Developing Systematic Maintenance & Aging Management Programs

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Abstract

AECL's Plant Life Management (PLiM) capabilities emphasize an integrated approach that fits well with the industry direction to follow industry best practices such as INPO AP-913. Integrated assessment processes supported by software tools, such as AECL's SYSTMS™, combined with knowledge databases available for direct application in these assessments has many benefits. This paper considers how these benefits contribute to the development of best practice maintenance and aging management programs. Enhanced abilities such as implementation of Maintenance Based Design, as is being applied to the ACR-1000®, and ongoing developments such as Risk Based techniques are also considered.

1. Introduction

Plant Life Management has been a topic of interest for nearly 20 years. In that time there have been many developments leading to improvements in Aging Management Programs (AMP) world wide. The initial focus of many PLiM activities was on long- lived passive components. In some cases, this required additional Research and Development (R&D) to support the aging evaluation and the potential methods to mitigate the identified risks.

In parallel, maintenance optimization was being considered by many utilities in the nuclear industry. There have been several variants of this process developed and applied, each with advantages and disadvantages. Ultimately, a standard was developed for Reliability Centered Maintenance (RCM) by the SAE; however the debate over the best approach carried on. One thing was clear, maintenance optimization usually is focused on the short term maintenance required for active components and was and typically still is treated as a completely independent consideration from the development of aging management programs.

Over the last decade there has been an increasing focus seen in plants world wide to apply more systematic processes; to move Operations & Maintenance (O&M) to be more proactive rather than reactive. In the same period, there have been enhancements in information management capabilities. Driven by an aging population of experts, there is now an increased focus on using these enhanced capabilities.

Best practices are now seen as bringing all the elements of aging management, preventive maintenance, knowledge management, and business decisions together. The most prominent example is INPO AP-913, which more and more utilities in North America are embracing. Such practices, although relatively simple in concept, are not as easy to implement in a consistent manner. As the actual programs that carry out Maintenance, Surveillance and Inspection (MS&I) at plants are somewhat independent, the integrated plan implied by the INPO model requires a change in thinking to achieve the best results.

