TOPIC:

Long Term Benefits of Life Extension for U.S. Nuclear Power Reactors

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Abstract. This paper will demonstrate the long-term economic and environmental benefits of extending the operation of the U.S.'s nuclear reactors to 80 years , and will provide perspective from those U.S. utilities that intend to pursue second license renewal (SLR.) While nuclear power plants require significant capital investment, they are the largest and most reliable emission-free source of electricity. Federal law and regulations governing the safety of U.S. nuclear reactors allow for extensions of the initial 40-year operating license in 20-year increments, putting the current operating lifetime of a U.S. nuclear power plant at 60 years. Extending the life of operating reactors in the U.S. through SLR makes economic and environmental sense for consumers, communities and the utilities that operate these facilities. America's evolving electricity marketplace is faced with growing requirements for baseload reliability and mandates for low-carbon electricity production, placing a high premium on preserving existing nuclear generating capacity and ensuring nuclear energy maintains its current 20 percent share of U.S. electricity supply. In 2013, electricity production from U.S. nuclear power plants was about 790 billion kilowatt-hours and nearly 20 percent of America's electricity supply. Over the past 20 years, America's nuclear power plants have increased output and improved performance significantly. Since 1990, the nuclear industry has increased total output equivalent to that of 26 large power plants, when in fact only five new nuclear power plants have been brought on line. But by 2030, the U.S. could experience electricity shortages if a significant number of nuclear plants are retired. By 2040, half of the U.S.'s nuclear power plants will have been operating for 60 years. Electrical utilities in the U.S. must begin planning either to continue operating these plants or to develop new sources of electric generation and decommission the reactors.

1. Introduction

In the mid-1990's, the U.S. Nuclear Regulatory Commission (NRC) finalized a rule in 10 CFR Part 54 to define the regulatory process for renewing the operating licenses of nuclear power plants. This rule allowed nuclear plant owners to extend the original 40-year licenses in 20 year increments. The first license renewal applications were submitted to the NRC in 1998, but the U.S. nuclear industry remained skeptical that this process would be practical. This was due to the previous experiences with the original NRC licensing process (Part 50) that resulted in protracted and unpredictable outcomes from the 1970s through the 1990s. [1]

In early 2000, the NRC approved the first renewals, for the two-unit Calvert Cliffs and the three-unit Oconee nuclear power plants. Both of these reviews were completed by the NRC in a timely, predictable, and stable manner. This regulatory success, combined with significant improvements in safety and economic performance of U.S. nuclear power plants, led to a steady stream of license renewal applications that continues today, as shown in Figure 1 below.

