How Did the United States Get to the Point of Renewing Nuclear Power Plant Operating Licenses to 80 Years?

Allen L. Hiser, Jr.

U. S. Nuclear Regulatory Commission
Division of New and Renewed Licenses
Washington, DC

Abstract. The approach used in the United States for license renewal (plant operation to 60 years) and subsequent license renewal (plant operation to 80 years) is focused on managing the effects of aging that can impede the function of certain systems, structures and components determined to be important to the safe operation of nuclear power plants. This limited scope review, when compared to the Periodic Safety Review of the International Atomic Energy Agency, is sufficient because it is implemented within a structured and robust regulatory framework that includes regulatory process "essential elements" that synergize to ensure continued safe plant operation.

License renewal in the U.S. relies on guidance documents, including the Generic Aging Lessons Learned or GALL Report and the Standard Review Plan for License Renewal (SRP-LR). These documents have been updated multiple times since their initial issuance in 2001, and additional versions, GALL-SLR and SRP-SLR, were developed to apply to an 80-year operating period for subsequent license renewal.

This paper discusses the development and evolution of these documents, using lessons learned from plant operating experience and application reviews, and provides lessons learned from the review of applications for subsequent license renewal.

1. Background

In accordance with Section 103c of the Atomic Energy Act (AEA) of 1954, as amended, nuclear power plants in the United States (U.S.) are licensed for a term not exceeding 40 years, and these licenses may be renewed. This original 40-year license term for reactor licenses was based on economic and antitrust considerations – not on limitations of nuclear technology. Due to this selected period, however, some structures and components (SCs) may have been engineered on the basis of an expected 40-year service life.

The U.S. Nuclear Regulatory Commission (NRC's) regulations related to renewal of operating licenses for nuclear power plants are provided in Part 54 of Title 10 of the *Code of Federal Regulations* (10 CFR Part 54) [1]. 10 CFR 54.31(b) specifies that licenses may be renewed for a specified additional operating period not to exceed 20 years, and the term of the renewed license (the remaining operating time from the prior license and the additional renewed operating term) may not exceed a total of 40 years. In addition, 10 CFR 54.31(d) states that a renewed license may be subsequently renewed in accordance with all applicable requirements, with no explicit limit to the number of "subsequent" renewals for each license.

License renewal is focused on aging management of long-lived, passive structures and components in nuclear power plants that may not be adequately addressed under the existing maintenance framework, including the reactor pressure vessel, steam generators, piping, seismic Category I structures, electrical cables and connections, among others. Items not included in the scope of license renewal are those that are active, such that their failure will be identified during surveillance and testing, or replaced on a fixed schedule. The scope of license renewal includes (1) safety-related systems, structures, and components (SSCs); (2) all nonsafety-related SSCs whose failure could adversely impact functionality of safety-

related SSCs; and (3) all SSCs relied on in certain safety analyses or plant evaluations for specific NRC regulations.

The fundamental principles that provide the basis for the limited scope of the NRC license renewal process are:

- The ongoing regulatory process used to regulate plants is adequate to ensure the safety of operating plants in the license renewal operating period.
- The plant's current licensing basis (CLB) is maintained during the renewal term.
  - The one change is that the CLB requires additional actions for aging management of passive, long-lived plant structures and components for license renewal.

The Standards for issuance of a renewed license (10 CFR 54.29) specifies that there is "reasonable assurance that the activities authorized by the renewed license will continue to be conducted in accordance with the current licensing basis." This section describes three specific areas for the review:

- Managing the effects of aging during the period of extended operation on the functionality of in-scope long-lived, passive structures and components
- Time-limited aging analyses (TLAAs)
- Satisfy requirements for environmental review

This paper provides an update on a paper from the 2017 PLiM conference [2].

2. License Renewal Early History

With the receipt of the initial license renewal applications (LRAs) in 1998, there was a clear recognition that existing programs (such as the inservice inspection, water chemistry, and environmental qualification programs) frequently form the major portion of the aging management activities for certain structures and components proposed by applicants for license renewal. Although these programs are effective to manage the effects of aging for the first 40 years of plant operation, their adequacy for a 60-year operating period had to be determined, along with the situations where the programs needed to be augmented to address age-related degradation. In addition, it was understood that the scope of existing programs was unlikely to be adequate and provisions for development of new aging management programs (AMPs) was necessary.

In June 1999, the NRC staff prepared a paper for the Commissioners [3], to gain guidance for several proposals to increase the efficiency of the license renewal review process. In response to this paper [4], the Commission stated that the NRC staff should:

- Proceed with the development of the Generic Aging Lessons Learned (GALL) Report, the Standard Review Plan (SRP), and a Regulatory Guide
- Ensure that regulatory guidance is clear and understandable to stakeholders so that the license renewal process is stable and predictable for future applicants.
- Seek stakeholders' participation in the development of guidance
- Update guidance, as appropriate, to capture the additional lessons learned and improve the license renewal process.