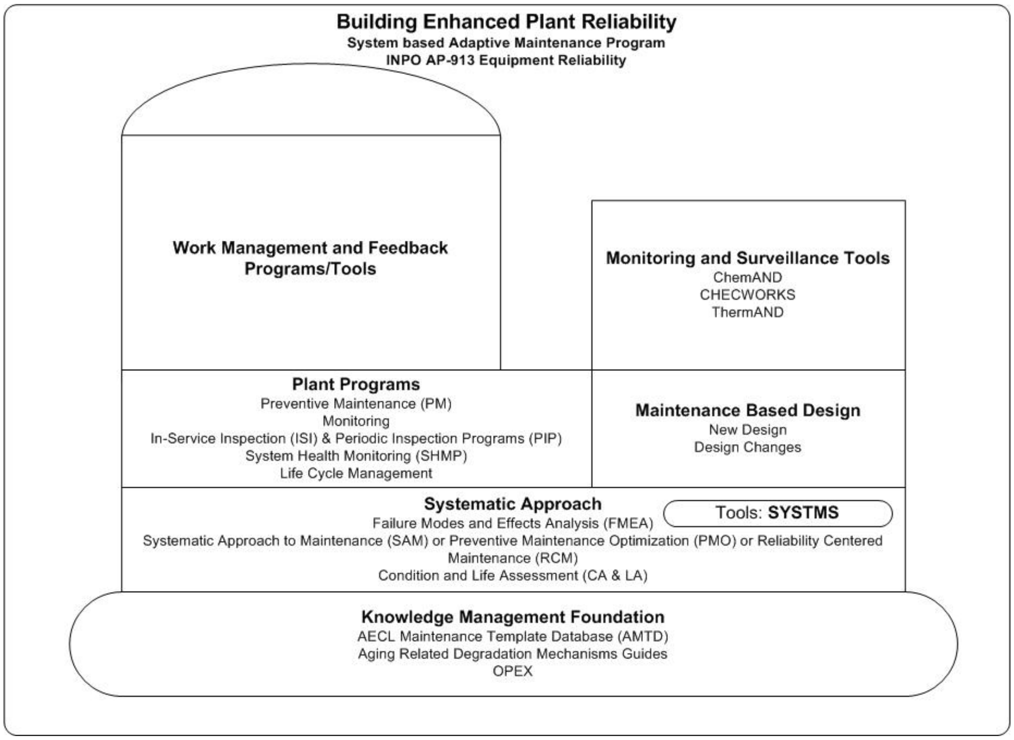

Figure 1: Building Enhanced Plant Reliability

AECL, through its own development efforts, has been looking at PLiM as a series of integrated elements for many years. This has led to the development of an overall approach that addresses many of the requirements of INPO AP-913. This approach will be described through consideration of program development, the assessment needs to establish the overall foundation, the systematic thinking behind the approach, and the information support needs that make the approach efficient and effective. An overview of the various components discussed in this paper is represented in figure 1.

2. Program Development

As noted, there is a tendency to treat management of active and passive components completely separate from each other. In the application of specific programs, this would make sense; however, the separation also has a price. The price is the loss of system perspective. The system perspective gives the context for the MS&I being applied and is important in ensuring that only the right maintenance is applied to manage the risk faced by the plant operator.

Realizing that there is value in understanding the plant condition from a system perspective, many utilities have put in place some form of system health monitoring program. These programs are often developed somewhat independently from the Preventive Maintenance (PM) and inspection programs. Monitoring parameters are not necessarily associated with the PM program.

In Canada, regulation drives the Periodic Inspection Program (PIP) and In-Service-Inspection (ISI) is dictated by utility needs. The requirements of these programs are also developed separately from the system health programs.

The thinking implied by INPO AP-913 is to look at this process as a whole. It becomes clear that when considering a component, one needs to consider the entire MS&I strategy of that component. Further, the strategy needs to be developed and subsequently maintained within the understanding of the system context. That is, why is this component important, or not, and as such, what kind of MS&I strategy is needed to manage the component adequately.

By way of example, consider a pump in an important system; say one important to safety. That pump may have a combination of time based and condition based or predictive maintenance together with a testing program to support reliability demonstration, plus PIP or ISI particularly for pressure boundary monitoring. These could be treated as completely independent elements, or they can be developed together, to ensure there is no more attention paid to the pump than needed while assuring equipment reliability to acceptable levels. Individual programs will ultimately implement the MS&I strategy and monitor its effectiveness, but these programs need to work together to provide the reliability assurance being sought. Hence, the integration or synergy of these MS&I programs should begin early.

3. Component Criticality and Maintenance, Surveillance, & Inspection Strategy

Through consideration of the specific areas identified in INPO AP-913 one can simplify the process into three parts; assessment, implementation (including economics), and monitoring and feedback. Scope definition, important or critical component identification, equipment reliability analysis, and parts of business planning and Life Cycle Management (LCM) can be treated as "assessment". The assessment can be effectively dealt with as a single process.

It was noted previously that the level of integration or separation in the overall program is determined in the assessment phase. The programs used to implement the MS&I strategy are inherently independent, so the ties to each other need to begin in the definition phase. System Health programs can tie the maintenance, inspection, and monitoring programs together if applied properly, but will not be as effective or efficient as can be achieved if the relationships are established in early stages.

To explain, consider within the assessment phase, the determination of component criticality and establishing the MS&I strategy. First, Component Criticality, a result that is at times determined independently of the rest of the process, is needed to effectively define the technical basis for the MS&I strategy. Consider how the Component Criticality is determined. Through understanding component function, within the context of the system and the system within the plant, an understanding of the consequence of failure is derived. Based upon the nature of the consequence, the component criticality is defined. Those components with tolerable consequences may become maintenance discretionary, subject to some qualifiers. This also helps to define those items with maintenance purely driven by economic considerations, and those that have a higher implied risk that goes beyond simple economic considerations. This then forms the foundation (or technical basis) for the level of effort deemed appropriate to address potential failures, and helps address the specific failures of interest. That is, the component criticality is the first step towards establishing the technical basis for the MS&I

strategy. For those components deemed to be maintenance discretionary, this may be the entire technical basis for this strategy.

As noted above, the determination of component criticality requires understanding the components role or function within the system context and in turn the role of the system within the plant context. Component Criticality requires taking the time to understand the system and its function before evaluating the component itself. The component is treated as a single unit that may provide several functions.

Component Criticality also requires understanding the owners (plant/utilities) perspectives regarding acceptable risk, and understanding what the utility considers an acceptable/unacceptable failure. This will be unique for each utility, as perspectives are inherently subjective. Utilities as corporate individuals will have unique perspectives as individuals.

