LIFE CYCLE MANAGEMENT AT THE HIGH FLUX ISOTOPE REACTOR

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The purpose of the High Flux Isotope Reactor (HFIR) Life Cycle Management Program (LCMP) is to identify HFIR structures, systems, and components (SSCs) required to be maintained as safe and reliable and to establish a process that evaluates acceptability of their current condition, provides recommendations for improvements if needed, and implements long term monitoring of the identified SSCs for a continued acceptable condition. An LCMP is necessary to satisfy various DOE requirements and guidance related to proper asset management.

With the high capital costs associated with the direct replacement of multi-purpose neutron production facilities, there is a great incentive to extend the usable life of existing multi-purpose facilities such as the HFIR, the implication being existing facilities were originally designed to perform an expected mission for a finite life-time. To successfully extend the usable lifetime of the HFIR, a comprehensive program is described to define the characteristics of life cycle management at the HFIR, identify affected plant SSCs, and prepare the appropriate life cycle management processes.

The HFIR LCMP encompasses the management of degradation due to ageing for all equipment. By segregating SSCs into those where ageing is managed by the normal maintenance process and those that are not, the scope of the LCMP is graded in its application and resources are appropriate. Both active and passive functions are addressed. The program is the responsibility of HFIR Systems Engineering and incorporates the general steps of grouping of SSCs, prioritization of safety or operations importance, estimation of remaining life under current conditions, identification of appropriate ageing counter-measures, if needed, and identification of processes to ensure continued future performance remains as expected.

1. Introduction

In reviewing the portfolio of existing multi-purpose neutron production facilities, most have accumulated decades of useful service time. However, at the time of their initial startup, all were expected to perform a mission for a finite period of time with new facilities built to replace them as the end of their design life was reached. However, with the high capital and construction costs now associated with the replacement of multi-purpose neutron production facilities such as the High Flux Isotope Reactor (HFIR), there is a great incentive to extend the usable service of existing facilities beyond their original design life.

Expected design lifetimes result from the fact that degradation of equipment occurs due to its use over <u>time</u>—in other words, it degrades due to <u>age-related</u> effects. Also, there are “pseudo-ageing” effects, such as changes in facility regulations, missions, or reliability requirements, which may be imposed on facilities as they continue operation past original design lifetimes. The ability to incorporate these changes in an economic and safety-sensitive manner needs to be included in a comprehensive Life Cycle Management Program (LCMP). Consequently, in order to successfully extend the usable lifetime of the HFIR, a broad program is described to define the characteristics of life cycle management at the HFIR, identify affected plant structures, systems, and components (SSCs), and prepare the appropriate life cycle management processes. With initial operation in 1965 and an expectation to continue operation beyond 2050, the HFIR is not excluded from the issues related to the ageing of reactor equipment and structures. A HFIR LCMP is being prepared to address all these aspects of age-related degradation.

The HFIR LCMP centers on the identification of HFIR SSCs required to be maintained safe and reliable operation and to establish a process that (1) continually evaluates the acceptability of their current condition, (2) provides recommendations for improvements if needed, and (3) implements long term monitoring of the identified SSCs for continued acceptable condition.

2.0. Identification of Equipment

In the initial development of the HFIR LCMP, it was quickly recognized that life cycle principles are already being applied to many HFIR SSCs. This observation resulted in the separation of all HFIR SSCs into groupings that would enable clear definition of appropriate processes for each. Segregation of all HFIR SSCs into groupings was based on a general "rule-of-thumb" as to whether or not replacement had been expected to occur during the original facility design lifetime. While not a clear arbitrator of every plant design circumstance, this "rule-of-thumb" did provide sufficient guidance to determine HFIR SSCs are enveloped by four general groupings—maintenance of wear out failure, fixed time replacement, reliability improvements, and plant life extension (PLEX). Figure 1 provides an overview of the scope and structure of the HFIR LMCP through the application of these four groupings with more detailed descriptions to follow.

