Advanced Life Cycle Management Planning

Building Confidence in the Future

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When asked, most nuclear utility executives say their organizations develop effective Life Cycle Management (LCM) plans. However, when analyzing industry data, a somewhat different story emerges as industry and regulatory groups continually flag deficiencies in LCM planning. A recent analysis of INPO Equipment Reliability AFIs found almost 25% were LCM-related. LCM is not new to the nuclear industry, but successful implementation appears to be a struggle for many licensees. How did the industry get to this point, and what can be done to fix it?

Typical Life Cycle Management Planning

A recent analysis of INPO Equipment Reliability AFIs found almost 25% were LCM-related.

The nuclear utility industry's Equipment Reliability Process Description (AP-913) defines Life Cycle Management as "the integration of aging management and economic planning to optimize the operation, maintenance, and service life of Structures, Systems and Components (SSCs); maintain an acceptable level of performance and safety; and maximize return on investment over the service life of the plant." LCM plans serve to identify work scope prior to maintenance outages, establish appropriate long-term planning horizons, create the platform to prioritize expenditures, and determine those projects and major expenses that merit funding and those that can be safely deferred.

MCR has reviewed LCM plans and LCM planning processes at over 20 nuclear plants; and, through our involvement with industry organizations, such as the annual ANS Utility Working Conference, we have talked to dozens of engineers responsible for developing LCM plans. It is clear from these reviews and discussions the industry relies heavily on an LCM planning guide as a roadmap for LCM plan development. It is equally clear that many plant staff are not able to adequately use the guideline to develop robust LCM plans. But, why?

Put simply, many LCM plans are developed without a comprehensive approach to the full discovery and integration of all the necessary information needed for success. Instead, typical LCM plans only incorporate readily available information, which doesn't adequately capture the real issues at the plant.

In specific, we find many LCM plans suffer from:

- Inadequate project identification
- Short planning horizons, often limited to two or three fuel cycles
- Lack of coordination with outage and online work planning
- Absence of reconciling project work to plant spending targets
- Limited plant health committee input to the plan beyond the current cycle
- Reliance on component-based LCM plans that are difficult to implement

Let's take a closer look at each of these issues.

The lack of long-term planning for reliability and obsolescence projects often becomes a source of unpleasant surprises.

Inadequate Project Identification

The process of identifying major projects is inconsistent across licensees and frequently reactive. Oftentimes, project identification efforts are driven by situations where a reliability, financial or regulatory event creates a sense of urgency to identify and submit projects for evaluation and approval. These situations tend to become an "all hands on deck" exercise where component and system engineers scour their notebooks searching for any safety, reliability or significant investment issue which has the possibility of becoming the next plant event.

Short Planning Horizons for Identifying Reliability and Obsolescence Projects

Planning horizons are typically driven by two-year budget requirements and established major maintenance projects. While major maintenance project schedules are often populated several cycles into the future for component replacements or refurbishments, reliability and obsolescence projects are generally limited to the two-year budget. The lack of long-term planning for reliability and obsolescence projects often becomes a source of unpleasant surprises.

Lack of Coordination with Outage and Online Work Planning

Work planning organizations are normally tasked with identification of outage scope three or more cycles into the future, and online scope at least one cycle into the future. These responsibilities give them a pseudo role as long range planners for a nuclear plant. A consequence of filling a long range planner role without all the accountabilities of long range planning is creation of outage schedules which for many have a feeling of completeness, but for project sponsors have a lingering feeling of scope being pushed out of outage without proper consideration and analysis.

Absence of Reconciling Project Work to Plant Spending Targets

Nuclear plants typically set financial performance goals, which translate into specific spending targets for capital and expense projects. These spending targets, typically driven by corporate, tend to be short term, i.e., two years. A short-term spending target approach does not lend itself to the creation of a viable long range plan. Ideally, the plant would create long range spending targets to align with the work identified in each year of an LCM plan reconciling with corporate targets, but we seldom see this in practice.