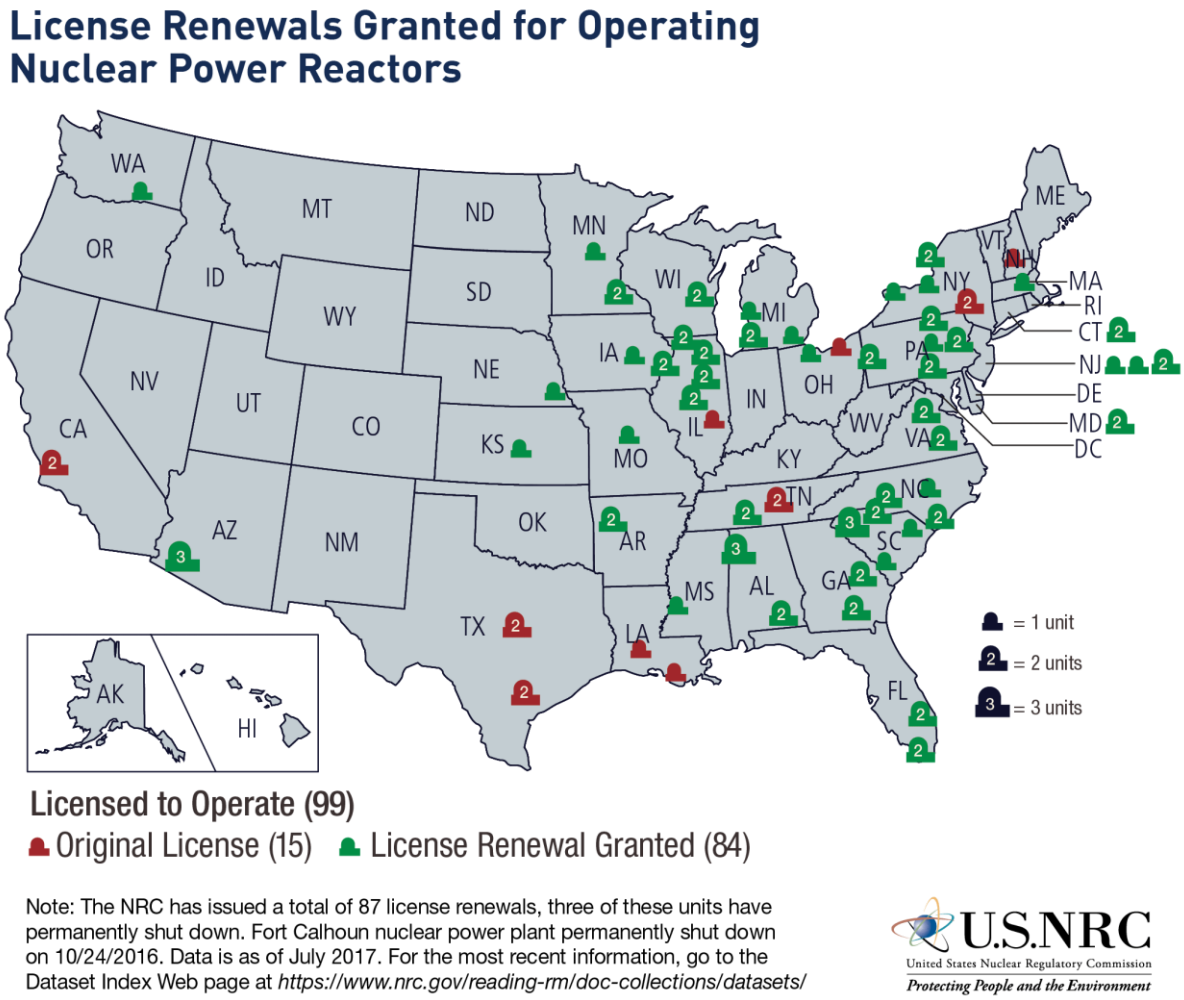

Figure 1. NRC License Renewals Granted for Operating Nuclear Power Reactors [2]

As of July 2017, the NRC has approved renewed licenses for 84 nuclear units operating at 46 sites, which represents 85% of the operating nuclear units in the U.S. The renewed licenses include:

- Calvert Cliffs, Units 1 & 2 – extended to 2034 & 2036
- Oconee Nuclear Station, Units 1, 2, & 3 – extended to 2033, 2033, & 2034
- Arkansas Nuclear One, Unit 1 – extended to 2034
- Edwin I. Hatch Nuclear Plant, Units 1 & 2 – extended to 2034 & 2038
- Turkey Point Nuclear Plant, Units 3 & 4 – extended to 2032 & 2033
- North Anna, Units 1 & 2 – extended to 2038 & 2040
- Surry Units 1 & 2 – extended to 2032 & 2033
- Peach Bottom, Units 2 & 3 – extended to 2033 & 2034

- St. Lucie, Units 1 & 2 – extended to 2036 & 2043
- McGuire, Units 1 & 2 – extended to 2041 & 2043
- Catawba, Units 1 & 2 – extended to 2043 & 2043
- H. B. Robinson Nuclear Plant, Unit 2 – extended to 2030
- R. E. Ginna Nuclear Power Plant, Unit 1 – extended to 2029
- V. C. Summer Nuclear Station, Unit 1 – extended to 2042
- Dresden, Units 2 & 3 – extended to 2029 & 2031
- Quad Cities, Units 1 & 2 – extended to 2032 & 2032
- Farley, Units 1 & 2 – extended to 2037 & 2041
- Arkansas Nuclear One, Unit 2 – extended to 2038
- D.C. Cook, Units 1 & 2 – extended to 2034 & 2037
- Millstone, Units 2 & 3 – extended to 2035 & 2045
- Point Beach, Units 1 & 2 – extended to 2030 & 2033
- Browns Ferry, Units 1, 2, & 3 – extended to 2033, 2034, & 2036
- Brunswick, Units 1 & 2 – extended to 2036 & 2034
- Nine Mile Point, Units 1 & 2 – extended to 2029 & 2046
- Monticello, Unit 1 – extended to 2030
- Palisades, Unit 1 – extended to 2031
- J.A. FitzPatrick, Unit 1 – extended to 2034
- Wolf Creek, Units 1 – extended to 2045
- Shearon Harris, Unit 1 – extended to 2046
- Oyster Creek, Unit 1 – extended to 2029
- Vogtle, Units 1 & 2 – extended to 2047 &2049
- Three Mile Island, Unit 1 – extended to 2034
- Beaver Valley, Units 1 & 2 – extended to 2036 & 2047
- Susquehanna, Units 1 & 2 – extended to 2042 & 2044
- Cooper, Unit 1 – extended to 2034
- Duane Arnold, Unit 1 – extended to 2034
- Palo Verde, Units 1, 2, & 3 – extended to 2045, 2046, & 2047
- Prairie Island, Units 1 & 2 – extended to 2033 & 2034
- Salem, Units 1 & 2 – extended to 2036 & 2040
- Hope Creek, Unit 1 – extended to 2046
- Columbia Generating Station – extended to 2043
- Pilgrim, Unit 1 – extended to 2032
- Limerick, Units 1 & 2 – extended to 2044 & 2049
- Callaway, Unit 1 – extended to 2044
- Sequoyah, Units 1 & 2 – extended to 2041 & 2041
- Byron, Units 1 & 2 – extended to 2044 & 2046
- Davis-Besse, Unit 1 – extended to 2037
- Braidwook, Units 1 & 2 – extended to 2046 & 2047
- LaSalle, Units 1 & 2 – extended to 2042 & 2043
- Grand Gulf, Unit 1 – extended to 2044
- Fermi, Unit 2 – extended to 2045

* Fort Calhoun Station was permanently shut down on October 24, 2016.
** Kewaunee Power Station was permanently shut down on May 7, 2013.

