Outline of Industry Guidance for Operations-Based Aging Management For Dry Cask Storage NEI 14-03

1.0 PURPOSE

The purpose of the guidance is to augment the 10 CFR 72 license and Certificate of Compliance (CoC) renewal review guidance in NUREG-1927, "Standard Review Plan for Renewal of Spent Fuel Dry Cask Storage System Licenses and Certificates of Compliance," Section 3.0, "Aging Management Review." This guidance is needed because there is currently a limited amount of operational and research data available on age-related degradation mechanisms unique to certain Dry Cask Storage (DCS) structures, systems, and components (SSCs).

Some DCS component age-related degradation mechanisms are well-known and a great deal of information is available from power plant experience (e.g., concrete and bolted connections exposed to the environment). However, some age-related degradation mechanisms, while they may be well-understood from a scientific standpoint, generally lack operating data to predict behavior when extending the storage life of the DCS system.

Furthermore, there may be some DCS component age-related degradation mechanisms that are not yet known due to the relatively short time periods the storage systems have been in service (less than 30 years nationwide). Augmented guidance is needed to guide the development of operations-based Aging Management Reviews (AMRs) and Aging Management Activities (AMAs) for storage systems (i.e., bare fuel casks, transfer casks, canisters, overpacks, and horizontal storage modules) that incorporate future operating experience, research, monitoring, and inspections in a "learning" manner. These factors make it difficult to develop, at the time of the renewal application submittal, Time-Limited Aging Analyses (TLAAs) and Aging Management Programs (AMPs) for all in-scope SSCs that address the maintenance of intended safety functions through the end of the renewed operating period. Two items of particular interest in this regard are High Burnup (HBU) fuel performance and DCS canister integrity with respect to Chloride Induced Stress Corrosion Cracking (CISCC).

2.0 SCOPE

The scope of this effort includes DCS SSCs that address the maintenance of intended safety functions through the end of the renewed operating period. The SNF canister and bare fuel cask pressure boundaries perform the confinement function that must be maintained throughout the renewed operating period. The exterior surfaces and components of canisters, casks, and storage modules clearly fall into the realm of aging management because a) they are subject to ambient environmental conditions and b) they are accessible for inspection to varying degrees

The stored fuel and basket internals are included in the scope of the guidance, but because they are not subject to ambient environmental effects or fatigue cycles, they are addressed in a unique context. See Section 4.3.1.1 for additional discussion.

This augmented guidance also is intended to be applied by the licensee and CoC holder only to the requested first renewed operating period of a maximum of 40 years beyond the initial term of

the license or CoC. Issues pertaining to extended storage beyond the first renewal period are not part of the initial renewal applications and are therefore not specifically addressed in this guidance. Even though some of the issues overlap, the knowledge base and expected level of understanding of these issues should be significantly improved after 40 years of renewed operating life. That knowledge will be used for subsequent renewal activities.

Not included in the scope of this augmented guidance are NUREG-1927, Section 1.0, "General Information Review" and Section 2.0, "Scoping Evaluation." These areas are adequately covered in NUREG-1927 (Reference 1) with additional information provided in Argonne National Laboratory Report FCRD-USED-2013-000294, "Managing Aging Effects on Dry Cask Storage Systems for Extended Long-Term Storage and Transportation of Used Fuel" (Reference 2). Also outside the scope of this augmented guidance is the transportation of spent fuel after storage at an ISFSI. While industry recognizes the linkage of many of the DCS component age-related degradation technical issues to transportation and the requirements in 10 CFR 71, these issues are not directly relevant to renewal of storage licenses and CoC under 10 CFR 72.