Limited Plant Health Committee Input to the Plan Beyond the Current Cycle

Plant Health Committees (PHC), Plant Health Working Groups (PHWG), and Unit Reliability Teams (URT), etc. are all intended to support equipment reliability processes, including LCM. These committees are essential to the ongoing operations of nuclear plants in providing guidance and decision support when evaluating safety and reliability issues. Their typical focus is on the near term, approving projects out of the context of LCM plans.

When project approval processes seem to be ineffective, renewed focus on the roles and responsibilities of committees may be seen as the best means to quickly improve results. Unfortunately, without a rigorous project submission, evaluation, prioritization and reconciliation process, these committees are not as effective as they could be. Any of these committees operating outside an integrated LCM process is not in a position to holistically address safety, reliability and cost issues.

The basic challenge with planning by component groups is management and staff do not maintain plants by component class; they schedule work and maintain assets by system.

Reliance on Component-Based LCM Plans that are Difficult to Implement

Many nuclear power industry organizations view long range planning and the more holistic approach to Life Cycle Management as processes best performed from a component perspective. A component-based LCM plan (LCMP) structures analysis around a group or related groups of components. At first glance, obsolescence of an entire class of equipment makes creation of component-based LCMP a logical choice.

However, in most cases, addressing common component issues for system-by-system implementation is laborious and disconnected from traditional work management and scheduling processes. In general, the basic challenge with planning by component groups is management and staff do not maintain plants by component class; they schedule work and maintain assets by system.

Advanced Life Cycle Management Planning – A Comprehensive Approach

To be successful in LCM planning, the industry needs to embrace an advanced approach built on three guiding principles:

Principle #1 – Proper Accountability. Advanced LCM processes must be driven by individuals with knowledge of the technical aspects of the plant as well as the operational and work management issues affecting the assets. In successful organizations, these individuals are often the system engineers. In Advanced LCM Planning, system engineers are the custodians of plant system assets and are required to plan for their systems through the LCM process. System engineers are in the best position to gather planning information relevant to their system and to work directly with Work Management to incorporate this information into system work windows. A system engineer should be conversant on work planned for their system during online and outage work windows for at least three cycles and preferably a minimum of six cycles into the future. Not only should a system engineer be conversant on planned work, they should also be in the best position to drive work through the approval processes to ensure the right work is completed at the right times. Working closely with Component Engineering, Work Management, Maintenance and others, the system engineers become the essential contributor to online and outage work management and answering project evaluation questions in the budgeting process.

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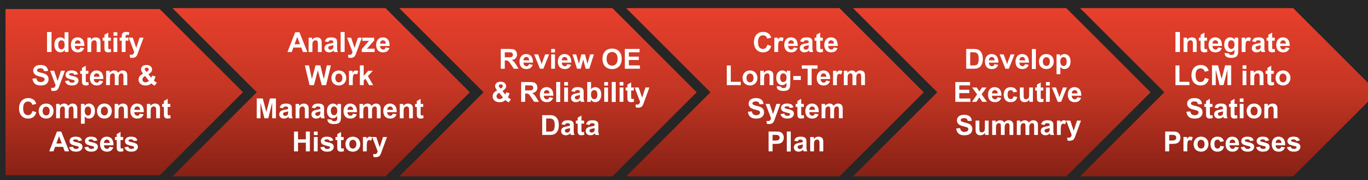
Principle #2 – System Based Approach. The Advanced LCM process must be system based (vs. component based). A system-based approach aligns with how nuclear power plants are designed, constructed, operated, maintained and even regulated. For example, Final Safety Analysis Reports (FSARs) are arranged by safety functions performed by systems. Technical Specifications are also arranged by safety functions performed by operable systems. Operating procedures provide instructions on operating systems as well as how to remove and restore systems from and to service. Online and outage maintenance is packaged by system and scheduled to align with system work windows. Packaging work by systems facilitates meeting system operability requirements, maximizing system availability, and ensuring the highest priority work on a system is completed first.

Principle #3 – Comprehensive Discovery. The Advanced LCM process must strive for the complete discovery of the known or knowable issues related to plant equipment, the rigorous evaluation of discovered information and the use of risk-informed financial evaluation to properly rank issues. Detailed reviews of available information including work order histories, operating experience, corrective actions, reliability data, industry notices and letters, vendor information, etc. are required to ensure complete discovery. Once discovered, the valuation of risk associated with the information balanced against the cost of addressing any issues provides insight to make optimum decisions on the

Exhibit 1: MCR's Advanced Approach to LCM



recommended scope and schedule for future work.