*** Vermont Yankee Nuclear Power Station was permanently shut down on December 29, 2014.
**** The Crystal River Nuclear Generating Plant, Unit 3 application was withdrawn by the licensee on February 6, 2013. The facility was permanently shut down on February 20, 2013.

Prior to the renewal of the 84 operating licenses, a large number of operating reactors would have shut down in the 2010's due to license expiration. This peak of license expirations has now moved to the 2030's and 2040's. In addition, the nuclear plants with licenses expiring in the next 10 years have either submitted a license renewal application or are in the process of preparing an application. If all of these applications are successful, which is likely, no plants operating under the initial 40-year operating license will be shut down due to license expiration.

The NRC is currently reviewing license renewal applications for 9 nuclear units operating at 6 sites, which represents an additional 9% of the operating nuclear units in the U.S. The applications under review include those from:

- Indian Point, Units 2 & 3
- Diablo Canyon 1 & 2
- Seabrook 1
- South Texas Project 1 & 2
- Waterford 3
- River Bend

In addition, owners of 4 more nuclear units (or an additional 4%) have indicated intent to submit license renewal applications over the next few years. This brings the total of completed license renewals, applications in review, and announced plans for renewal to alll but one of the 99 currently operating nuclear units in the U.S.

License renewal is a prerequisite for long-term operation and is dependent on excellent plant management that ensures safe and cost effective operation.

2. Regulatory Process for License Renewal in the U.S.

The NRC requirements for license renewal and second license renewal (SLR) are contained in 10 CFR Part 54, Requirements for Renewal of Operating Licenses for Nuclear Power Plants, which was finalized in 1995. The regulations address the required contents of a license renewal application, which includes summarizing the results of a safety review and an environmental review. The safety review includes an Integrated Plant Assessment (IPA) and an evaluation of Time-Limited Aging Analyses (TLAA).

The IPA, which is part of the safety review, is an assessment to demonstrate that managers have identified the structures and components that will require aging management review and that the effects of aging on the functionality of such structures and components will be managed, to maintain the current licensing basis (CLB) such that there is an acceptable level of safety during the additional 20 years of operation.

The evaluation of TLAA, which is also part of the safety review, includes identifying certain safety-significant analyses that consider the effects of aging and involved time-limited assumptions (e.g., beyond 40 to 60-years of operation). For each identified analysis, applicants must demonstrate that: (i) the analyses remain valid for the period of extended

operation; (ii) the analyses have been projected to the end of the period of extended operation; or (iii) the effects of aging on the intended function(s) will be adequately managed for the period of extended operation. Typical TLAAsinclude metal fatigue, environmental qualification, and neutron embrittlement.

The environmental review is focused on assessing the environmental impacts of the 20 additional years of operation. The environmental areas evaluated include: surface water quality, hydrology, and use; aquatic ecology; ground-water use and quality; terrestrial resources; threatened or endangered species; air quality; land use; human health; socioeconomics; postulated accidents; uranium fuel cycle and waste management; decommissioning; and environmental justice.

Once the NRC has received an application for license renewal, it typically takes 22 to 30 months to complete the safety and environmental reviews. For second license renewal (SLR), the NRC has committed to the goal of an 18-month application review timeline. Of the renewed licenses issued so far, the shortest NRC review took less than 17 months (Arkansas Nuclear One, Unit 1) and the longest NRC review took more than 60 months (Indian Point). The NRC license renewal review process is shown graphically in Figure 2 [3].