3.0 APPROACH

The overall approach of this guidance is to create a framework for integrating feedback from DCS operating experience, research, monitoring, and inspections into the management of age-related degradation for in-scope SSCs at Independent Spent Fuel Storage Installations (ISFSIs). This feedback can affect implementation of any of the three primary steps of an aging management review (Reference 1, Figure A):

1. Materials and Environments
2. Identification of Aging Effects Requiring Management
3. Activities Required to Manage the Effects of Aging
    a. Time-Limited Aging Analyses
    b. Aging Management Programs

Managing age-related degradation (both from known and unknown causes) in a "learning" manner means ISFSI owners would monitor for both the known SSC degradation mechanisms and the symptoms that would be indicators of an unknown SSC degradation mechanism. This guidance is intended to assist licensees and CoC holders in developing and implementing operations-based aging management reviews with the following attributes:

- Safety-focused
- Operations-based
- Implemented within existing corrective action and operating experience programs
- Qualitatively risk-informed based on relevant failure modes and effects
- Forward-looking
- Proactive
- Responsive to condition-based monitoring

The concept of "toll gates" is introduced with this augmented guidance in Section 4.3.4. "Analysis and Assessment (Toll Gates)" are periodic points within the renewed operating period when licensees would be required to document a safety assessment to continue operation to the next toll gate, and ultimately to the end of the renewed operating period. Licensees would be committed to complying with toll gate requirements by the aging management review requirements approved as part of the license or CoC renewal. Compliance with toll gate requirements during the renewal period is an extra layer of assessment beyond the normal continuous assessment of operating experience, research, monitoring, and inspections on DCS component performance that is part of normal ISFSI operations for licensees during the initial license period as well as the renewal period.

4.0 AGING MANAGEMENT REVIEWS

Aging Management Reviews always begin with assessing the materials and service environment for DSC SSCs determined to be in-scope for age-related degradation during the renewed operating period. Identification of known and potential age-related degradation mechanisms applicable to the in-scope SSCs are defined.

4.1 Current Licensing Basis

Section 2.3 of NUREG 1927 states:

> "The NRC bases a license or CoC renewal on the continuation of the existing licensing basis throughout the period of extended operation and on the maintenance of the intended functions of the SSCs important to safety. The NRC does not intend a license or CoC renewal to be a vehicle for imposing new regulatory requirements. If new safety-related deficiencies are discovered, they must be addressed through the license or CoC amendment process. The renewal process cannot be used to facilitate approval of design changes."

Consistent with this guidance, it is important for the licensee or CoC holder who is preparing a renewal application to be aware of and document the current licensing basis upon which the renewal application is based. The licensing basis for renewal excludes physical security and emergency planning (Reference 1, Section 1.2). The licensing basis for renewal includes:

- The current 10 CFR 72 regulations as they apply to license/CoC renewal
- NRC orders that may exist, but not those for physical security, access control, etc.
- The specific license, as amended
- The initial CoC and all approved amendments
- The ISFSI or cask UFSAR, as modified by changes authorized under 10 CFR 72.48 and to reflect approved amendments
- The versions of codes, standards, and guidance specifically committed to in the license, CoC, and UFSAR (e.g., Regulatory Guides, NUREGs, ISGs, ASME Code, ACI Code, ANSI Standards, ASTM Standards, etc.)

License and CoC renewal is not a re-licensing of the ISFSI or cask technology. It is specifically focused on the management of age-related degradation mechanisms required to provide reasonable assurance of safe spent fuel storage through the period of renewed operation (up to 40 years).

4.2 Time-Limited Aging Analyses and Aging Management Programs

Aging Management Reviews for known degradation mechanisms having known (or well-understood) durations will be handled as they have been historically. Appropriate Time-Limited Aging Analyses (TLAAs) and Aging Management Programs (AMPs) should be created as described in NUREG-1927 for these SSCs.

Feedback from DCS operating experience, research, inspection, and monitoring will be used as appropriate to update TLAAs and AMPs based on new information.

4.3 Operations-Based Aging Management

The concept of Operations-Based Aging Management (OBAM) is to manage DCS age-related degradation mechanisms and time frames (duration to loss of intended function) that are either not known or not well-understood. Known and potential age-related degradation mechanisms will be managed using existing corrective action and operating experience programs.