MCR's Blueprint for Advanced Life Cycle Management Planning

With these guiding principles in mind, the blueprint for developing Advanced LCM plans (as seen in Exhibit 1) involves the following steps:

1) Identify System and Component Assets

Identifying assets provides the basis for LCM plan development and clearly defines the tangible basis for the LCM plan to control scope. While LCM plans need to be system based, the components within systems need to be identified using either the plant's master equipment list (MEL) or by system-based searches in the work management system. The resulting system-based MEL becomes the basis for work management searches, while component groupings within the MEL become the basis for searches in external information systems.

The appropriate LCM threshold must be chosen carefully as the major vs. minor component distinctions are not always obvious.

The selection of LCM-related system components does not occur in a vacuum and is subject to several organizational, financial and accounting constraints. The appropriate LCM threshold must be chosen carefully as the major vs. minor component distinctions are not always obvious. Major factors to consider are:

- **Component Cost:** The station needs to understand what minimum level of component cost qualifies for LCM plan inclusion. What constitutes a material impact for the business planning or finance teams? What cost level dictates divergence of equipment issues from the system monitoring process into routine work management or long range planning?
- **Aggregate Impact:** While the cost of an individual component may be below the LCM threshold, the aggregation of components can have a dramatic impact on the station's budget. Obsolescence of electrical components provide a good example as relatively small unit costs are multiplied by sometimes thousands of components throughout the plant (e.g., relays).
- **Failure Impact/Consequence:** Sometimes, relatively inexpensive components have dramatic failure consequences and need to be monitored using a vehicle like an LCMP to ensure reliability over the long term. Influences to consider are operating environment, recent industry operating experience, boundary conditions, and obsolescence.

- **Finance/Accounting Constraints:** Components are not always treated the same across regulatory regimes (regulated vs. deregulated) and fuel types (nuclear, coal, gas, renewables, etc.). The accounting treatment of major components can dictate Capital vs. O&M classifications and require additional diligence on the part of the LCM plan developer. The financial size and health of an organization can be an LCM threshold input as well.

2) Analyze Work Management History

Reviewing and analyzing work management data helps to identify LCM-related issues and future work for consolidation into system work packages. Current and historical work orders are analyzed to identify potential reliability issues, which may need to be addressed during LCM planning. Preventive maintenance (PM) is reviewed to identify major maintenance items which should be considered separately in budgeting or scheduling processes. Review of all work management data creates a starting point for LCM scope and schedule (PMs) supplemented by any needs (vulnerabilities, upcoming issues, error precursors, etc.) identified in the station work orders.

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3) Review Operating Experience and Reliability Data

While the review of work management data forms a starting point, review and analysis of both internal and external industry operating experience (OE) and equipment reliability data add an integral layer of known or knowable scope to the LCM plan. Equipment reliability (ER) data for the purposes of this discussion comes from either in-house performance monitoring outputs or from industry ER-centric databases like ICES (the INPO Consolidated Events Database, formerly EPIX). Regardless of the source, the key tenets of OE and ER data integration are three fold:

a) Control the scope of inputs (which years, what component level, what are the required inputs for analysis goals)