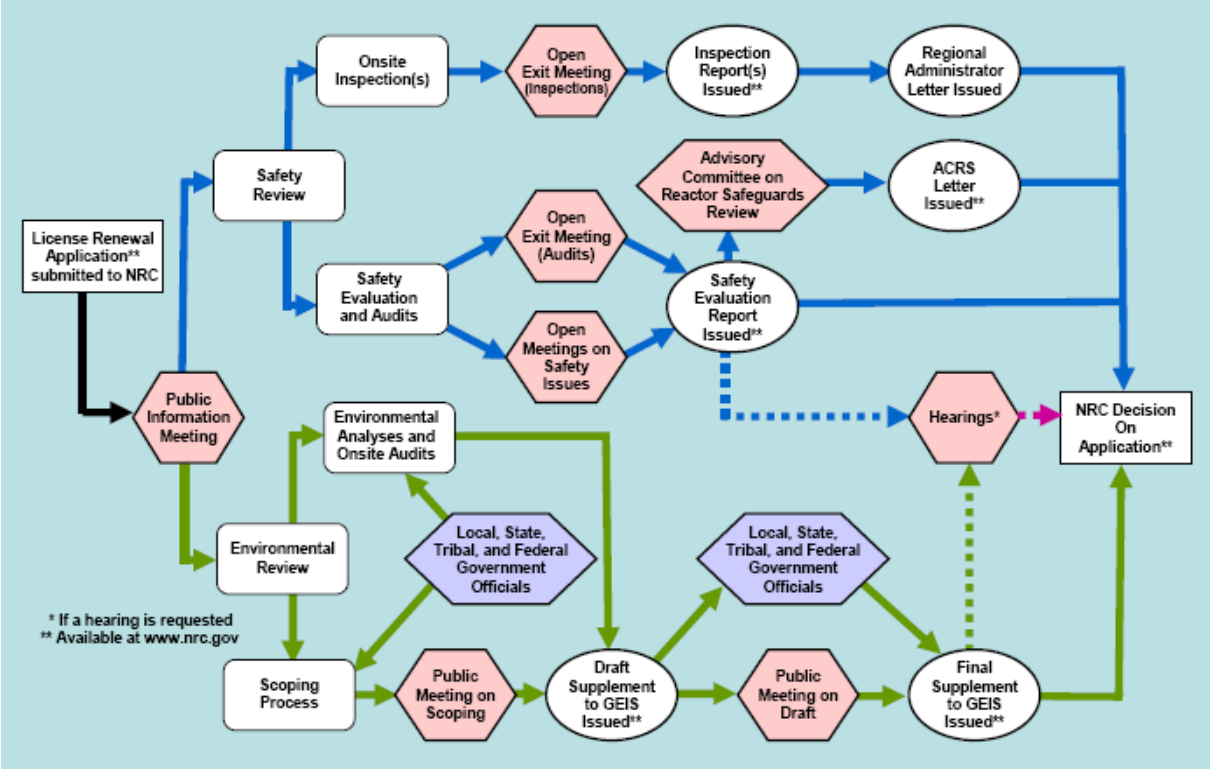

Figure 2. NRC LR and SLR Review Process [3]

In order to document the experience and lessons learned from the many license renewal reviews and to establish better guidelines for future license renewal applicants, the NRC and the U.S. nuclear industry prepared and continue to update various guidance documents. For example, the Nuclear Energy Institute (NEI) has prepared NEI 95-10, Industry Guideline for Implementing the Requirements of 10 CFR Part 54 – the License Renewal Rule [4], which is endorsed by the NRC as an acceptable method for preparing a license renewal application. Further, NEI has developed NEI 17-01, Industry Guideline for Implementing the Requirements of 10 CFR Part 54 for Second License Renewal [5]. In addition, the NRC has published NUREG-1800, Standard Review Plan for Review of License Renewal Applications

for Nuclear Power Plants [6]; and NUREG-1801, Generic Aging Lessons Learned (GALL) Report [7]. In July, 2017, NRC published the completed and revised NUREG-2191, Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report [8]; and NUREG-2192, Standard Review Plan for Review of Subsequent License Renewal Applications for Nuclear Power Plants (SRP-SLR) [9].

The GALL reports (NUREG-1801, NUREG-2191) contain the NRC's generic evaluation of the adequacy of certain existing aging management programs for use during the additional 20 years of operation. The results indicate that many of the programs already in use are adequate to manage the aging effects, as demonstrated by operating experience over the past few decades. The GALL report also contains recommendations where existing programs should be augmented for license renewal. Specific aging management programs evaluated in the GALL report include:

X.M1 Metal Fatigue of Reactor Coolant Pressure Boundary
X.M2 Neutron Fluence Monitoring
X.S1 Concrete Containment Tendon Prestress
X.E1 Environmental Qualification (EQ) of Electric Components
XI.M1 ASME Section XI Inservice Inspection, Subsections IWB, IWC, and IWD
XI.M2 Water Chemistry
XI.M3 Reactor Head Closure Studs
XI.M4 BWR Vessel ID Attachment Welds
XI.M5 BWR Feedwater Nozzle
XI.M6 BWR Control Rod Drive Return Line Nozzle
XI.M7 BWR Stress Corrosion Cracking
XI.M8 BWR Penetrations
XI.M9 BWR Vessel Internals
XI.M10 Boric Acid Corrosion
XI.M11 Nickel-Alloy Nozzles and Penetrations
XI.M12 Thermal Aging Embrittlement of Cast Austenitic Stainless Steel (CASS)
XI.M13 Thermal Aging and Neutron Irradiation Embrittlement of CASS
XI.M14 Loose Part Monitoring
XI.M15 Neutron Noise Monitoring
XI.M16 PWR Vessel Internals
XI.M17 Flow-Accelerated Corrosion
XI.M18 Bolting Integrity
XI.M19 Steam Generator Tube Integrity
XI.M20 Open-Cycle Cooling Water System
XI.M21 Closed-Cycle Cooling Water System
XI.M22 Boraflex Monitoring
XI.M23 Inspection of Overhead Heavy Load and Light Load Handling Systems
XI.M24 Compressed Air Monitoring
XI.M25 BWR Reactor Water Cleanup System
XI.M26 Fire Protection
XI.M27 Fire Water System
XI.M28 Buried Piping and Tanks Surveillance
XI.M29 Aboveground Steel Tanks
XI.M30 Fuel Oil Chemistry
XI.M31 Reactor Vessel Surveillance
XI.M32 One-Time Inspection
XI.M33 Selective Leaching of Materials