Because some postulated age-related degradation mechanisms and/or timeframes for in-scope DCS SSCs are not characterized by operating data, aging management must be implemented in a manner that feeds information back in a timely fashion to the licensees who operate the ISFSIs. This feedback will be used to perform corrective actions on DCS components to preclude the loss of safety function over the renewed operating period.

OBAMs should include the following attributes for the known and unknown degradation mechanisms and time frames:

- Recognition and Evaluation (Key Technical Issues)
- Canister Inspections
- Monitoring and Operational Inspections
- Analysis and Assessment (Toll Gates)
- Feedback and Corrective Actions (Mitigation/Repair and or Analysis)

4.3.1 Recognition and Evaluation (Key Technical Issues)

A number of stakeholder organizations, including EPRI, DOE, and the NRC have embarked on efforts to identify areas where technical information is currently lacking for DCS age-related degradation mechanisms. These so-called “gaps” in technical information are being identified in various reports, including the DOE Aging Management Effects Report, the High Burnup Dry

Storage Cask Research and Development Project[1] and EPRI's Extended Storage Collaboration Program (ESCP).

The mission of EPRI ESCP and technical needs for extended storage of spent nuclear fuel are summarized in Reference 7. ESCP is comprised of the following subcommittees:

- Fuel/Internals
- Marine Environment
- Non-Destructive Examination
- Concrete
- High Burnup Demonstration Project
- International

To date, ESCP has issued reports such as DCS Failure Modes and Effects Analysis (Reference 5) and the international DCS gap analysis report (Reference 6).

SECY-13-0057 (Reference 3) and the NRC's draft report on technical issues pertaining to extended storage and transportation (Reference 4) identify several material degradation processes for which "the level of knowledge is relatively low (i.e., for which operating experience is limited and other supporting information is still in technical development)." Reference 3 identifies two tiers of technical information for further investigation, the first tier being higher priority. The first tier issues are:

1. Stress corrosion cracking of austenitic stainless-steel canisters and welds
2. Swelling of fuel pellets over time, including fuel fragmentation and potential gas release
3. More realistic models for thermal evolution [evaluation] of storage components and SNF over time
4. Effects of residual moisture after drying
5. Inservice monitoring methods for storage systems, structures, and components

The items in the second tier for further investigation are:

1. Propagation of existing flaws in cladding
2. Impacts to fuel-assembly hardware from wet corrosion, stress corrosion cracking, and metal fatigue
3. Metal fatigue of cladding caused by temperature fluctuations, stress corrosion cracking, and delayed hydride cracking
4. Low-temperature creep and galvanic corrosion of cladding
5. Microbiologically influenced corrosion of stainless-steel, carbon-steel, and cast-iron body, welds, lids, and seals

[1] The High Burnup Demonstration is an EPRI-managed, DOE-funded project being implemented at the Dominion Energy North Anna ISFSI.

6. Embrittlement of fuel-basket welds at low temperature, and metal fatigue caused by temperature fluctuations
7. Thermal aging and creep of neutron absorbers
8. Concrete degradation, particularly for less-accessible components

The above lists are representative of the NRC staff's state of knowledge on extended storage and transportation at the time of this writing. They are being used by the NRC to direct research activities and evaluate the potential need for adjusting the regulatory framework with respect to extended storage (including beyond the initial 40-year renewal) and subsequent transportation. They are not necessarily all-inclusive lists nor are all of the items listed relevant to renewal activities for a 40-year renewed operating period. That is, some issues could turn out to be inconsequential and some could be relevant only for longer operating periods (i.e., greater than 60 years). Thus, it is the responsibility of the Part 72 licensees and CoC holders to identify the age-related degradation mechanisms that could affect the ability of in-scope SSCs to perform their intended storage safety functions through the renewal period of storage operation. Furthermore, fuel and internals are not subject to aging management in the traditional sense. See Section 4.3.1.1 for additional discussion.

Specific licensees address only age-related degradation mechanisms applicable to the particular ISFSI site. CoC holders, on the other hand, address age-related degradation mechanisms that could affect the in-scope SSCs wherever the storage system may be used. The aging management reviews for CoC renewals must be devised to permit the licensee users to identify which of the identified age-related degradation mechanisms apply at their particular site and how those mechanisms will be managed to avoid the loss of safety function over the renewed operating period.