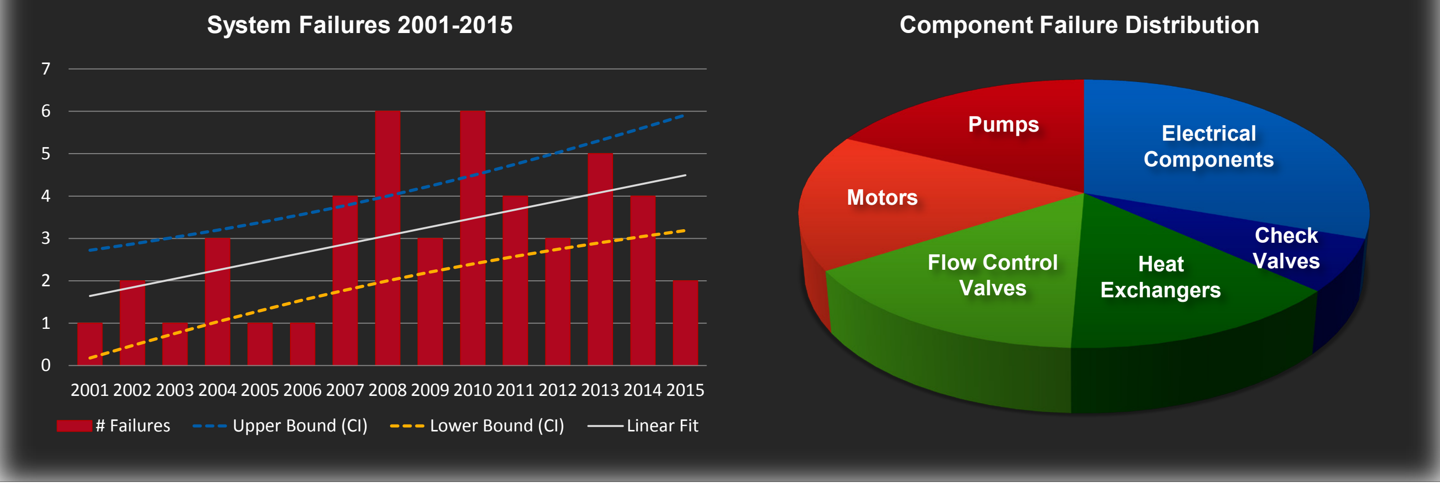
b) Standardize the analysis (software program, trending methods, regression, binomial distribution, Monte Carlo, ANOVA, etc.)

c) Create actionable results (what projects/major PMs are added or removed and why, which projects are validated by the underlying data)

With this information in hand, analyses can be created to show the results and projections of equipment failures by system and component. An illustrative example of operating experience analysis using basic failure trending and distribution is provided in Exhibit 2 on the next page.

In Exhibit 2, System Failures are presented showing failures by year with a trending analysis of expected failures within a typical year and provide insight as to the direction failures are headed. In this example, failures are trending

Exhibit 2: Illustrative Failure Trending and Distribution



upward from 2008 to 2015. Additional analysis can be performed which drill down into system failures showing failures by component. For example, additional analysis for Electrical Components would show the specific components (relays, breakers, etc.) responsible for failures. This basic information can then be used to develop failure probabilities to evaluate future equipment replacements ensuring the most value adding replacements are completed at the optimum time.

4) Integrate Asset Analytics to Create a Long-term System Plan

Developing a long-term system plan integrating scope, schedule and cost is a key element of an effective LCM process. Plants have finite, multi-year O&M and capital targets, which are perennially less than the list of projects vying for funding. Without a clear picture of cash flow requirements for each year it is difficult, if not impossible, to plan effectively and avoid unpleasant surprises; it's often explained as, "We didn't see the need for the extra $100 million dollars in capital until right before it happened." To avoid this problem, a robust bottom-up aggregation and reconciliation of LCM-related expenditures is essential.

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While there is immense detail required to create an LCM project plan with scope, schedule and cost, the high-level plan is completed in major steps:

a) Create the basic plan structure through the addition of major PM items showing recurring instances to the defined end of the plan

b) Add existing major projects with cost and schedule to include elements of the plan already in existence in some plant information system