XI.M34 Buried Piping and Tanks Inspection
XI.M35 One-Time Inspection of ASME Code Class 1 Small Bore-Piping
XI.M36 External Surfaces Monitoring
XI.M37 Flux Thimble Tube Inspection
XI.M38 Inspection of Internal Surfaces in Miscellaneous Piping and Ducting Components
XI.M39 Lubricating Oil Analysis
XI.M40 Monitoring of Neutron-absorbing Materials other than Boroflex
XI.M41 Buried and Underground Piping and Tanks
XI.M42 Internal Coatings/Linings for In-scope Piping, Piping Components, Heat Exchangers and Tanks
XI.S1 ASME Section XI, Subsection IWE
XI.S2 ASME Section XI, Subsection IWL
XI.S3 ASME Section XI, Subsection IWF
XI.S4 10CFR 50, Appendix J
XI.S5 Masonry Wall Program
XI.S6 Structures Monitoring Program
XI.S7 RG 1.127, Inspection of Water-Control Structures
XI.S8 Protective Coating Monitoring and Maintenance
XI.E1 Electrical Cables and Connections Not Subject to EQ Requirements
XI.E2 Instrument Circuit Cables and Connections Not Subject to EQ Requirements
XI.E3 Inaccessible Medium-Voltage Cables Not Subject to EQ Requirements
XI.E4 Metal Enclosed Bus
XI.E5 Fuse Holders
XI.E6 Electrical Cable Connections Not Subject to EQ Requirements
XI.E7 High Voltage Insulators

The regulatory process for license renewal in the U.S. has continued to be successful in part due to the development of useful and effective guidance documents such as NEI 95-10, NUREG-1800, and NUREG-1801. The continual updating and incorporation of lessons learned has been beneficial to this regulatory process and has been used to develop (?) the guidance that has been developed for SLR.

3. Second License Renewal in the U.S.

The first U.S. reactors will reach 60 years of operation by 2029; end of period of extended operation covered by the first license renewal. The nuclear industry is considering whether extending a nuclear plant's operation beyond 60 years is desirable. If so, similar to first license renewal, these utilities must begin planning years in advance whether to continue to operate beyond 60 years, as shown in Figure 3, the NEI Second License Renewal Timeline [10] that documents the industry's assessment of the milestones that must be reached so that the NRC can review SLR applications for the first utilities that seek them. [11]

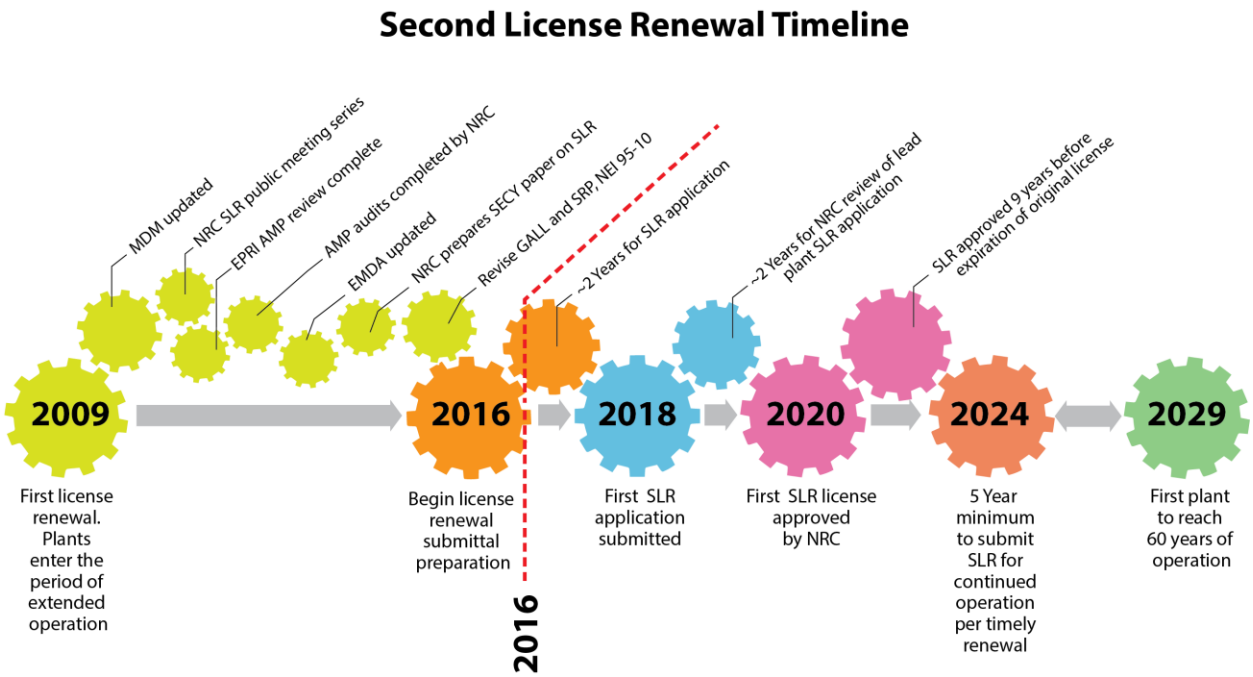

Figure 3. NEI Second License Renewal Roadmap [10]

Two utilities have already announced their intention to submit SLR applications: Exelon Corparation for two reactors at its Peach Bottom Atomic Power Station in Pennsylvania in 2018, and Dominion Energy for its twin-reactor Surry Power Station in Virginia in 2019.

