Approach for the Management of Plant Aging

W.M.C. Knowles, T. Andreeff, C.W. Gordon and C.I. Jobe

Ontario Hydro
595 Bay Street
Toronto, Ontario

ABSTRACT

Increasing attention both internationally and within Ontario Hydro is being focused on the need to better understand and manage the effects of aging on the materials and components in nuclear generating stations. The overall objective is to ensure that nuclear generating stations meet their long-term production targets at an acceptable cost and with acceptably low risks to the public and the environment. This paper presents a general model for aging management which provides a logical basis for the many programs and activities undertaken by a utility to achieve this objective.

1. INTRODUCTION

The first generation of commercial nuclear power plants is reaching the halfway point in its design life. In Ontario Hydro's Demand/Supply Plan, a high priority is assigned to maintaining the effectiveness of Ontario Hydro's nuclear power plants over their remaining economic life. We need to better understand and manage the effects of aging on the materials and components in these facilities. The overall objective is to ensure that Ontario Hydro nuclear generating stations meet their long-term production targets at an acceptable cost and with acceptably low risks to the public and the environment.

Within utilities, including Ontario Hydro, many activities and programs have been or are being developed which address various aspects of component aging. To provide a structure for these programs and show that they form an integrated approach, a general model for aging management has been developed. The model includes a simplified representation of the aging degradation process and the functions required to manage this process. Examples of specific activities or programs which perform these functions are also described.

2. AGING MANAGEMENT MODEL

2.1 Overview

The systems and components comprising a nuclear power plant are designed to perform acceptably over a specified nominal life. The majority of components achieve this goal; however, in some cases premature failures may occur. Some of these failures may be caused by aging degradation. Although this is generally a gradual process, if allowed to progress undetected, it may affect the reliability and safety of a nuclear power plant in several ways including:

a. the erosion or reduction of safety margins afforded by defence in depth;

b. the occurrence of common-mode or simultaneous failures in redundant safety systems under conditions resulting from design-basis events;

c. the increase in the failure frequency of process systems resulting in production losses and increased frequency of safety system usage; and

d. increased operation and maintenance costs leading to uneconomic operation.

To address aging degradation and thus maintain the required level of reliability and safety of nuclear stations over time, a variety of activities and programs are executed during the life of a plant. These are applied to differing degrees based on the nature and significance of the component. In order to provide a logical basis for the comparison of aging-related activities and programs, a model has been developed for the aging degradation process and the functions performed to manage this process.

2.2 Aging Degradation Process

A component experiences a number of stresses over its life. The cumulative effect of these stresses is to degrade the functional performance of the component until, eventually, it may fail (a component fails when its minimum required functional performance is no longer met). To ensure that the functional performance of a system remains at an acceptable level over the nominal design life of the plant, a number of strategies may be adopted based on the nature and function of the system and its components. These strategies may involve the repair or replacement of components as follows:

a. on demand - for non-critical components. The system functional performance may be maintained by repairing or replacing components as they fail;

b. time-based - for critical components, the system functional performance may be maintained by conservatively repairing or replacing components after a specified period of time. The time interval may be based on calender time since installation, operating time or operating cycles; or

c. condition-based - for critical components, the status of a component is monitored and repair or replacement decisions are taken based on the condition of the component.

The repair or replacement of critical components at some specified point before the end of their design life is a relatively simple approach. However, it can be inefficient leading to more frequent repairs or replacements than necessary or impractical in the case of components designed for the life of the plant. This approach can also be ineffective if the rate of aging degradation is faster than anticipated. Our understanding of aging degradation and the complex interactions between in-service stresses is, in some cases, limited. Consequently, the trend is towards the periodic monitoring of the condition or functional performance of critical components so that corrective action may be taken prior to component failure.

2.3 Aging Management Functions

To maintain continued safe and reliable operation, aging degradation needs to be effectively managed. Internationally, several programs have been proposed or developed to address aging (1,2,3). Based on these programs and an understanding of the aging degradation process, top-down structured analysis was used to develop a consistent set of functions that are necessary to manage the aging degradation process and to define the interfaces between them (4).