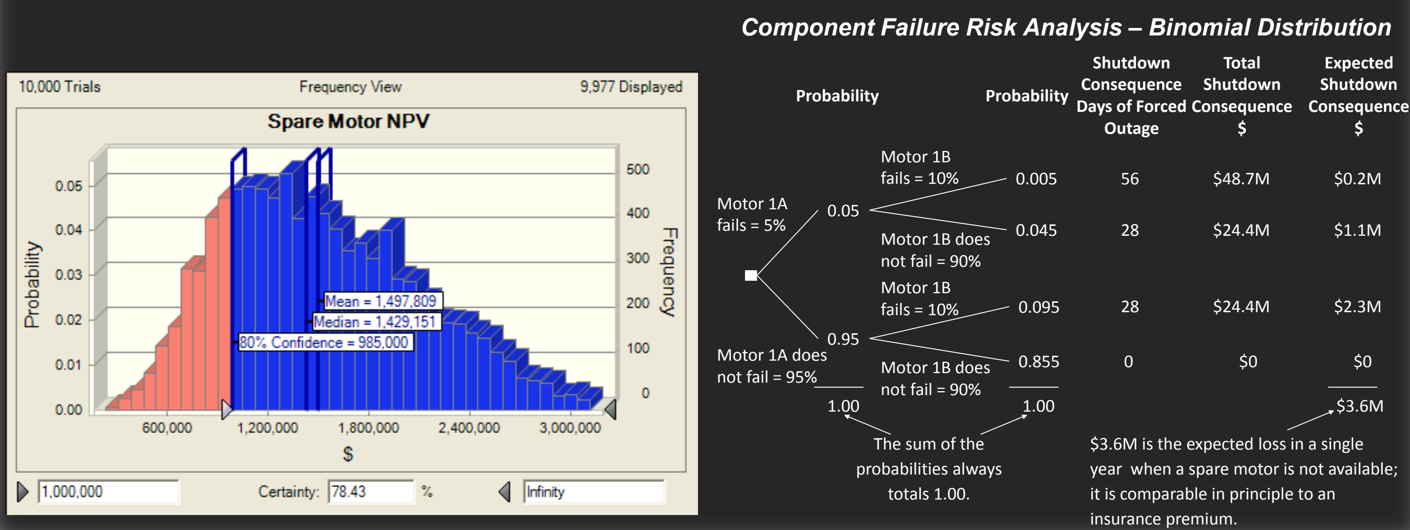
c) Add new items driven out of the complete discovery review as new PMs, new projects or new recommendations for design changes

d) Evaluate combined cash flows using risk-based evaluations as necessary to levelize the plan

Exhibit 3, presented below, illustrates LCM cash flows for System A and System B with the aggregate for both systems overlaid to assess total capital planning requirements over a 30-year period. In this example, the combined capital requirements for Systems A and B in year 2026 exceed allowable spending targets for these systems. To address this issue, a levelization of capital spending can be performed to stay within spending targets. While technical justifications for individual projects for a specific timeframe can be sound, when

Exhibit 3: Illustrative LCM System Cash Flow Levelization

Exhibit 4: Financial and Risk Analytic Tools



viewed in the aggregate, funding limitations raise questions about these decisions and often require revisiting the fundamental equipment reliability strategies that drove the original investment decisions. As a result, some projects are accelerated, delayed or re-scoped based on the need to levelize capital spending. Evaluating costs, benefits and risks of individual projects using business case evaluation will help plants optimize the cost-risk trade off when rescheduling critical projects.

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Advanced LCM plans also evaluate key individual projects identified within a system by incorporating risk analytic tools in order to conduct sensitivity and breakeven analysis, which can translate failure rates into expected net present value (NPV) results. Exhibit 4 shows an example of this type of analysis where a spare motor acquisition is valued against the probability of installed motor failure. In this example, the project engineer models the expected value of the investment decision to procure a spare motor or not. The probability distribution shows the expected value of all modeled outcomes providing greater insight into the alternative selected. This probabilistic project-specific analysis, coupled with accumulated cash flows of baseline system work, form the basis of an Advanced LCM plan that can be used for evaluating station risks and making strategic decisions around large, generational asset replacements and license extensions.

5) Develop an Executive Summary

Once the detailed Advanced LCM plan is completed, the next step is to develop a concise, high-level executive summary, which effectively communicates the extent of reviewed industry documentation and subsequent system strategy actions. Ideally, this summary should be focused on longer-term, capitalintensive projects involving aging equipment and integration of these projects with the collective station requirements and the ways in which they meet strategic performance objectives. These summaries should demonstrate the value of the plan as a critical piece of business, maintenance, engineering, and work management strategy.