4.3.1.1 Fuel, Cask Internals, and Aging Management

The SNF canister and bare fuel cask pressure boundaries perform the confinement function that must be maintained throughout the renewed operating period. The exterior surfaces and components of canisters, casks, and storage modules clearly fall into the realm of aging management because a) they are subject to ambient environmental conditions and b) they are accessible for inspection to varying degrees. It is understood that yet-to-be developed tools or techniques may be required to perform inspections of canister exterior surfaces, including welds. The fuel assemblies and cask internals do not have a confinement function. However, there are regulatory requirements that must be met by the fuel and internals through the renewed operating cycle. In particular, the fuel assemblies must be retrievable, fuel cladding must not undergo gross rupture unless it is canned, and the basket structure (including neutron absorber panels) must maintain its ability to perform its structural, criticality control, and all other design functions credited in the cask safety analysis.

The materials inside the casks, including the SNF, non-fuel hardware, and the internals of the canister or bare fuel cask cannot be inspected in-situ due to radiation levels and accessibility (i.e., seal-welded canisters). The materials inside the casks are carefully processed in preparation for

dry storage, including a final backfill to establish an inert gas environment (typically helium) in the fuel cavity. Dry storage system designs require maintaining the inert gas environment indefinitely so that these internal components will not become subject to known age-related degradation mechanisms during the storage interval. Because these materials are generally inaccessible, a demonstration project was conducted that provides the basis for ensuring that the internals are not degrading to unacceptable levels during the extended storage period (Reference. 9). This demonstration project, however, used lower burnup fuel and could not be used to address higher levels of burnup for fuel now being moved to dry storage.

Potential age-related degradation mechanisms have been postulated that could degrade the performance of fuel and other internals of dry storage casks during extended renewal periods (e.g., hydrogen embrittlement of fuel cladding at higher burnup levels, the effect of residual moisture after drying on cask internals). The information needed to evaluate these potential mechanisms and whether they could impact cask internals, however, contains several gaps. Activities are underway to provide information to fill in gaps but in some cases, they will take several years to complete. The high-burnup demonstration program is one such activity that will be used to verify that high burnup fuels can continue to be safely stored in dry cask systems for extended storage intervals. In cases where gaps in knowledge exist and those gaps cannot be addressed prior to the start of a renewed storage period, a toll gate as described in Section 4.3.4 will need to be introduced to ensure analysis and assessment of licensed storage systems are conducted once that information becomes available.

4.3.2 Canister Inspections

Reference 1, Appendix E, "Component-Specific Aging Management" states "This [lead canister] inspection is expected to be performed before submittal of the license renewal application." It seems clear from the language of NUREG-1927 referring to "license renewal application" that this guidance was written for specific licensee who control all aspects of their Part 72 license and have the direct authority of activities at the ISFSI to perform lead canister inspections (LCIs) they deem necessary to support the license renewal application.

CoC holders, on the other hand, do not have the authority to require that any general licensee performs LCIs, nor do the Part 72 regulations require general licensees to perform LCIs as part of CoC renewal. Thus, CoC holders need to develop a strategy as part of their CoC renewal application that addresses the subject of canister inspections in the aging management portion of the renewed CoC. Once the CoC (and therefore, the general licenses for those using that cask design) is renewed, those inspections become conditions of the renewed general license for those casks.

Add suggested revisions to NUREG-1927, Appendix E here.

4.3.3 Monitoring and Operational Inspections

The concept of operations-based aging management recognizes that there may be potential unknown age-related degradation mechanisms due to the lack of inspection data. By definition, these degradation mechanisms are not attributable to a particular SSC. Therefore, in addition to monitoring and inspection of SSCs with known degradation mechanisms, key variables should be monitored such that, if a change is detected in the variable, it could indicate a potential degraded safety function.