This analytical process begins with a top-level view of the interactions between an aging management program and the external environment. This establishes the context and constraints within which aging is managed. In general, aging is managed in the context of an existing licensed in-service plant. The established design basis, safety and reliability analyses, quality assurance programs and operating and maintenance procedures assure an acceptable level of safety at the beginning of plant operation. Thus, the aging management model depicts those functions necessary to address the effects aging may have on this level of safety.

The aging management model evolves from this context in a series of data flow diagrams which include functions and interfaces between functions or the external environment. The top-level data flow diagram is illustrated in Figure 1 and includes the following basic aging management functions:

a. *Assure Component Qualification* - ensure safety-related components are able to perform their intended functions, even if subjected to harsh environmental conditions resulting from design-basis events, over the nominal life of the component;

b. *Verify Safety and Risk* - verify that the risk to the public continues to remain within acceptable limits over the life of the plant (that is it meets Ontario Hydro risk-based safety goals and plant licensing basis);

c. *Manage Reference Configuration* - manage the reference configuration consisting of the design and operating and maintenance programs over the life of the plant by identifying the configuration and by controlling changes to it;

d. *Understand Aging* - review system design, fabrication, commissioning, operation and maintenance information to understand aging mechanisms and interrelationships between stressors;

e. *Detect Aging* - for safety-related components, inspect and monitor component status to detect aging degradation to ensure that functional capability of the component exceeds the minimum required over the nominal life of the component; and

f. *Mitigate Aging* - where aging mechanisms are detected which were unanticipated or whose rate is unacceptable, instigate measures to mitigate the effects of aging, such as changes in operation, rehabilitation or replacement, to ensure that overall plant safety is maintained.

Lower-level data flow diagrams may be developed, as required, to provide additional insight regarding the aging-related activities and programs which may fulfil the key aging management functions.

2.4 Application of Aging Management Model

The model described above outlines a general approach to assuring continued nuclear station safety; however, a nuclear station is composed of a wide range of components and materials of varying significance and susceptibility to aging. As a result, the activities or programs which perform the aging management functions for individual or groups of components may vary depending on a number of factors including:

a. the safety significance of the component;

b. the ease of component replacement;

c. the expected nominal life of the component;

d. the cost of the component; and

e. the effect of the component on overall reliability.

Based on these factors, components can be categorized as follows (5):

a. Category I Components - those components which are considered significant for safety or long-term reliability and which are essentially non-replaceable. The nominal design life of these components typically govern the overall life of the station. Examples of components within this category include the calandria vessel and the containment structure.

b. Category II Components - those components which are considered significant for safety or long-term reliability and which are replaceable. Replacement though is costly both in terms of capital expenditure and outage time. Examples of components within this category include pressure tubes and steam generators.

c. Category III Components - those components which, as a group, are considered significant for plant safety or reliability and are replaceable on a routine basis. Examples of components within this category include instrumentation, shutoff rods and valves.

d. Category IV Components - all other remaining components not included in the above categories.

Categories I and II represent a small number of large, generally unique components. These components are highly significant in terms of their impact on plant life, economics, safety and reliability. For components in these categories, specific aging-related programs may be developed. The emphasis is primarily predictive to ensure that unacceptable aging degradation is detected early and that steps are taken to mitigate the degradation before it has an adverse effect on plant life, safety or reliability.

Category III represents a large number of smaller, replaceable components which are typically provided with a high degree of redundancy. Single failures of individual components are generally not significant to safety or to long-term reliability. The plant may, however, need to be derated or shutdown for short periods while the component is repaired. Safety or long-term reliability is only affected by common failures of several components or by adverse trends in the rate of individual component failures. For components in this category, broader-based activities and programs are used to perform the functions in the model. The emphasis is on inspection and preventive maintenance to prevent or detect individual component failures and on surveillance to assess overall trends. General mitigative measures may be taken when adverse trends in the performance of individual or groups of components begins to affect plant safety or long-term reliability.

This categorization scheme is illustrated in Figure 2.

Aging-related activities and programs are undertaken throughout the entire life-cycle of a nuclear plant and embrace design, operations and research functional organizations. The relationship between aging management function, component category and typical aging-related programs is summarized in Table 1.