6) Integrate the Advanced LCM Plan with Station Processes

Once the Advanced LCM plan is completed, the system engineers need to have a process in place to ensure the plans are maintained and kept up to date. The key to a sustainable Advanced LCM process is that it can't stand alone; it has to become an integral part of the station's long range planning. In addition, Advanced LCM plans (both creation and review cycles) need to be proceduralized with a strong root in the roles and responsibilities of the system engineers. Engineers should understand both review frequency (e.g., aligned with budget cycles) as well as what constitutes a thorough review. As proper long range planning dictates, Advanced LCM plans need to have explicit connections to station objectives tracked by key performance indicators. With this in place, Advanced LCM plans will play an integral role in the reconciliation of safety and reliability with cost.

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The Benefits of Advanced Life Cycle Management Planning

Advanced LCM planning focuses on practically achievable results integrated with station processes and procedures to create a lasting impact. Some crucial, immediately realized station benefits include:

- **Greater confidence in the plan: no surprises**. Instead of reactive calls for projects, long range planning is completed continuously from the ground up with requested system work having complete scope, schedule and cost estimates. In aggregate, station work can then be more easily prioritized with allocated budget while simultaneously having a high degree of confidence nothing was missed.
- **Better planning for all work (outage and non-outage)**. Long range planning responsibilities are now assigned at the correct level with appropriate responsibilities interfacing with work management. LCM plans are designed to align with online and outage windows showing a true, executable plan of work.
- **More accurate budgets and forecasts**. The station can now use a true bottom-up approach in meeting spending targets based on a complete body of risk-valued system work. Spending targets no longer limit marginal system needs or creative alternatives.

- **More project review rigor and better prioritization**. Station plant health committees are more effective as they are integrated with finance and work management, which adds rigor to the project prioritization and LCM review process
- **Better alignment of plans and work management.** LCM plans are now aligned with the work management system work windows based on how nuclear power plants are designed, constructed, operated, maintained, and regulated. The responsibility for developing and maintaining LCM plans is now clear and falls on the best people for the job, namely the system engineers.
- **Clear view of long range station work and spending requirements**. The LCM plans allow longer-term strategy discussions with station executive management concerning generational asset replacements and license extensions. The LCM plans are linked to performance objectives and measurable key performance indicators that align business planning with the Life Cycle Management process.
- **Overall reduction in cost required to operate to end of plant life**. By conducting robust business case evaluations of major projects, plants can reduce project costs by approximately 20% from initial estimates. Robust business cases include risk valuation methods such as binomial distributions and Monte Carlo analysis for executive review of project alternatives. The risk tolerance of executive review teams informed by risk valuation methodologies is normally higher than individual engineers taking on responsibility for project alternative selections. The analyses themselves provide confidence to executive review teams in alternatives selected across competing projects.
- **Key knowledge preservation**. By capturing the decades of experience and knowledge embedded throughout the plant about each system, the risk of personnel turnover (attrition, retirements) is minimized. The importance of effectively managing system knowledge in the organization cannot be understated; and, LCM plans have a key role in fulfilling this objective (see: "The Role of LCM Plans and Second License Renewals" on the next page). By keeping new engineers focused on the right priorities at the right time with key technical and economic content, LCM plans become the documents to educate new personnel, as well as maintain continuous discovery, evaluation and analysis of asset issues into the future.