The development of further details of the MS&I strategy can be performed so as to begin the separation of the MS&I elements. For example, if the passive functions are treated completely independently, then the separation begins, as the basis for what is usually ISI programs will be separated. If testing is treated as a means only to meet reliability targets, then the basis for Periodic Testing Programs is separated and may not be included as part of the preventive maintenance strategy. If time based maintenance is defined independently of condition based or surveillance type maintenance, then PM program tasks can becomes independent elements.

A complete Technical Basis for the component's MS&I strategy must consider:

- component function and importance (defined in Criticality evaluation)
- operating context
- design margins (including environmental effects eg. EQ.)
- unique features of the component
- typical degradation mechanisms
- need to understand how to prevent degradation mechanisms or mitigate their consequences
- need to understand limitations due to maintainability, economics, and personnel capability (skills and equipment)
- need to understand the economics of managing the component's life.

The overall MS&I strategy addresses all aspects of the components life, whether short term or long term. It does not need to be broken down or separated. By considering the MS&I strategy as a whole, one can link the various programs and identify where generic program tasks need to be adapted for unique component MS&I needs.

4. Systematic Approach

4.1. Systems Approach

The treatment of Component Criticality and the MS&I strategy development as a single analysis can be extended to include Life Cycle Management plans. This requires two characteristics:

- Consideration first of the system as a whole ('system level'), followed by consideration of system components ('component level')
- Requires systematically working through the system (address all parts of the system)

That is, the initial perspective is the system. Then using that system thinking to work down to the component level. This kind of thinking is characteristic of Failure Modes & Effects Analysis (FMEA) or similarly, Failure Modes & Effects Criticality Analysis (FMECA), which is effectively the basis of the various Maintenance Optimization strategies such as Reliability Centered Maintenance (RCM) and Preventive Maintenance Optimization (PMO). It is worth noting that one needs to be careful when using these optimization approaches as many strategies offer the opportunity to ignore the system and focus on components only. This will tend to require breaking down the process to first determining component criticality independently and then evaluating maintenance. RCM style techniques, when properly applied can address all these requirements in a single process. PMO processes are more likely to eliminate the system perspective, but can be applied such as to address this need.

4.2. Systematic Assessment of Maintenance (SAM)

AECL has developed a systematic approach to assessing system MS&I, known as SAM. It is based upon a Streamlined RCM technique, adapted initially through work with Point Lepreau, and then further adapted to enhance the process efficiency and effectiveness. The process provides a systematic approach to developing component criticality and technical basis needed to provide consistency and effectiveness. The overall SAM process is shown in figure 2. The process generally includes the following steps (individual steps are described in more detail in a previous paper [1]):

1. Function and functional failure analysis
2. Criticality analysis (failure modes, effects and criticality analysis)
3. Task selection
4. Task comparison
5. Task packaging
6. Surveillance matrix development
7. Implementation feedback (to monitor the effectiveness of a selected task)

Consistent with the description in section 3, determining component criticality relies on understanding the component failure modes and their consequences within the system context. An important part of this is the development of a comprehensive set of criterion for the evaluation of failure consequences. This needs to address a range of possibilities, as failure consequences are dependent on a number of assumptions. A consistent set of criterion can eliminate ambiguity and ensure a more reasonable result. This set of criterion must reflect the plant goals and risk adversity. Again, if properly thought through the end result will be a more efficient and effective assessment process.

The Component Criticality review (Step 2) provides the first part of the technical basis for each component's MS&I strategy. It also represents the entire needed basis for components whose failure is detectable and the consequence of failure is acceptable to the plant operator. As such, these components require no further assessment, can be deemed maintenance discretionary, and can be eliminated from further analysis.

For those components that are identified as more critical, the SAM process is carried out further to determine those measures needed to deal with the consequence or reduce the likelihood of the component failure (Step 3). The measures in this case are the maintenance, surveillance, inspection and testing strategy applied to each component. Steps 4-7 of the SAM process go even further to identify associated information, such as whether it is an outage task, or what state the component is in (running/off), or estimated maintenance effort, and associated organizational responsibility.

4.3. Condition & Life Assessment

AECL has developed a separate set of techniques for Aging Assessment originally developed and applied to older aging plants considering life extension (eg. PLGS, G-2, W-1, and recently Embalse). While similar in overall approach to SAM, the process is geared to address aging related degradation mechanisms (ARDMs), which are at a deeper level of detail than the failure causes typically required for active components. The process also lends itself to support for Life Cycle Management.

