition, but the bottom shield plug circumferential weld was not accessible. A few small surface rust spots were noted on the DSC shell base metal, and they were attributed to contamination with free iron during fabrication or handling prior to being placed in service.

DISCUSSION

In a recent paper [24] titled “An Aging Management Plan for Spent Fuel Dry Storage and Transportation,” the author discussed many issues associated with an “Aging Management Plan,” which represents a collection of AMPs and TLAAs that are necessary to manage aging effects on the SSCs of DCSSs/ISFSIs so that they can maintain their intended functions for the period of extended storage and post-storage transportation. Use of guidance for justification is one of the issues discussed, and the paper states, “Guidance, in a regulatory sense, is a recommendation of a method to meet a regulation or conduct an evaluation. Guidance is based on knowledge at the time the guidance was developed and may change as new information is obtained. Guidance may be applicable only to a particular time period.” The NRC ISG-18 and ISG-25 are cited as examples that, when combined, are not sufficient as a basis for claiming that no AMP is necessary for Cl-induced SCC of welded canisters. ISG-11 (Rev. 3) is another example cited in the paper, since no confirmation of cladding behavior yet exists for high-burnup fuel during extended storage and transportation. The assessments are correct since all NRC ISGs are “interim” staff guidance that reflect existing knowledge and good practices; they need to be revised to incorporate any significant lessons learned and when new pertinent information becomes available. However, note that ISG-18 and ISG-25, as well as ISG-5, and ISG-15, are included in AMPs IV.M3 and IV.M4 of the Rev. 0 report because they are considered good practices as part of Element 2, Preventive Actions, of these two AMPs.

In an earlier paper [25] on advanced surveillance technologies for extended storage and transportation of used fuel, monitoring the interior conditions of casks and canisters for temperatures of fuel-rod cladding, moisture level, or fission gas release, etc. is identified as a major challenge for development of enabling technologies such as radiation-hardened sensors, in-canister energy harvesting, and data transmission. For welded-closure canisters, direct measurements of interior conditions are very difficult, if not impossible. Condition monitoring of canister surface temperatures continuously by wireless means may be able to detect the loss of helium cover gas, if significant change occurs in the gradient of surface temperatures. One method based on the ARG-US Remote Area Modular Monitoring (RAMM) system [26] has been suggested for future investigation.

Work continued after the Rev. 0 report was published, and the progress made and the interim results are highlighted in a paper [27]. New information also became available after the Rev. 0 report; of particular interest are the NRC and industry initiatives [19, 20] and the ongoing NRC review (and the applicant responses) of license renewal applications for the ISFSIs at Prairie Island [28] and Calvert Cliffs [21] that employ, respectively, the TN-40 bolted-closure casks and NUHOMS welded-closure canisters with overpacks. The renewal application for the Certificate of Compliance of the VSC-24 ventilated storage cask [29] is also of interest, since it pertains to another DCSS design of a welded-closure canister with an overpack. Each of these renewal applications must address aging effects on the SSCs that are important to the safety of the entire DCSS designs, and the two AMPs discussed in this paper focus on managing aging effects on the confinement boundary of the bolted-closure and welded-closure casks and canisters. The AMP IV.M4 for bolted-closure casks and AMP IV.M3 for welded-closure canisters are mutually exclusive because they apply to different DCSS designs. However, these two AMPs alone are not sufficient to manage the aging effects on the SSCs of DCSS designs without the use of other AMPs and TLAAs described in the Rev. 0 report, which is being updated to include all the new pertinent information into the Rev. 1 report. Also added to the Rev. 1 report are three additional DCSS designs for the HI-STAR storage and transport cask, CASTOR V/21 and X/33 dry storage casks, and W150 Fuel*Solutions* storage system. These additions to the Rev. 1 report essentially complete the inclusion of all DCSS designs currently operating in the U.S. under 10 CFR 72.214. The Rev. 1 report will be submitted to DOE on September 30, 2013, for review and comment by stakeholders and members of the Electric Power Research Institute's Extended Storage and Collaboration Program.

CONCLUSIONS

As part of DOE's Used Fuel Disposition Campaign R&D program, researchers at Argonne prepared a report titled *Managing Aging Effects on Dry Cask Storage Systems for Extended Long-Term Storage and Transportation of Used Fuel, Rev. 0.* The report provides recommended AMPs and TLAAs for structural and mechanical components in ISFSIs, including AMPs concerned with confinement boundary integrity and leakage monitoring of bolted-closure casks and welded-closure canisters. The AMP for bolted-closure casks is a program that focuses on leakage monitoring and visual inspection. The leakage monitoring activity provides for continuous monitoring of the pressure between the two seal assemblies or inside the cask cavity. The inspection activity provides for periodic visual inspections of the closure seal components and maintenance of the overpressure leakage monitoring system and associated instrumentation. Because welded-closure canisters do not include provisions for continuous leakage monitoring, the AMP for these components is based on periodic visual inspections to monitor for degradation due to stress corrosion cracking, general corrosion, and pitting. It also includes provisions for evaluating conditions at the surfaces of the canisters (temperature, humidity, and surface deposits) to determine the corrosion susceptibility. When direct or indirect visual inspections are not feasible, alternative monitoring techniques should be considered.

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