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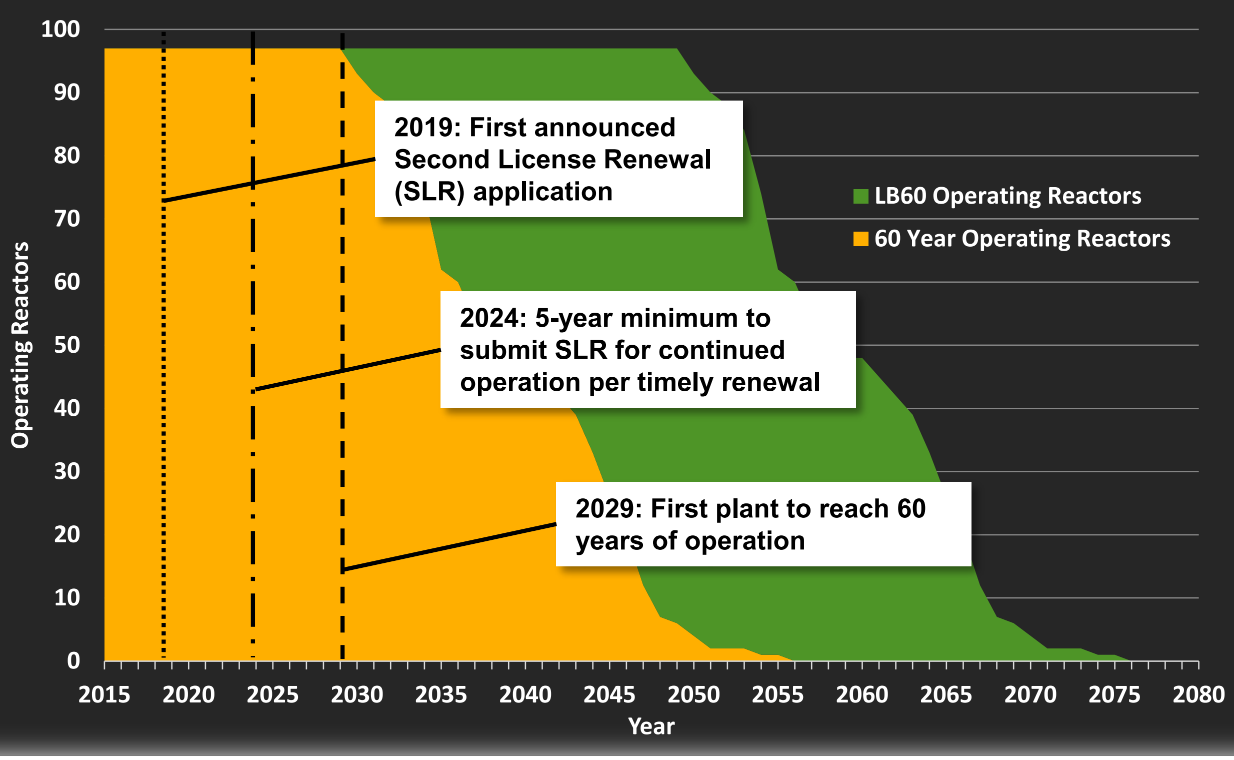
As management teams look to run their nuclear plants for the next decade and beyond, effective life cycle management planning will play a key role in

Continued on page 13

The Role of LCM Plans with Second License Renewals

Second License Renewals (SLR) (aka, Subsequent Licenses Renewal or LB60, as in life beyond 60 years) have implications for long-term strategy and LCM. As stated, system engineers should be conversant on work planned for their system during online and outage work windows for at least three cycles and preferably at least six cycles. As shown in Exhibit 5, the timeline places the bulk of planning needs in the mid-2020s with the first SLR application expected by 2019,the minimum 5-year submission window by 2024 and the expiration of the first renewal by 2029. As of 2015, there are 75 reactor license renewals, with 38 currently past 40 years of operation. By 2040, half of the nuclear plants will be operating at 60 years. Per the NEI SLR timeline, key regulatory decisions are happening now in preparation for the 2024 initial SLR applications. Key industry equipment aging management program documents (e.g. NUREG-1801 on Generic Aging Lessons Learned) are being updated, which will have significant impacts on how plant systems and underlying materials are managed. A full complement of robust LCM plans can be used to quickly gain holistic insights into station resource requirements, allowing management to make more informed, realistic decisions concerning these generational investments.

Exhibit 5: U.S. Reactors Operating to License Expiration—60-Year and 80-Year (LB60)



their success. A focused effort in developing and maintaining Advanced LCM plans will put plant management on a path to ensure their facilities remain operationally and economically viable to meet long-term goals.

Creating Advanced LCM plans can be time consuming and it is not uncommon for an LCM initiative to linger and lose momentum, or place an inordinate burden on system engineers. MCR’s solution uses experts in LCM to minimize the time required to create advanced plans and minimize the time required by system engineers to provide input to and take ownership of their plans. MCR's comprehensive approach to LCM planning builds confidence in the future by thoroughly integrating safety, reliability and cost requirements far beyond traditional planning horizons. MCR

For more information on Advanced LCM planning, visit our website www.mcr-group.com/nuclear.

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