3. License Renewal Guidance Documents – Operation for 60 Years

The NRC developed several documents to aid in effective and efficient evaluation of LRAs, including the Generic Aging Lessons Learned Report (GALL) report (NUREG-1801) [5] and the Standard Review Plan for Review of License Renewal Applications for Nuclear Power Plants (SRP-LR, NUREG-1800) [6]. The NRC also developed Regulatory Guide (RG) 1.188, entitled "Standard Format and Content for Applications to Renew Nuclear Power Plant Operating Licenses" [7].

The process used to develop and finalize these documents and other NRC guidance documents and regulations involves several steps: (1) development of "for comment" versions of the document, usually with public meetings or workshops to gain external stakeholder views, (2) issuance of the document for public comment, which includes not just U.S. industry and the general public but can also include comments from other countries, (3) review of the public comments, incorporation of revisions to the document, preparation of a report that provides responses to the public comments, and (usually) completion of a technical basis report for the revised document, and (4) issuance of the final document for use, along with the report(s) on public comment responses and technical basis.

The GALL Report provides generic assessments for aging management review (AMR), including identification of materials, environments and applicable aging effects for structures or components that are typically in the scope of license renewal for plants and are passive and long-lived. For each aging effect requiring management, the GALL Report identifies acceptable AMPs that are believed to be acceptable on a generic basis, and describes these AMPs using ten elements that characterize the AMP. Applicants may propose plant-specific alternatives should they choose. In all cases, applicants must be able to demonstrate that either the GALL Program is acceptable based on plant consistency with the operating conditions and operating experience (OE) assumed in the GALL Report, or the plant-specific program is adequate. To ensure consistent use of the GALL Report, definitions are provided for structures and components, materials, environments, aging effects, and significant aging effects and mechanisms. In certain cases where a universal generic approach cannot be defined, the GALL Report identifies "Further Evaluation," which is linked to specific provisions of the SRP-LR for plant-specific evaluation by the staff, based on additional information provided in the LRA. Note that the GALL Report is a generic document that does not provide a comprehensive scoping and screening (screening identifies the in-scope SCs that are passive and long-lived) basis; scoping and screening are based on a plant-specific review that is performed in accordance with 10 CFR Part 54 by the applicant.

The SRP-LR assures the quality and consistency of staff reviews and presents a well-defined technical basis from which to evaluate a licensee's application. Availability of the SRP-LR aids in the transparency of NRC staff reviews of LRAs such that applicants can understand the types and detail of information needed by the staff for its reviews. The SRP-LR provides guidance for staff review of scoping and screening, AMR, TLAAs, and Updated Final Safety Analyses Report (UFSAR) supplement descriptions of AMPs and TLAAs. The SRP-LR also defines the contents of each of the ten elements used to describe plant-specific AMPs.

Although the GALL Report and the SRP-LR have undergone full-scale revisions in 2005 and 2010, intermediate changes to the guidance to address OE have been implemented through the License Renewal Interim Staff Guidance (LR-ISG) process. LR-ISGs modify specific portions of the guidance using a public comment process to ensure public input. Once issued as final, the revised text in an LR-ISG represents a change to the guidance in the GALL Report and/or SRP-LR.

When revisions to the documents are completed, applicants with an LRA under review (e.g., based on the prior revision of the documents) have been queried on the applicability of the new OE addressed in the latest revision and how their programs account for this new OE.

RG 1.188 [7] endorses Nuclear Energy Institute (NEI) guidance NEI 95-10, “Industry Guideline for Implementing the Requirements of 10 CFR Part 54 –The License Renewal Rule” [8]. This document provides a standard format of LRA and includes guidance on applicants’ procedures for scoping and screening, identifying aging effects, developing AMPs and evaluating TLAAs. NRC endorsement of NEI 95-10 came after extensive interactions between the NRC and the industry to ensure the adequacy of the document.

The development of the GALL Report enabled significant efficiencies in the development of LRAs and in the NRC staff review of them. Specifically, the designation by an applicant of an AMP as “consistent with GALL” results in a truncated description of the AMP in the LRA, with a short description of the AMP, identification of any enhancements or exceptions to the GALL AMP, and description of applicable OE related to the AMP. In contrast, a plant-specific AMP has a complete description of all 10 program elements provided in the LRA. For the programs submitted in the LRA that the applicant claims are consistent with the GALL Report, the NRC staff verifies that the applicant’s programs are consistent with those described in the GALL Report and/or with plant conditions and OE during the performance of an AMP audit (to review undocketed program basis documents) and review. The focus of the balance of the NRC staff review of an LRA is on those programs that an applicant has enhanced to be consistent with the GALL Report, those programs for which the applicant has taken an exception to the program described in the GALL Report, and plant-specific programs not described in the GALL Report.