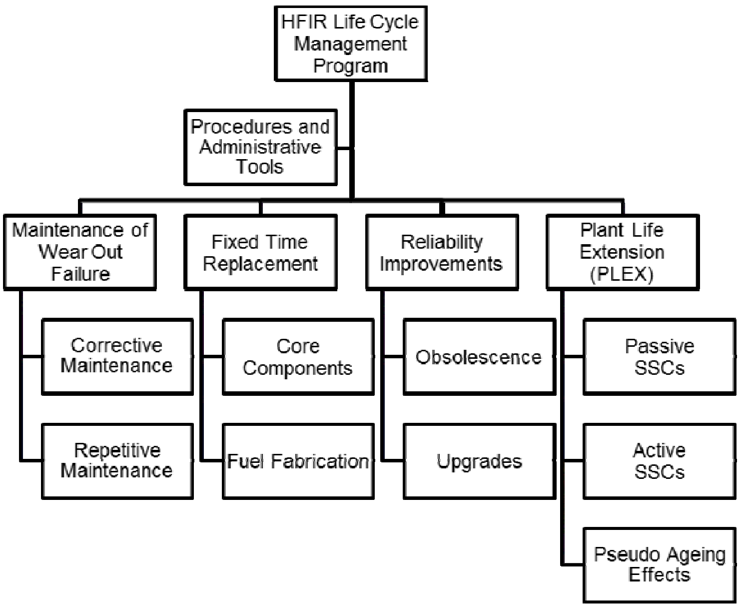

Fig. 1. HFIR LCMP Structure

2.1. Wear Out Failure

Wear-out failure represents the most common activity of life cycle management and is associated with replacement of equipment due to normal operation of the plant. Life cycle management for these SSCs is through the plant maintenance program. Examples of these SSCs are pumps, motors, valves, sensors, transmitters, and batteries. Most equipment in this grouping is considered to be "active" in its function. There are some SSCs represented within this grouping that are considered more "passive" in their function, but still exhibit degradation that can be characterized as "wear out" phenomena. Examples of these are filters, gaskets, and resins. An attribute of this group of equipment is their replacement as individual failures occur over time.

As the expectation for these SSCs is their replacement during the original plant design lifetime, “ageing” is an expected occurrence and resources for correction of equipment degradation associated with this grouping are built into the normal plant operation through the maintenance program.

At the HFIR, this aspect of life cycle management is carried out through the HFIR maintenance program. Control of these maintenance activities is accomplished by the HFIR Computer Maintenance Management System (CMMS). The maintenance program consists of two types of maintenance.

Corrective maintenance. Corrective maintenance is performed as equipment failures are reported through the HFIR problem reporting processes. Any staff member can report a component that is in need of corrective maintenance. Decisions on the urgency of repair actions are made the by maintenance coordinator depending on the importance of the equipment to reactor operation or nuclear safety. Formal work packages are prepared to ensure all personnel safety work requirements are met, spare parts are available, potential nuclear safety issues are addressed, work instructions are complete and clear (including post-maintenance test requirements), and proper authorizations and training (as required) are obtained prior to the initiation of work.

Repetitive maintenance. Repetitive maintenance is performed as it is scheduled in the CMMS. Repetitive maintenance includes equipment maintenance activities, inspections, calibrations, and special surveillances related to nuclear safety. While both preventive (time-based) maintenance as well as condition-based maintenance activities are applied through this program, condition-based technologies such as vibration, oil-analysis, acoustic, and infrared analysis are a large part of equipment maintenance, and application of these technologies continues to increase.

2.2. Fixed Time Replacement

Fixed-time replacement represents those SSCs that have a known life-time or rate of degradation and their end-of-life can be monitored and predicted with a high level of confidence. Examples would be fuel stock, fuel elements, control plates, and the high precision manufacture of unique reactor and core components. For nuclear facilities, radiation damage is a frequent degradation cause for equipment in this group. Most equipment of this grouping is generally considered to have “passive” functions. An attribute of this group of equipment is their degradation, while known, is not subject to intervention or repair for its mitigation. Another attribute is the vulnerability of these SSCs to supplier problems due to loss of expertise at external providers.

As with “wear-out failure” SSCs, these ‘fixed-time replacement” SSCs also have an expectation for replacement during the original plant design lifetime. As such, these SSCs and their replacement are also generally independent of the plant lifetime.

At the HFIR, replacement of these components is usually handled through individual projects due to the uniqueness of the component, the length of time to manufacture, the quality control required, and the use of external suppliers. Accumulated radiation exposure is tracked for the numerous reactor and reflector components and systems engineers report on components nearing their end-of-life. Fuel inventory is also tracked.

2.3. Reliability Improvements

This group represents SSCs that require modifications due to reasons related more to changes in technology than ageing degradation. This grouping can be further segmented into obsolescence and upgrades.

Obsolescence. Obsolescence is not generally considered to be an “ageing” consideration in the sense of degradation over time. If repair parts remain available, the original component can be restored through the maintenance process to an “as new” condition where future plant operation would not differ from past operation. Under this set of circumstances, the component would meet the attributes of the “wear-out” group of SSCs and is not susceptible to “ageing.” However, as the options for repair disappears over time due to lack of parts or expertise, replacement with newer equipment becomes a necessity. Improvements in equipment function or monitoring may result from replacement for obsolescence but this is not the primary motivation for re-design. Situations of obsolescence are usually identified though monitoring of spare parts availability.