Licensees and CoC holders should also develop appropriate environmental monitoring, such as atmospheric monitoring, that can be used to compare site-specific DCS service conditions to susceptibility criteria to be used for aging management program implementation. Different site-specific environments can mean different age-related degradation mechanisms and different time frames for degradation to affect DCS safety functions. This information would be used in aging management to determine the frequency of inspections and corrective actions.

Using existing industry standards is desirable for monitoring and inspection techniques, frequency, and acceptance criteria. For example, ASME Section XI is one resource that the NRC has accepted for such activities in Part 50 power plants. Other consensus bodies such as the American National Standards Institute (ANSI), American Society for Testing and Materials (ASTM), and the American Concrete Institute (ACI) also produce standards for monitoring and inspection that may be used as appropriate for the age-related degradation mechanism or variable being monitored or inspected.

4.3.4 Analysis and Assessments (Toll Gates)

Operations-based aging management has, at its core, the requirement for collecting continuous feedback in the form of operating experience, LCIs, monitoring, and research. Feedback that could affect the ability of an SSC to perform its intended storage safety function for the duration of the renewed period of operation would generally be handled via the licensee's corrective action program. In addition, confirmatory data showing positive results such as non-active degradation mechanisms or longer durations for the progression of known degradation mechanisms will also be recognized and assessed at the toll gates. This is not a new concept and is simply a continuation of practices that were used during the initial license term. Fundamentally, the toll gate concept provides a structured way for industry to pause and formally assess aggregate information at specific points in time and also allow the NRC to see the state of DCS aging in real time across the spectrum of DCS technologies and ISFSI environments.

This guidance introduces the concept of "toll gates" to be included in any operations-based aging management review. Toll gates are commitments, implemented by both specific and general licensees to formally evaluate the aggregate feedback at points in time during the renewed operating period and perform a safety assessment that confirms the safe storage of spent fuel

until the next toll gate is reached. The impact of the aggregate feedback should be assessed and actions taken when warranted, such as:

- Perform repairs or replacements
- Modify TLAAs and/or AMPs
- Adjust age-related degradation monitoring and inspection programs (e.g., scope, frequency)

The toll gate concept amplifies the existing licensee practice of continuously evaluating site-specific and industrywide DCS operational experience for impacts on one's own DCS aging management program. Toll gates are defined by the licensee or CoC holder at points in the renewed operating period defined either by time frame (e.g., every X years) or by research milestone (e.g., publication of CISCC susceptibility criteria). To proceed through a toll gate, the licensee must perform an assessment of operating experience and research findings to confirm the continued safe storage of the spent fuel until the next toll gate is approached. The toll gate is also a formal opportunity for the licensee and/or CoC holder to make adjustments to TLAAs, AMPs, and any other monitoring or inspection programs in place to support DCS operations through the renewed operating period. Licensees would also be expected to share this information with each other and with the designer of the dry cask storage system to factor into future designs and/or future aging management submittals (e.g., for the second license or CoC renewal).

4.3.5 Feedback and Corrective Action (Mitigation, Repair, and/or Analysis)

Feedback received during the renewed operating period from OE, research, monitoring, inspection, and toll gate assessments should be processed through the licensee's OE and corrective action programs, as appropriate. Licensee's will determine appropriate corrective actions, including mitigative, preventive, and analysis options to assure continued safe operation through the remaining years of the renewed operating period. In addition, changes to aging management activities as a result of feedback or toll gate assessment made at licensee sites should be shared with the cask vendor for consideration of generic applicability.

4.4 Reporting

Operations-based aging management activities should include thresholds or criteria for new information and monitoring or inspection results pertaining to age-related degradation to be reported to the NRC at the time they occur.

4.5 Records

Age-related degradation information collected by licensees from monitoring, inspections, toll gate assessments, and research should be maintained as plant records. Licensees, cask users groups, and cask designers should devise a method to share this information efficiently.