Exceptions are identified for those portions of the GALL Report AMP that the applicant does not intend to implement. Enhancements are revisions or additions to existing AMPs or implementing procedures that the applicant commits to implement prior to the period of extended operation. Enhancements include, but are not limited to, those activities needed to ensure consistency with the GALL Report AMP.

Pre-GALL

Prior to the issuance of the license renewal guidance documents, LRAs were provided on a plant-specific basis, using evaluative reports from the Nuclear Utility Management and Resources Council (NUMARC, a predecessor of NEI), owners’ group and vendor reports, and reports from the Electric Power Research Institute (EPRI). NRC review of these applications was based on a variety of technical basis documents, as described in more detail in [9]. LRAs for 8 reactor units were prepared “pre-GALL.”

Initial Versions - Revision 0

The initial versions of the license renewal guidance documents were issued in July 2001. These documents were preceded by a number of reports and activities, as described in detail in [9]. The contents of these documents were based on extensive NRC research results, industry technical reports, plant OE, NRC generic communications, LRAs and NRC staff LRA review experience.

The GALL Report was designated as NUREG-1801 [5], and the SRP-LR [6] was designated at NUREG-1800. RG 1.188 [7] endorsed NEI 95-10, Revision 3, [8] in part based on the results provided in [10]. Along with these documents, the NRC issued NUREG-1739, which presented an analysis of stakeholder comments on the guidance [11].

LRAs for 40 reactor units were prepared using GALL, Revision 0.

Revision 1

The process to revise the license renewal guidance documents began in 2002, following the issuance of 26 renewed licenses. The focus of Revision 1 of the GALL Report (NUREG-1801, Rev. 1) [12] was on improvements to the AMR guidance to consolidate them and make them less prescriptive, and included implementation of reformatting and corrections. Revision 1 also included some AMP revisions, and a new chapter on definitions

to standardize terms for structures/components, materials, environments, aging effects, and degradation mechanisms.

Revision 1 of the GALL Report and the SRP-LR [13] incorporated approved LR-ISGs, domestic and foreign OE since the issuance of the initial documents, information from relevant generic communications, and lessons learned from applications and staff evaluations. These revisions were issued in September 2005.

Along with Revision 1 of the documents, the NRC also issued NUREG-1832 [14] and NUREG-1833 [15] as supporting documents to provide the basis for the revisions and to address public comments.

Revision 1 to RG 1.188 [16] was issued in September 2005 to endorse Revision 6 of NEI 95-10 [17].

LRAs for 27 reactor units were prepared using GALL, Revision 1.

Revision 2

The development of Revision 2 of the documents began in 2009. This revision focused on improving the content of AMPs, including changes to the SRP-LR 10-element template for AMPs and updating the AMPs for consistency with this template. Revision 2 of the GALL Report [18] and the SRP-LR [19] were issued in December 2010; RG 1.188 was not revised at this time. The NRC also issued NUREG-1950 [20] as a supporting document to provide the basis for the revisions and to address public comments.

LRAs for 21 reactor units were prepared using the GALL Report, Revision 2. LRAs for four more reactor units are planned by the operators, and two reactor units are not scheduled. Because of the limited number of remaining applications for license renewal, a further revision of the GALL Report and the SRP-LR are unlikely, and Revision 2 plus all current and future LR-ISGs [21] will provide the staff guidance for renewal of operating licenses to address 60 years of plant operation. However, relevant OE that occurred since these documents were issued is expected to be addressed in the LRAs.

4. Subsequent License Renewal – Operation for 80 Years

Revision 0

Considering guidance to address plant operation for 80 years is significantly different from making routine revisions to the license renewal guidance documents for plant operation to 60 years. Of particular concern is the identification of potential aging issues that may arise with the extended operating time and greater exposure levels, such as neutron fluence levels. This could include potential new aging degradation phenomena either in new locations from that where it would be expected to occur, different forms of degradation, or greater severity than expected from past OE. The degradation could be from known mechanisms that could become more active, due to either exceeding incubation times or activation energies, or the development of “late blooming phases,” or potentially new phenomena not previously seen.

To address the potential for new aging phenomena, the NRC implemented an expert elicitation using a modified phenomena identification and ranking table (PIRT) process, in conjunction with the U.S. Department of Energy, to identify the issues that may be of concern for 80 years of operation, termed the “Expanded Materials Degradation Assessment” (EMDA). The results from the EMDA [22] were among the key inputs used by the NRC in developing the guidance for SLR. The PIRT process is described in Volume 1 [22].