The HFIR has also found that for certain types of equipment, obsolescence can be a relatively short process. Due to the rapid advances in digital and computer technologies, several of HFIR on-line control and monitoring SCADA (supervisory control and data acquisition) systems for the cold source and the reactor have now technically reached their “end-of-life.” These systems are based on the Microsoft Windows XP operating system which debuted in 2001. The XP operating system is in an “extended support phase” from Microsoft with support ending in 2014, meaning these systems will have reached obsolescence in only 13 years. As there will no longer be any “spare parts” for continued maintenance, a new operating system will have to be implemented in the future at a significant cost of planning, time, and resources.

Upgrades. Upgrades are where advancements in technology are incorporated into equipment to provide improvements to energy efficiency, component performance monitoring, or human factors. In this situation, the exact replacement of the original component remains available and would provide continued “as designed” performance. However, its replacement with an “improved” design addresses some additional value-added function. Upgrades are also instituted when the original design of the SSC proves itself to be inadequate from a mission, function, maintenance, or reliability perspective. The most recent “upgrade” was completed at the HFIR cold source where a single-point vulnerability was resolved by installation of a redundant vacuum system configuration.

Although the reliability improvements grouping is not necessarily associated with degradation ageing of SSCs, this grouping is important to the LCMP as it can significantly affect, positively or negatively, facility mission and reliability. Future ageing concerns and issues should be included in the design for these improvements.

2.4. Plant Life Extension

Within the population of plant equipment and structures, there is a group of SSCs for which equipment replacement was not expected during the lifetime of plant. In other words, when the plant was originally designed there was an expected operating life for the facility, after which the facility would be decommissioned. As a result, some of the larger or more complex SSCs were designed for operation for the full design life. These SSCs are largely difficult, if not impossible, to replace and can have either a “passive” or “active” function.[1] For the HFIR LCMP, these SSCs are grouped as plant life extension, or PLEX, SSCs.

PLEX SSCs are a principal focus of the world’s nuclear industry’s efforts in extending the available life of existing nuclear power plants. Both passive and active SSCs are within the PLEX scope of review. While there are multiple programs proposed to deal with this issue, all have similar process elements for (1) identification of affected SSCs, (2) prioritization of importance as to plant safety first and then plant operation, (3) estimation of remaining life for expected future operating conditions, (4) identification of appropriate ageing countermeasures, and (5) implementing processes to monitor SSCs to ensure continued future performance remains as expected. At the HFIR, established processes that address SSCs that belong to PLEX are those generally related to in-service inspection/in-service

[1] The term “function” is broadly interpreted as being associated with operation, shutdown, maintenance, and safety activities.

testing, maintaining water chemistry, material condition control, and corrosion control.

PLEX examples of “passive” SSCs would include piping, cable, buildings and structures, and the reactor pressure vessel. Examples of “active” SSCs would include diesel generators, high voltage switchgear, motor control centers, and high voltage transformers.

For plant SSCs that are not within established plant programs, individual plans should be prepared for the monitoring and management of ageing concerns. For example, the HFIR has recently implemented a continuing cable monitoring program to regularly check the condition of cables and implement trending of test results. The program is on a graded approach with safety-related cables to be completed first and testing of remaining cables to be segregated for subsequent evaluation based on importance. There are also situations where as an individual component fails, it is replaced under the normal maintenance programs. However, if there are hundreds of these aged components found throughout the plant, a strategy to replace them as they fail presents a high risk to the reliability and safety of the facility. In this situation, a program can be implemented to replace all components pre-emptively. This type of maintenance is grouped as a PLEX action as a replacement of entire collections of components is generally not anticipated within the original operating lifetime of the HFIR. However, this has been done at the HFIR with the complete replacement of all nuclear-related relays, again performed on a graded and phased approach. The retrofit of all 45-year old switchgear breakers is proceeding to avoid the significant costs of complete replacement of switchgear (estimated factor of 10 cost savings). The HFIR reactor startup system is in the process of being converted from an analog system to a digital system due to increasing failure rates and inability to obtain spare parts. The battery chargers for the essential batteries are of 1965 vintage and have been sent to the original manufacturer for determining if backfit of obsolescent parts can be upgraded and the charger refurbished. Table 1 provides some additional PLEX activities that have been completed and are planned.

PLEX Actions Completed	PLEX Actions In-Progress or Planned
Primary Coolant Pump Refurbishment	HVAC Unit Replacement
Instrument Air System Replacement	Building Steam Refurbishment
Pressurizer Pumps Replacement	Emergency Diesel Generation Replacement
Pool Water Storage Tank Replacement	Switchgear/Motor Control Center Replacement
Oil-Filled Transformer Replacement	Bus Duct Replacement
Secondary Pump Replacement	Primary System Seismic Upgrades
Cooling Tower Replacement	Reactor Safety/Control System Replacement

Table 1. Examples of PLEX activities at the HFIR

One of the unique characteristics of these SSCs is their degradation may be very slow with hidden failure mechanisms present. In these cases, special attention or knowledge by the systems engineer may be needed. To assist in this area, the HFIR brought ageing subject matter experts from the Electric Power Research Institute to provide to HFIR systems engineers a series of SSC-specific training on ageing mechanisms and symptoms.

