14th International Symposium on the Packaging and Transportation of Radioactive Materials (PATRAM 2004), Berlin, Germany, September 20-24, 2004

Paper # 039

Aging Management Assessment of Type B Transportation Packages

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ABSTRACT

The condition of a physical system such as a radioactive materials transportation package can change as it ages. The degree to which aging effects are identified, prevented or mitigated will depend on the types of inspections and maintenance performed on the critical components of the system. Routine inspections and maintenance may not address degradation mechanisms that are difficult to observe and can act over long periods of time. Aging management is a systematic effort to ensure that the system performs as designed over its entire service life and that degradation mechanisms do not prematurely end the service life.

The Nuclear Waste Management Division (NWMD) of Ontario Power Generation (OPG) has developed an Aging Management Procedure and began performing aging management assessments on its Type B(U) packages. This paper discusses the Procedure and briefly describes the aging management assessment performed on the Roadrunner Transportation Package to demonstrate a practical application of the aging management process.

1.0 INTRODUCTION

An aging management procedure has been developed by the Nuclear Waste Management Division (NWMD) of Ontario Power Generation (OPG) for application to its nuclear waste management facilities and equipment including radioactive materials transportation packages. The procedure is based on the Electric Power Research Institute (EPRI) guidelines for aging-related assessments and analyses of nuclear power plants [1], [2]. The EPRI documents provide guidance on identifying systems, structures and components in the nuclear power plant that require aging management reviews and also describe methods for performing effective aging assessments. The OPG-NWMD procedure is a simplification and customization of the processes described in the EPRI documents. This paper describes the OPG-NWMD aging management procedure as it applies to radioactive materials transportation packages and its usage in the aging assessments of one Type B package from OPG's transportation fleet.

The objective of aging management is to identify and control the effects of aging on a system. Aging management offers several benefits when applied to radioactive materials transportation packages:

1. It can protect design margins through the identification and mitigation of "stealthy" degradation mechanisms which can affect structural elements over long periods of time. Aging management therefore complements the routine inspection and maintenance efforts which are typically focused on replaceable and accessible components obviously subject to wear

2. It can improve return on investment by ensuring the longest service life for a package.

3. It can support licensing efforts by providing evidence that in-service packages are "healthy" and comply with their safety requirements.

4. It supports business planning by providing predictions of when extra inspection and maintenance may be required, when package re-building may be required, or when replacement of an entire transportation package may be required (e.g. complete system replacement after a shorter service life may be more cost effective than the detection, monitoring and mitigation measures required for a longer service life).

2.0 THE AGING MANAGEMENT PROCEDURE

The OPG-NWMD Aging Management Procedure contains the major steps described below.

Step 1: Identification of Components Subject to Aging Management

The first step in the aging management procedure is the identification of the primary functions of the system and the designation of the system's components that support the primary functions as either active or passive. Primary functions are those functions that must be performed throughout the service life of the system (e.g. shielding or containment). Active components have moving parts that change in configuration, or have parts that change properties, to perform their functions (e.g. valves, filters). Passive components are stationary and do not change their configuration or properties to perform their functions (e.g. bolts, static seals). Passive components are further categorized as either long-lived (not replaceable during the service life of the system) or short-lived (replacement is expected either according to a planned schedule or as degradation is detected).

Usually the majority of the aging management efforts will be directed to the long-lived passive components of the system if the aging effects on active and short-lived passive components are already well-managed through routine inspection, maintenance and planned or occasional replacement. The long-lived passive components cannot be readily (in terms of physical effort, time and cost) repaired or replaced if they are found to be damaged or in a deficient condition. Safe operation of the system with the defective components may not be possible or it could require the imposition of unwanted diminished performance limits (e.g. reduced capacity, lower operating speeds). It is therefore desirable to identify and manage the aging effects before they impair the functions of the system.

The description of the system including the primary functions, critical components, interfaces, and the designation of passive and active components is documented in a *System and Structure Report*.

Step 2: Component Condition Assessment & Identification of Relevant Aging Management Practices

Component condition assessment involves the identification and evaluation of the following factors.

- The external conditions or environments (e.g. moist air or salt-water exposure, high or low temperatures) that the component is exposed to in any phase of the system's existence including operation, maintenance, storage between usage, etc.
- Stressors (e.g. chemical, mechanical, electrochemical, thermal and radiological) that may be present in any phase of the system's existence including operation, maintenance, storage between usage, etc. Stressors have the potential to cause, promote or accelerate degradation.
- Specific degradation mechanisms involving the stressors (e.g. galvanic corrosion, stress chloride cracking, wear, fatigue). A degradation mechanism causes an undesirable change in the ability of a component to perform its primary function.
- Indicators (e.g. debris, cracks, rust spots) that these degradation mechanisms are acting upon the components.
- Consequences of the degradation mechanism if left unchecked (e.g. bearing failure, inability to carry load).

Aging management practices or measures are then identified to address the results of the component condition assessment. These measures can include a range of options to be performed separately or in combination.