A second key input was the results from AMP effectiveness audits conducted at one BWR and two PWRs [23, 24]. These audits reviewed the results from both one-time and periodic AMPs to assess the findings from the programs, including any findings of unanticipated or expected degradation found, or to confirm no degradation. Of particular interest were any

accessibility issues, the adequacy of the inspection methods, and any conclusions from AMP trending information.

In addition to these two sources, information from relevant domestic and foreign OE from 2010 to 2017, internal and external stakeholder comments, lessons learned from LRAs and NRC reviews of LRAs, and LR-ISGs since issuance of Revision 2 were compiled in a database for consideration by internal NRC panels. These panels utilized the GALL Report, Revision 2, and the SRP-LR, Revision 2, as amended by the LR-ISGs, and this database information to develop the "Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report" (NUREG-2191) [25] and the "Standard Review Plan for Review of Subsequent License Renewal Applications for Nuclear Power Plants" (SRP-SLR) [26] as NUREG-2192. These documents were issued in July 2017. The NRC also issued Revision 2 of RG 1.188 [27] to endorse NEI guidance specific to SLR applications [28]. Separate documents on "Technical Basis" [29] and "Resolution of Public Comments" [30] were issued in December 2017. More recently, Subsequent License Renewal Interim Staff Guidance (SLR-ISG) has been issued in four areas [21].

Six units have been approved for operation to 80 years, although four of these licenses have had the expiration date of their subsequent renewed licenses reset to 60 years due to Commission orders related to the environmental review for those units. The Commission's direction will hold until the NRC staff completes its re-evaluation of generic environmental issues for subsequent license renewal. In addition, reviews of subsequent license renewal applications (SLRAs) have been completed for another four units and are on-going for five units. Applications for five units are expected in 2023.

Planned Revision 1

The NRC has historically issued revisions of its license renewal guidance documents on an approximate 5-year basis, when sufficient additional OE, application review experience, increase in state of knowledge and revisions to supporting industry and NRC documents have accrued to warrant revisions. With the issuance of GALL-SLR and SRP-SLR in 2017, the NRC previously began interim modifications to the documents through the issuance of SLR-ISGs [21]. The NRC has recently begun an activity for a revision of GALL-SLR and SRP-SLR, with plans to issue proposed revised documents for public comment in the summer of 2023 and final revised documents by the end of 2024 [31].

This revision is not planned to be a comprehensive review of each document, focusing on recommendations by NRC staff and members of the public and industry identified in multiple public meetings. Changes to the documents will be based on the following criteria:

- Updates to revised and new guidance
    - Industry guidance, including codes and standards
    - Plant OE
    - Results from research reports
    - Technical revisions (lessons learned) identified from previous SLRA reviews
- Substantive editorial corrections
- Incorporate completed SLR-ISGs that have been issued since the initial GALL-SLR documents

5. Status of License Renewal and Subsequent License Renewal

The number of operating reactors has decreased significantly since 2017 [2], when the U.S. had 99 operating reactors; today there are 92.

As of the end of September 2022, licenses have been renewed for operation to 60 years for a total of 94 nuclear power plant units in the U.S., although ten of those units have since shut down permanently (one unit of these ten ceased operation before reaching 40 years of operation). Of the 92 units that are currently in operation, 78 units have renewed licenses to operate for 60 years. Of eight units operating under their original 40-year licenses, four reactor units have indicated that they will apply for license renewal by early 2024.

Subsequent license renewal has also been very active. As described previously, six units have been approved for operation to 80 years, reviews of SLRAs have been completed for another four units and are on-going for five units. Applications for five reactor units are expected in 2023.

6. Summary

The U.S. license renewal program is a mature program that has successfully evaluated and renewed licenses for 94 units for operation to 60 years and 6 of the renewed licenses have been subsequently renewed for operation to 80 years. The use of guidance documents, in particular the GALL Report and the SRP-LR, has been a key part of an efficient, consistent and predictable license renewal process. Incremental changes to these documents are made through the interim staff guidance process, pending the implementation of broader document revisions. Guidance document revisions for license renewal have focused on incorporating LR-ISGs and SLR-ISGs, new domestic and foreign OE, lessons learned from LRA reviews, and changes to NRC regulations and codes and standards.

Because of the few plants that require initial renewed licenses, Revision 2 of the GALL Report and the SRP-LR as amended by LR-ISGs represent the final guidance for 40–60-year license renewal. However, relevant OE that occurred since these documents were issued is expected to be addressed in the LRAs.

To address subsequent license renewal plant operation for 80 years, the NRC has issued guidance documents for 80 years, specifically the GALL-SLR Report and the SRP-SLR. An on-going activity will result in the issuance of revision 1 of these documents.

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