Although Peach Bottom and Surry are the only two sites that have publicly announced intent to pursue SLR in the U.S., Figure 4 represents the number of utilities considering SLR applications in the coming years. This information was consolidated by NEI, based on an unofficial survey conducted of the nuclear industry in May, 2016. The data is based on the number of plants considering SLR, rather than individual operating reactors.

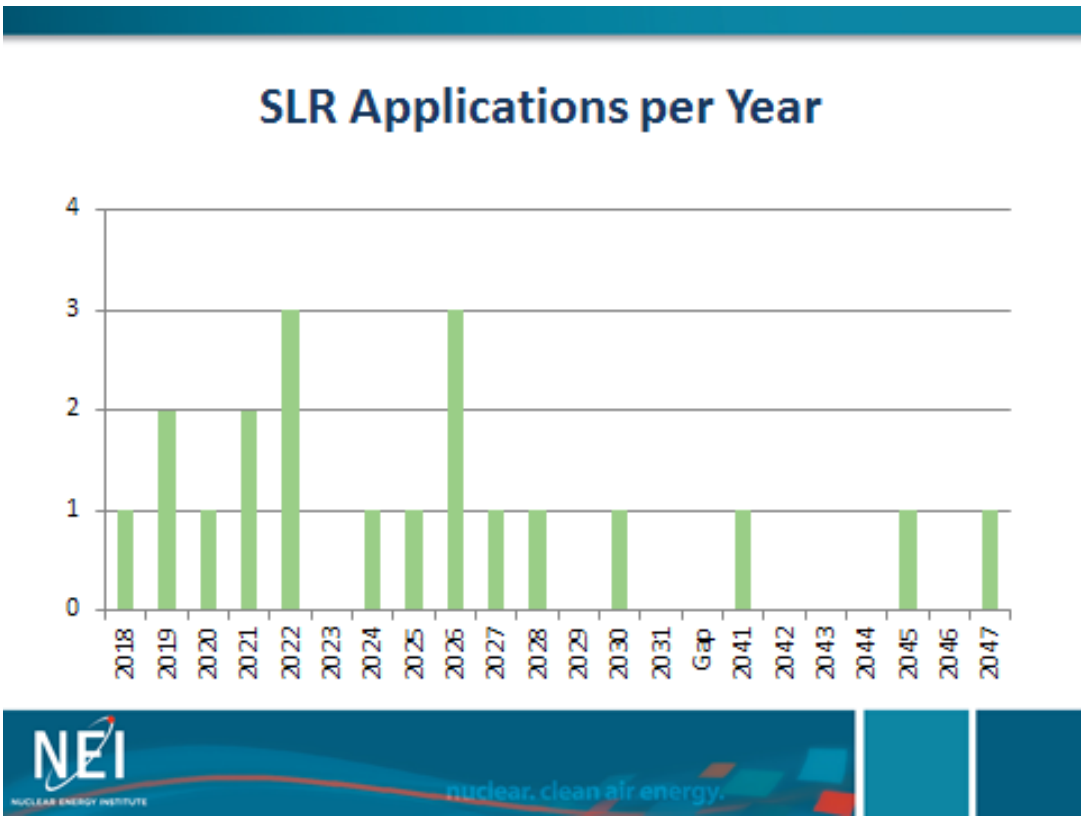

Figure 4. SLR Applications Per Year [12]

At the time the survey was conducted, NRC was still in the process of completing the revision to the SLR-GALL Report and SRP to address SLR. Even though there was uncertainty as to whether the NRC would extend requirements beyond the scope of those for first license renewal, based on this information, 20% of the industry still indicated its intention to move forward with operating for 80 years.

Following the public release of the draft SLR-GALL Report and SRP in December, 2015, industry stakeholders provided over 300 pages of technical comments to the NRC in February, 2016, and participated in nine SLR-GALL-focused public meetings with the NRC through the remainder of the year.

Although a number of significant technical issues were initially identified by industry stakeholders, by May of 2017, these issues had been resolved to the satisfaction of both the NRC and industry stakeholders. In July, 2017, NRC published the completed final SLR-GALL Report and SRP. The completed NRC guidance reflected the operating experience and lessons learned data collected from first license renewal used to inform guidance for SLR; no new requirements are needed. This resulted in predictable guidance and served to enhance regulatory stability while providing high assurance that the sites will continue to operate safely to 80 years. This resulting guidance will likely have a profound and positive impact on the number of utilities considering SLR going forward.

4. U.S. Economic Performance Implications Supporting Life Extension

America's evolving electicity marketplace, faced with growing requirements for 24/7 reliability and mandates for lower-carbon electricity production, requires that policymakers and the electric industry place a high premium on preserving existing nuclear generating capacity. This means ensuring workable regulatory requirements for SLR and building new

reactors to maintain supply. SLR makes economic and environmental sense for consumers, the community and companies that operate these facilities. Although nuclear facilities require significant capital investment to ensure safe and reliable performance, they are the largest and most reliable emission-free sources of electricity. Maintaining the operation of a nuclear plant during an SLR period will extend the economic, environmental, energy security and energy diversity benefits of the reactors within the U.S.