- Detecting: techniques and technologies to detect the effects of degradation mechanisms may be identified. Additional measures must then be defined depending on whether effects are or are not detected.
- Monitoring: when the effects of degradation mechanisms are acceptable (i.e.: below a defined threshold) then it may be acceptable to monitor the effects at a specified inspection frequency and defer taking other measures. The techniques and technologies for this monitoring will usually be the same as for initial detection.

- Preventing: methods for eliminating or blocking the effects of degradation mechanisms may be found. Prevention measures may include the removal of unfavourable conditions, environments or stressors through modification of operating practices and procedures or changes to interfacing equipment.

- Mitigating: methods for reducing or slowing the effects of degradation mechanisms may be identified. Again these measures could require modification of operating practices and procedures (e.g. removal of rust when detected and repainting).

- Re-working or re-building: it may be possible to “zero-time” the component back to its initial as-built condition (e.g. annealing to eliminate accumulated stresses), essentially restarting the effects of the degradation mechanisms.

- Replacing: the results of the assessment may provide a basis for estimating the end of service life (point at which it effectively ceases to perform as required) for a component. This may also define the end of service life for the system. However technological advances since the time of system fabrication may be identified that make it possible to replace the degraded component without unacceptable disruption of the system configuration or operation.

The findings, conclusions and recommendations of this step in the aging management procedure are documented in a *Component Condition Assessment Report*.

Step 3: Assessment and Recommendation of Aging Management Practices on a System Level

In this step the aging management practices identified in Step 2 are compared, at the system level, with the existing inspection and maintenance activities. The required system performance is reviewed with the operational, inspection and maintenance histories. The aging management practices that are not addressed in the existing inspection and maintenance activities are identified. A set of “baseline inspections” is also undertaken prior to the final step of preparing an Aging Management Implementation Plan.

Step 4: Aging Management Planning & Implementation

In the next step of the procedure an *Aging Management Plan* is developed. The Plan identifies the aging effects on the system that are worthy of concern and how they will be managed. The Plan may be simple or complex depending on the complexity of the system, the sources and forms of age-related degradation and the management measures selected. Whenever possible the estimated service life of each component and of the overall system is provided in the Plan. There are two important factors that must be addressed in the Plan:

- Timing: estimates of the times of the onset of degradation mechanisms and when their effects on the components can reach significant levels must be provided. The timing of the associated management measures (e.g. inspections, mitigation work, etc.) must also be specified.

- Costs: the costs of the management measures must be determined or estimated over the entire service life of the components and system. There must be a relationship between the Aging Management Plan and business planning to ensure that funds are available when and as needed.

The Aging Management Plan is reviewed on a periodic basis or whenever significant modifications are introduced to the system configuration or usage.

3.0 EXAMPLE OF AGING MANAGEMENT APPLIED TO A RADIOACTIVE MATERIALS TRANSPORTATION PACKAGE

OPG-NWMD has begun applying its Aging Management Procedure to its Roadrunner Transportation Package (RRTP). A photo of the package is shown in Figure 1. The RRTP is a large (23,000 kg) package used to transport irradiated components (e.g. pressure tubes, end-fittings, flux detectors) from OPGs nuclear generating stations to waste storage facilities or laboratories for inspection and analysis. OPG owns, operates and maintains one RRTP that has been in service for six years. The RRTP makes approximately 10 shipments per year, usually on a campaign basis. The package design is currently licensed as a Type B(U)-85 under the Canadian regulations derived from the 1985 Edition (As Amended 1990) of the IAEA Regulations [3].

The identification and assessment phases (Steps 1, 2 and 3 of the Aging Management Procedure) have been completed for the RRTP and they are described in summary below to illustrate the practical application of the Procedure.

Figure 1. Roadrunner Transportation Package

3.1 Identification and categorization of package functions and components

The primary functions for each package design were identified in accordance with Step 1 of the Aging Management Procedure. These functions conform to the regulatory requirements [3], [4] and [5] for radioactive materials transportation packages:

Primary Functions of the Roadrunner Transportation Package				
Containment	Shielding	Mechanical protection	Thermal protection	Structural support (including tie-down and lifting functions