When applied to older plants, as originally developed, the primary goal is to establish a prognosis for life attainment (i.e. design life or refurbishment date) and reaching a predetermined life extension. The Condition Assessment (CA) process lends itself to assessment of systems, structures, and commodities or components. Life Assessments (LA), being a process intended to be a more detailed assessment, is geared toward the most important structures and components.

A secondary goal is also achieved for the older plant assessment. That is the existing aging management practices associated with the System, Structure or Component (SSC) are evaluated. For a system study, the system components are prioritized, each component's ARDMs of interest are identified, and the plant's management strategy for those ARDMs are evaluated, resulting in the inputs for developing an aging management strategy or as a minimum, identifying those unknown parameters needed to establish a workable aging management strategy. Through the addition of a current condition evaluation, the prognosis for life extension is achieved. With the application of the economics of the management strategy, a LCM plan can be established.

For a younger plant, the life prognosis is not the primary goal. The identification of potential aging issues and the establishment of a proactive aging management program is the goal. Establishing the component current condition is not as important to achieving this goal, although identifying any potential issues unique to an SSC is still important. The assessment process in this case is completely complementary to SAM. In fact, the processes can be combined such that a single overall strategy is applied.

5. Supporting the Assessment

To make the overall systematic assessment process more effective, AECL has developed enhancements in 3 areas:

- Improved detailed processes to increase overall assessment consistency and efficiency [2]
- Developed the SYSTMS™ tool
- Focused effort on developing a knowledge management strategy that supports the assessment process

5.1. SYSTMS™ Tool

SYSTMS™ (SYtematic approach for the STrategy development for Maintenance and Surveillance or approach SYstematique pour development de STrategy pour Maintenance et

Surveillance) is a fully integrated, user friendly, software tool designed by AECL to perform the Systematic Assessment of Maintenance process in a highly efficient way.

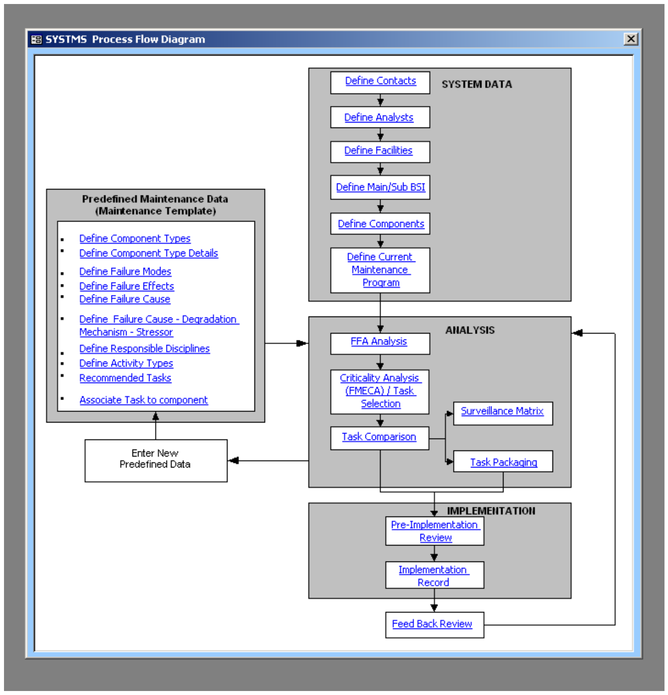

Figure 2: SYSTMS™ Process Flow Diagram

This tool facilitates the SAM process described in the previous section, beginning with the performance of function and functional failure analysis and uses the expert knowledge gathered from a centralized maintenance template database to support the analysis to establish the technical basis for the MS&I strategy of each system component. The tool then assists in implementation tasks such as task comparison, task packaging, surveillance matrix development and tracking of implementation of packaged tasks. Additionally, the effectiveness of the implementation tasks can be fed back into SYSTMS for continuous improvement in task selection. This latter capability facilitates the System based Adaptive Maintenance Program (SAMP) or equivalently concepts as such as “Living Program” and INPO’s AP-913 Equipment Reliability Guideline. The interactive help screen from SYSTMS™ is captured in figure 2, showing the overall assessment process.