Over a 20-year period, a typical 1,000-megwatt reactor will generate $9.4 billion of economic output, $800 million in payroll, $320 million in state and local taxes and $1.3 billion of federal tax revenue, which includes approximately $470 million in economic output. These sums include the plant's expenditures for goods, services and labor as well as spending attributable to the presence of the plant and its employees, as expenditures filter through the local economy, which helps support schools, roads and other infrastructure. [11]

Figure 5 shows the economic benefits of nuclear power generation compared to other forms of electricity generation within the U.S.

Technology[3]	Jobs/MWe	Average Size (MWe)	Direct Local Jobs	Average Salary ($/hour)	Workforce Income ($ Million/year)
Nuclear	0.50	1,000	504	$31	$32.49
Coal	0.19	1,000	187	$28	$10.99
Hydro > 500 MW	0.11	1,375	156	$33	$10.79
Hydro Pumped Storage	0.10	890	85	$38	$6.70
Hydro > 20 MW	0.19	450	86	$33	$5.79
Concentrating Solar Power	0.47	100	47	$27	$2.62
Gas Combined Cycle	0.05	630	34	$28	$2.02
Solar Photovoltaic	1.06	10	11	$15	$0.33
Micro Hydro < 20 MW	0.45	10	5	$35	$0.33
Wind	0.05	75	4	$35	$0.29

Donald Harker and Peter Hans Hirschboeck, "Green Job Realities: Quantifying the Eco- nomic Benefits of Generation Alternatives*," Public Utilities Fortnightly*, May 2010.

Figure 5. Green Job Realities [13]

Even with aggressive expansion of nuclear energy, the U.S. will nonetheless lose substantial capacity to generate clean air energy unless existing nuclear power plant licenses are extended. Over 20 years, a single reactor will prevent approximately 120 million metric tons of carbon dioxide from being emitted into the air. This is equal to 5 percent of the carbon dioxide emissions from the entire electric sector in 2014 (2.2 billion metric tons).

SLR may be economically feasible for many nuclear plants if future electricity prices in the region seem likely to be adequate to justify the cost of refurbishment, but not all nuclear plants will seek SLR. Additional capital investment will almost certainly be required to operate past 60 years and, in some cases, market conditions or other factors may not justify that capital investment. However, producing electricity through 80 years will be economically feasible for many nuclear plants , but there are other factors and uncertainties that will influence a utility's decision to apply for SLR. Technical, political and economic factors to be considered for SLR include:

- future wholesale electricity prices
- need for, and cost of, equipment upgrade and replacement
- national energy policy, carbon policy and security of energy supply. [11]

In summary, nuclear life extension activities in the U.S. have been successful in ensuring safe and economic performance of the nuclear industry such that license renewal for long-term operation is a viable goal.

5. White House Energy Policy and National Security Perspective

The White House declared the week of June 29, 2017, as "Energy Week," to highlight its energy priorities in several venues. The administration's main theme was asserting the U.S.'s global energy dominance. On Thursday of that week, President Trump gave a speech on "American Energy Dominance," in which he announced a plan for an in-depth review of U.S. nuclear energy policy.

"We will begin to revive and expand our nuclear energy sector, which I'm so happy about, which produces clean, renewable and emissions-free energy," President Trump said. "A complete review of U.S. nuclear energy policy will help us find new ways to revitalize this crucial energy resource."

NEI President and Chief Executive Officer Maria Korsnick attended the event with other industry and labor leaders. She said the industry welcomed a comprehensive study of the challenges facing America's nuclear energy industry. "Nuclear energy is a critical pillar of our nation's national security, a reliable creator of high-skill, high-paying jobs and the backbone of clean electricity generation," Korsnick went on to say, "If the president wishes for our nation to achieve nuclear energy dominance both at home and abroad, he'll do it by preserving the existing nuclear fleet, paving the way for the deployment of advanced nuclear designs and stimulating exports abroad. We look forward to working with the administration on these incredible opportunities."

Figure 6. Energy Secretary Rick Perry holds press conference during "Energy Week" [14]

Of the other administration officials to weigh in on the importance of nuclear energy to the nation's energy portfolio that week, Energy Secretary Rick Perry was by far the most enthusiastic.

"I believe no clean energy portfolio is truly complete without nuclear power, and so does the president. If you want to see the environment and the climate that we live in affected in a positive way, you must include nuclear energy with zero emissions to your portfolio. Do it safe, do it thoughtfully, do it economically. Under the leadership of the United States, the world can benefit from that," Perry said at a June 27 press conference. He added, "This administration believes that nuclear energy development can be a game-changer and an important player in the development of our clean-energy portfolio globally. I believe we can achieve this by focusing on the development of technology, for instance, advanced nuclear reactors, small modular reactors

Answering questions during the June 27 press conference, Perry went on to say that the U.S. should not cede its historical leadership in nuclear technology to other countries abroad. This is a massively important issue in terms of security for the U.S. and its allies and that America should remain engaged in the development of nuclear technology.