5.0 IMPLEMENTATION

5.1 Specific Licenses

The Part 72 specific license is owned by the licensee and pertains only to the ISFSI at that licensee's site. Implementation of license renewal requirements, including aging management activities will have a strong parallel to implementing operating plant aging management activities. In the case of specific licenses, the licensee owns the TLAAs and AMPs, and can set up appropriate controls for revising them as information is returned from OE, research, monitoring and inspection activities during the renewal period.

5.2 General Licenses

The Part 72 general license involves two regulated entities, namely the CoC holder and the general licensee. The CoC holder is responsible for renewing the CoC, including defining generic requirements for ensuring the cask will perform as designed through the renewed operating period. Once a renewed CoC is approved by the NRC, the general licenses for the casks operated under that CoC are also renewed. General licensees are responsible for implementing the requirements, including AMPs, for each cask once the cask has been in service for its initial license term. For example, a general licensee may have deployed casks at their ISFSI over several years in accordance with a single CoC. At a minimum aging management requirements must be implemented by the general licensee for each cask at the ISFSI as it begins its renewed operating period (typically after 20 or 40 years) and for the ISFSI as a whole. Licensees could choose to implement aging management for casks not yet through the initial operating term, but they are not required to do so.

Once the first cask at a general license ISFSI is in the renewed operating period, the aging management activities and other requirements applicable to the renewed CoC apply. Given the dual-entity nature of the general license, the CoC holder needs to carefully consider the appropriate level of detail and use precise wording in the licensing documents for the generic aging management activities they create. Implementation details should be appropriately segregated between generic requirements and those to be determined by each general licensee based on site-specific conditions.

In an operations-based aging management scheme, it is expected that information obtained from operating experience, research, inspection, and monitoring during the renewal period, particularly at the toll gates, may prompt changes, deletions, or additions to the AMAs. Therefore, the CoC holder should allow the flexibility for licensees and themselves to modify the AMAs in the cask UFSAR by keeping the AMA information in the CoC (and subject to NRC change control) limited to programmatic descriptions including key elements of those programs (i.e., toll gates must be established).

Both CoC holders and general licensees would have the ability to modify the AMAs in the UFSAR under the provisions of 10 CFR 72.48. Any change to an AMA by either entity should

be shared among all general licensee users of that cask design for consideration of the same change being made by other licensees or generically by the CoC holder.

5.3 Implementation Guidance

Insert guidance pertaining to the applicability and use of NEI 03-08 (Reference 8).

6.0 REFERENCES

1. *Standard Review Plan for Renewal of Spent Fuel Dry Cask Storage System Licenses and Certificates of Compliance*, NUREG-1927, March, 2011.

2. *Managing Aging Effects on Dry Cask Storage Systems for Extended Long-Term Storage and Transportation of Used Fuel*, Report No. FCRD-USED-2013-000294, U.S. Department of Energy, Used Fuel Disposition Campaign, Revision 1, September, 2013.

3. *Annual Status Report: Activities Related to Extended Storage and Transportation*, USNRC, SECY-13-0057, dated May 31, 2013.

4. *Identification and Prioritization of the Technical Information Needs Affecting Potential Regulation of Extended and Transportation of Spent Nuclear Fuel*, USNRC, Draft Report, dated May, 2012.

5. *Failure Modes and Effects Analysis (FMEA) of Welded Stainless Steel Canisters for Dry Cask Storage Systems*, Electric Power Research Institute Technical Report 3002000815, December 2013.

6. *International Perspectives on Technical Data Gaps Associated with Extended Storage and Transportation of Used Nuclear Fuel,* Electric Power Research Institute Extended Storage Collaboration Program International Subcommittee Report 1026481, November 2012.

7. *Needs for Extending Dry Storage of Spent Nuclear Fuel*, K. Waldrop and J. Kessler, Electric Power Research Institute, paper for the 2012 International Youth Nuclear Congress.

8. *NEI 03-08, Guideline for the Management of Material Issues*, Nuclear Energy Institute, Revision 1, January 2010.

9. *Examination of Spent Fuel Rods after 15 Years in Dry Storage*, NUREG CR-6831, U.S. Nuclear Regulatory Commission, September. 2003