SYSTMS also includes many standard pre-defined reports, import and export of SAM data. Analysis of similar component types can be copied to make the system assessment process faster. Another useful feature is a tracking system to track the progress of analysis at every stage and a fully secured system to track users access as well as privileges for modifying analysis data.

5.2. Knowledge Management

An important aspect of generating consistent assessments (whether SAM, CA, or LA) is the availability of relevant support information to be used to decide which failure modes or ARDMs are important and also knowing what can be done about each. With the retirement of many experienced experts, the problem is exasperated. To deal with this AECL is actively dealing with enhanced knowledge management activities. An example of this is the AECL Maintenance Template Database (AMTD).

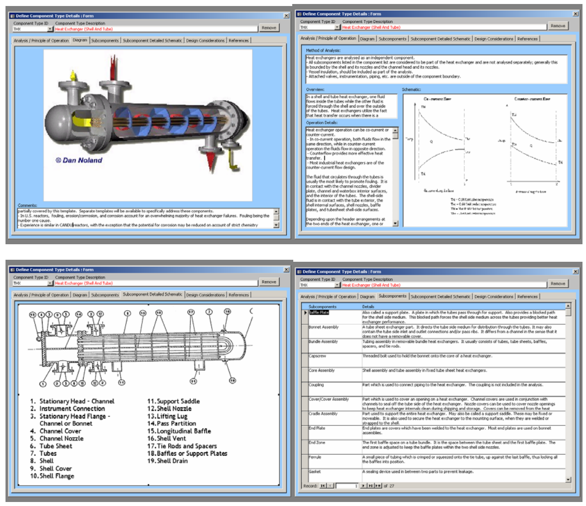

Figure 3: Examples of the AECL Maintenance Template Database within SYSTMS™

Individual templates (example shown in figure 3) for approximately 110 different component types in a NPP have been created which contain CANDU and generic information describing how each component can potentially fail in service and provide guidance in the selection of an appropriate maintenance strategy to address these failures.

The data within each component template is organized to include:

<u>Failure Modes</u>: Way in which the component fails to perform a function for which it is intended. Typically high level modes, similar to those used in PSA (eg. failures to run, start, stop)

<u>Failure Causes</u>: Major root causes of the failure mode that generally identifies the area or subcomponent which is not functioning as it should thereby resulting in a failure mode. Many causes can be associated with a single failure mode (eg. bearing seizure).

<u>Degradation Mechanisms</u>: Any mechanism that acts to degrade the performance or integrity of the component thereby resulting in a failure cause. Again, many degradation mechanisms can lead to one failure cause (eg. fatigue, wear)

<u>Stressors</u>: A physical state or stimulus which is caused by fabrication, installation, operational conditions, and/or environmental conditions that may induce or activate a degradation mechanism. Multiple stressors are potentially associated with each degradation mechanism (eg. temperature, bearing load))

<u>Maintenance Tasks</u>: Maintenance, surveillance or inspection technique

This data is inter-linked to facilitate selection of the expected component failures for the application under consideration. Based upon the identified failure causes effective the maintenance activities are selected.

The templates are a valuable information source. They incorporate industry experience, including CANDU specific operating experience, design and lessons learned, AECL's technical expertise, industry standards, in-house and external aging assessments, manufacturers operation and maintenance recommendations, and research programs. They also serve as a learning tool for the less-experienced analyst by providing the basics of component operation and design.

The SYSTMS tool can be populated with the data that originates from AECL's Maintenance Template Database. This provides the analyst with information for consideration (presented in the tool an options that can be selected based on analyst judgment) as they build the MS&I strategy for each component. In this way, analysis is performed consistently, and those with less experience are also provided with guidance to achieve a more appropriate result.

The database includes templates for both passive and active components. The information collected and maintained in this database was used as an input to derive ARDM guidelines for each of: Instrumentation, Controls, and Electrical (ICE) devices, Process and Mechanical Equipment, and Concrete Structures, developed for the Embalse CA project [2]. This also facilitates the assessment of all components for maintenance purposes, within the SYSTMS tool. That is, the capability to perform CA, LA and SAM for the purpose of MS&I strategy development is provided.

6. Design Applications

It was noted earlier that the thinking behind these systematic techniques is characteristic of FMECA approaches. In fact, the approach, and therefore the tools to apply these approaches require very little adaptation to allow FMECA to be completed within the SYSTMS™ tool. Prototype adaptations to the tool included providing a means to track all resulting actions and dispositions that result from the FMECA. Also, the Templates in the AMTD contain much more detailed information than needed to carry out FMECA assessments for the purposes of system design verification. Some simplifications to SYSTMS are necessary to make the process completely automated.