"One of the things we want to do at DOE is to make nuclear energy cool again." Perry said. [14]

In summary, the U.S. nuclear energy industry is experiencing a dramatic shift in the attitude toward nuclear power since the 2016 election. Nuclear is being viewed and referred to by Administration officials as a clean source of renewable energy that needs to be maintained and included in any future U.S. energy portfolio. Although the discussion on nuclear energy is positive, the likes of which this industry has not heard in decades, a discussion of nuclear energy simply is not enough; more needs to be done to turn words into action and establish energy policies that provide incentive to preserve nuclear power as a clean source of renewable energy, necessary for America's energy future.

6. Conclusion

Nuclear energy continues to safely and economically supply approximately 20% of the electricity needs of the U.S. Nuclear energy also supplies more than 60% of the U.S. electricity that comes from sources, including renewable technologies and hydroelectric power plants, that do not emit controlled pollutants or greenhouse gases into the atmosphere.

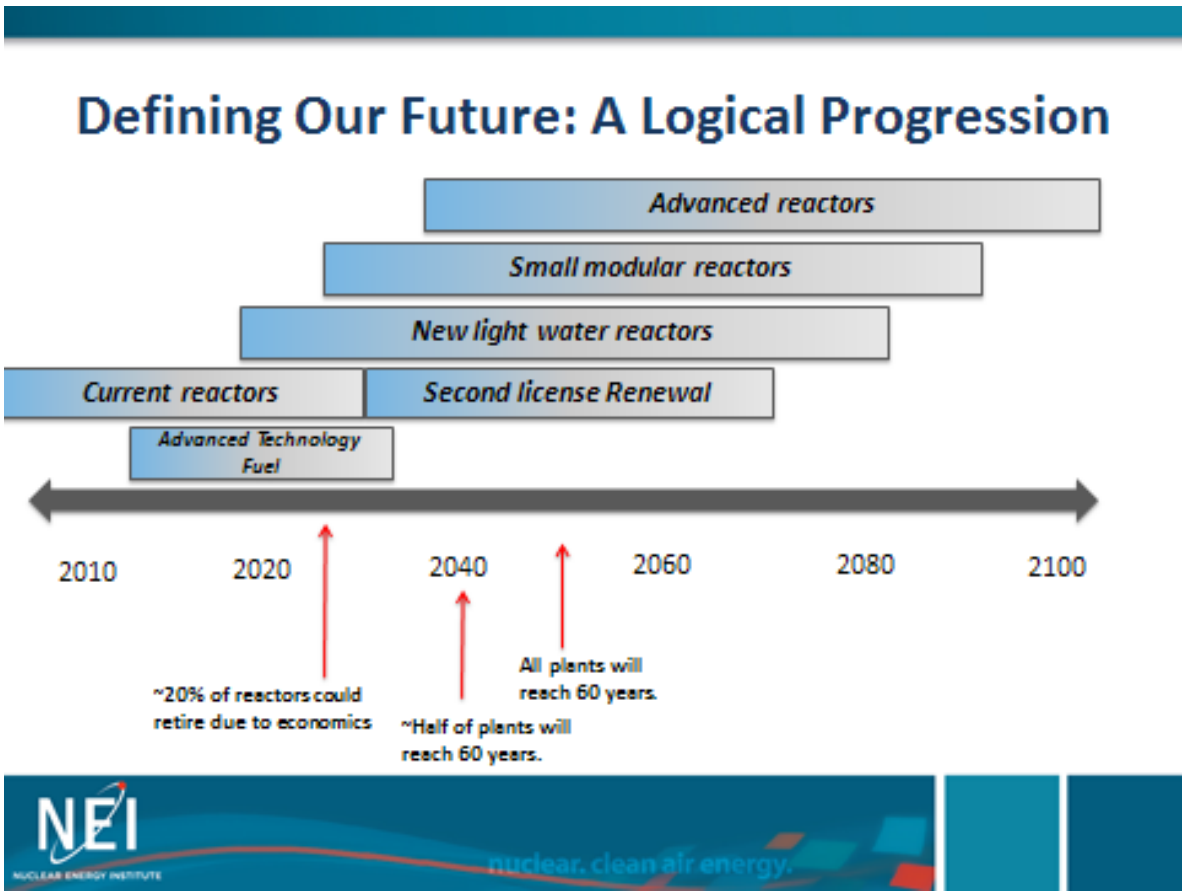

Figure 7. Defining our Future: A Logical Progression [15]

As demonstrated in Figure 7, the current direction of the U.S. extending the life of its existing nuclear reactors provides a platform for the future of nuclear technology in the United States and around the world. Only by continuing to be successful in operating our nuclear power plants safely and efficiently while providing a reliable source of clean and affordable baseload electricity, can nuclear plant life extension be a bridge to future nuclear technology. And by building, licensing and bringing online new-technology reactors in America, the U.S. can maintain its position as a global leader in nuclear technology. In summary, America's nuclear future is riding on the life extension of its existing nuclear power reactors.

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