The PLEX portion of the LCMP has been recognized as a critical element of the long-term vision and processes are being developed and prepared to identify PLEX-related equipment, define degradation vulnerabilities, and implement effective appropriate monitoring methods.

3.0. Additional Ageing Effects

There are additional effects that can provide adverse impacts to equipment. Increasing regulatory requirements can impose a “pseudo-ageing” effect by reducing the available remaining margin of the SSCs. For example, for US Department of Energy nuclear-related facilities, new seismic hazard curves are established every 10 years. If the hazards increase as a result of these studies, the result effectively “accelerates” the ageing of the component by reducing the available seismic margin for the SSCs. Another pseudo-ageing effect results from simply increasing the window of hazard exposure time. An example would be where a facility life time is extended from 40 years of operation to 80 years. With this 40-year extension, the interval for a possible tornado strike at the facility is lengthened with affected SSCs being more vulnerable due to effects of ageing.

4.0. Procedures and Administrative Tools

At this time, formal processes for maintenance of equipment, both for corrective as well as preventive maintenance, are fully in place and controlled by procedures. These processes address the group of "wear-out" failures and are supported by computer-based tools that identify maintenance needs, schedule and control work, and provide a database for equipment maintenance history.

SSCs that are included in the "fixed-time replacement" have been largely identified and are monitored. It remains for this grouping to be defined by a formal process and integrated within the HFIR LCMP. The HFIR is preparing a process to track accumulated radiation exposure for reactor and reflector components through a web-based Cycle Data Management System application with pre-populated reports and graphs generated upon request. The power of the computer is also being exploited to disseminate maintenance information and results to HFIR staff such as the web-based Condition Monitoring Analysis Report (CMAR), the Master Equipment List (MEL), and the HFIR Data system. In the CMAR, results from condition monitoring activities are posted and color-coded for quick equipment status information. These color codes are sortable allowing quick review of equipment status across the plant. The underlying database also provides for recording information on a particular reading or the attachment of reports in order to maintain a comprehensive condition-monitoring history for each component in the program. The MEL contains information related to equipment specifications, photographs, manuals, operability status, and maintenance work history. Summary icons of the condition monitoring history for that component are posted as well as a performance percentage over the previous 365 days.

The grouping of "reliability improvements" is administered through both traditional (control of plant modifications) and staff-focused (plant heath and reliability action tracking or PHRAT) plant processes. The PHRAT computer tool is where any staff member can identify problems with obsolescence or reliability which is then regularly reviewed by management and staff for prioritization, coordination of resources, and monitoring of corrective measures.

At a high level and broad administrative level, the HFIR LCMP is overseen by a Plant Health Committee (PHC) which is chaired by the plant manager and consists of the managers of operations, systems engineering, maintenance, nuclear safety, and reliability. This committee meets weekly to discuss events of interest to the health and reliability of the plant. All plant systems are grouped into 16 Engineering Reliability System Groups (ERSGs) with a team of systems engineering, maintenance, operations, and nuclear safety assigned to each. Two times each year, each ERSG team is to present a current health status of their systems to the Plant Health Committee, providing HFIR management with detailed information on all systems on a routine schedule for any necessary action and planning with more frequent presentations requested by the PHC Chair if determined necessary. Special issues of concern to plant reliability are also brought to the attention of the PHC.

5.0. Conclusions

Because the ORNL High Flux Isotope Reactor is one of the few remaining multi-purpose neutron production facilities still operating in the US, it is vital that its operating lifetime be lengthened to the greatest extent possible from both an economic and safety standpoint. Indeed, the current plans are for the HFIR to operate until 2050 or beyond. However, HFIR management and staff recognize that in order to meet this objective, it is imperative for the facilities and SSCs to be preserved and maintained at a high level of safety, reliability, and efficiency. This long-range vision is to be accomplished through a systematic and planned shift from the more traditional maintenance processes and methods that are focused on short term production objectives to a more holistic view of ensuring long-term operation and reliability goals. To that end, the HFIR is preparing a comprehensive Life Cycle Management Program that defines the roles for and integration of existing and new maintenance processes in a manner that maximizes the effectiveness of existing programs, identifies gaps in maintaining SSCs health, and integrates the disparate needs for long-term monitoring of HFIR facilities and equipment.