Acknowledging this potential, there are two design applications for the processes and tools presented herein. The first is the application for new plant design such as the ACR 1000®. The Maintenance Based Design concept [3] can be supported through these tools. Currently pilots are underway to explore the benefits and refine the process for this design application. The SYSTMS™ tool and AMTD are used without modification for this application. A benefit, amongst many, from this process is the understanding and definition of the maintenance strategy required for the new plant that complements the component, system, and overall plant design to ensure operational goals are achieved.

The second design application is for FMECA design assist support. AECL has completed such an application for the AECL CANDUclean system with good success. The prototype adaptations noted above were developed for this application. It is expected that similar design assist activity will be carried in the future.

7. Next Steps

While these processes are effective to dealing with the assessment work, and in providing a facility to track implementation and changes over time, they don't provide for direct tracking of maintenance results, nor do they assist in carrying out these MS&I strategies. Hence there is often a need to ensure effective monitoring and experience feedback on a system as service operation continues e.g. an adaptive aging management program. AECL does have a number of tools to assist in this area; ChemAND & ThermAND [4] to name a couple. There continues to be significant development in this area.

Beyond the feedback and monitoring, there are areas for enhanced decision making within the assessment process. In this regard, Risk Based Inspection (RBI) is the next area of improvement. The techniques described in this paper lend themselves to facilitating qualitative Risk Based Inspection. Specific protocols are required to apply this. Qualitative RBI processes are widely available in industries outside of the nuclear industry, so there is primarily a need to adapt existing technology. This would focus on the passive components primarily, although there is the potential to enhance the application of Risk Based decision making for active component programs as well.

Quantitative RBI is also possible, although the largest single hurdle is the lack of useful statistical data to support such quantification. However, there are approaches available combined with new information being gathered that promise to make this a viable technology as well.

8. Conclusions

Maintenance, Surveillance, and Inspection programs are usually quite independent of one another, requiring unique tools and technologies to implement. Yet, the best practices reflected in processes like INPO AP-913 reflect a more integrated approach.

AECL has been developing its maintenance and aging assessment processes maintaining the vision of providing an integrated solution. The SAM, CA, and LA processes work together to address passive and active components, addressing component criticality, and establishing the technical basis for the MS&I programs. The overall approach uses a systems approach, working from the system as a whole to the individual component parts. In so doing, the resulting MS&I programs have their links established during the assessment process.

To support this assessment process, AECL has been working to improve the details of the process to ensure consistent results in an efficient manner. The SYSTMS™ tool was developed to guide analysts through the assessment process. This tool takes advantage of AECL's knowledge management activities to further enhance the effectiveness of this process. In this case the AECL Maintenance Template Database provides the needed background information to support the assessment process.

The processes and tools available today are being used to improve AECL's own design processes. They also are forming a foundation to move forward, to provide Risk Based technology.

9. Acronyms

AECL	Atomic Energy of Canada Limited
AMP	Aging Management Program
AMTD	AECL Maintenance Template Database
ARDM	Aging Related Degradation Mechanism
CA	Condition Assessment
CANDU	CANada Deuterium Uranium, registered trademark of AECL
ChemAND	Chemistry Analysis and Diagnostic system
FMECA	Failure Modes and Effects Criticality Analysis
FMEA	Failure Modes and Effects Analysis
INPO	Institute of Nuclear Power Operations
ISI	In Service Inspection
LA	Life Assessment
LCM	Life Cycle Management
MS&I	Maintenance, Surveillance and Inspection
O&M	Operations and Maintenance
PIP	Periodic Inspection Program
PLGS	Point Lepreau Generating Station
PLiM	Plant Life Management
PM	Preventive Maintenance
PMO	Preventive Maintenance Optimization
RBI	Risk Based Inspection
R&D	Reasearch and Development
RCM	Reliability Centered Maintenance
SAE	Society of Automotive Engineers
SAM	Systematic Assessment of Maintenance
SAMP	System based Adaptive Maintenance Program
SSC	Structures, Systems and Components
SYSTMS	SYstematic STrategy development for Maintenance and Surveillance
ThermAND	Thermomechanical Analysis and Diagnostic system

10. References

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