3. CONCLUSION

This paper has presented an approach for managing the effects of aging. The approach establishes a logical framework from which program requirements are defined. The objectives and scope of design, operating, maintenance and research programs are compared to these requirements to ensure their adequacy and to identify areas requiring improvement.

4. REFERENCES

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Table 1:
Aging Model Application

Aging Management Function	Component Category[1]	Typical Programs
Assure Component Qualification	I, II and III expected to function in harsh post-accident environmental conditions	Environmental Qualification
Verify Safety and Risk	I, II and III	Safety Analysis Updates Risk Assessments
Manage Reference Configuration	All	• General Design & Operations Activities • Configuration Management
Understand Aging	I,II	• NPLA
	All	• Operating Experience • Technical Surveillance
Detect Aging	I,II	• Periodic Inspection • NPLA
	II (fatigue sensitive)	• Transient/fatigue monitoring
	III	• Operational Reliability
	All	• Preventive Maintenance Programs • Technical Surveillance
Mitigate Aging	I, II	• NPLA
	All	• As required

[1]. Component categories are as follows:

I. Critical components whose replacement is impractical.
II. Critical components whose replacement is feasible but expensive.
III. Critical, replaceable components.
IV. Non-critical components

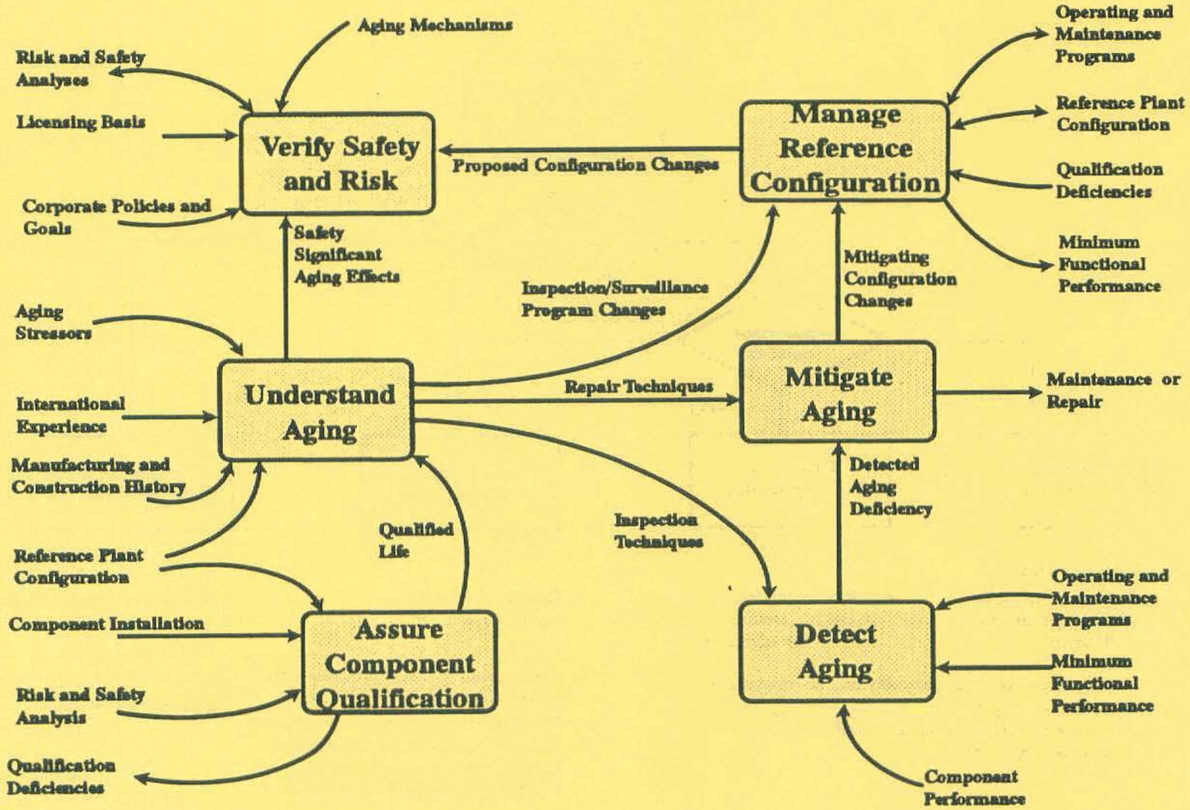

Figure 1:
Aging Management Functions

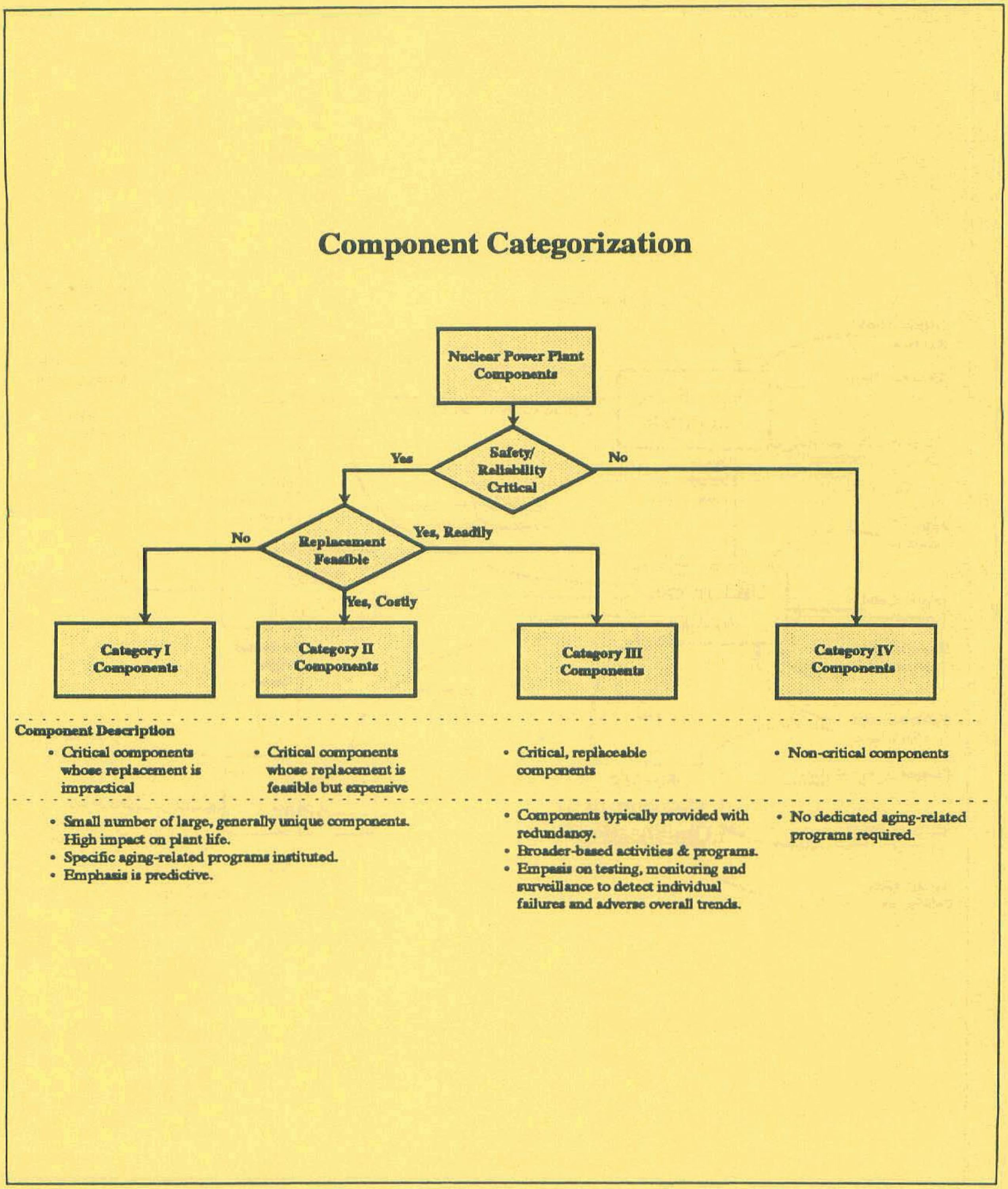

Figure 2:
Component Categorization