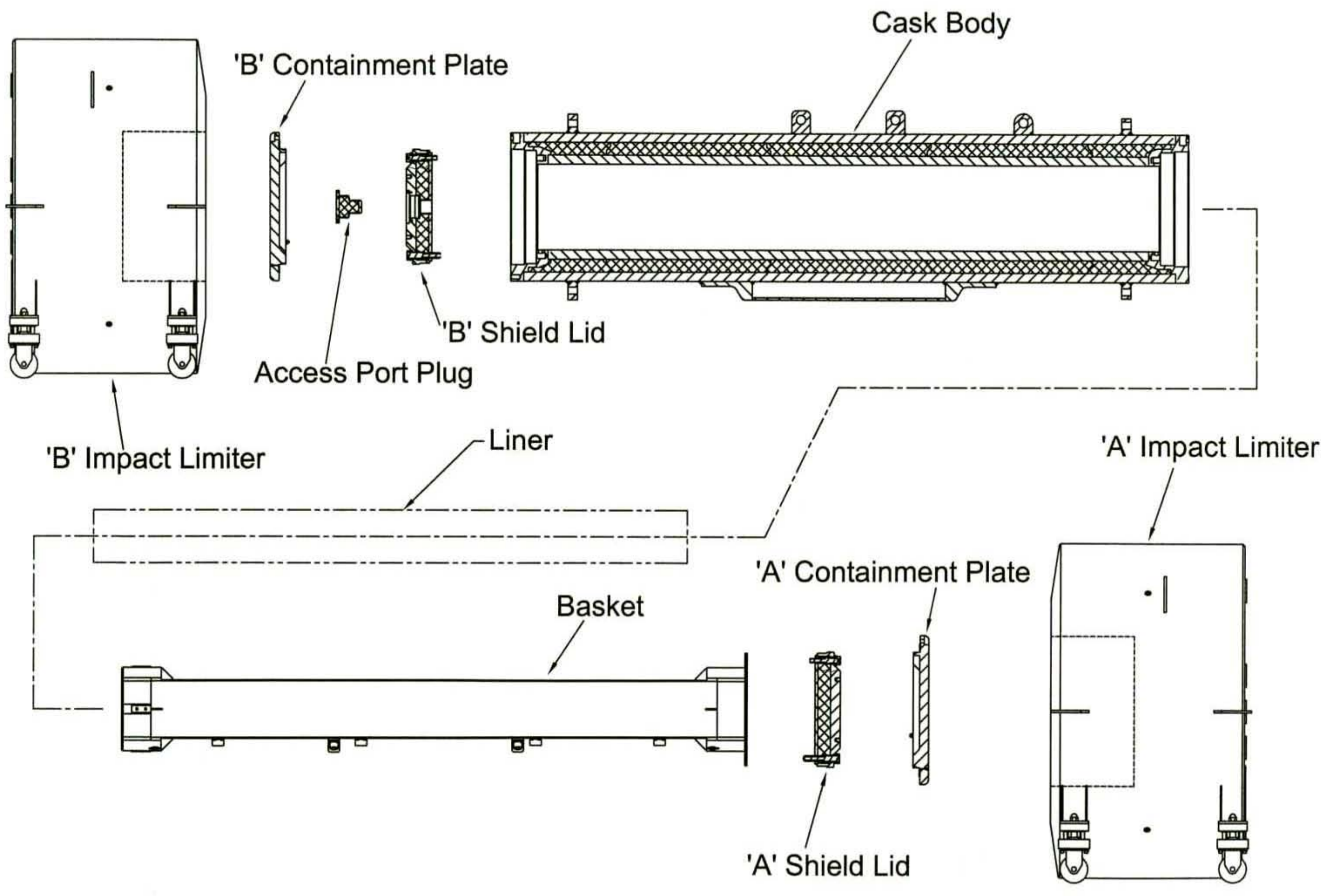

Figure 2: RRTP Components

The major components of the package design that perform or support these primary functions were then listed.

Roadrunner Transportation Package Major Components (see Figure 2)					
Cask Body	Containment Plates	Shield Lids	Access Port Plug	Impact Limiters	Basket

The major components were then broken down into sub-components and, in some cases, critical parts, such as welds and sealing surfaces that merited additional scrutiny. The components, subcomponents and parts were then evaluated and categorized as either active, or passive and short-lived, or long-lived. These decisions were based on design intentions, inspection and maintenance practices, and cost considerations. A portion of the list for the RRTP is presented in Table 1. All of the package components were found to be passive since there are no moving parts. With one exception, the components were considered to be short-lived. Not surprisingly, o-rings (replaced on a periodic basis or whenever damage is observed) and cap screws (replaced whenever damage is observed) were categorized as short-lived. However there were components such as the Containment Plates (made from machined stainless steel plates) that were designated as short-lived even though they were intended to last the entire service life of the package. The logic behind this decision was that these components could be re-built or replaced relatively easily and at an acceptable cost if degradation were detected. Only the RRTP Cask Body was categorized as long-lived as it was the largest and costliest part of the package. There were still parts of the Cask Body, such as lifting and tie-down lugs, that were treated as short-lived category because they could be repaired or replaced without affecting the service life of the Cask Body.

Table 1: Sample Component List

Component **● Subcomponent**	**Primary Functions Supported by Component**	**Periodic Inspection & Maintenance**	**Category**
Containment Plate	Containment	Visual inspection pre-shipment and during annual maintenance.	Passive, short-lived
Containment Plate ● O-rings	Containment	Visual inspection pre-shipment. Replaced if damaged or cannot pass pre-shipment leak test. Replaced during annual maintenance.	Passive, short-lived
Containment Plate ● Fasteners	Containment	Visual inspection pre-shipment and during annual maintenance. Replaced if damaged.	Passive, short-lived
Cask Body ● Outer Shell	Mechanical protection, structural support	Visual inspection of external surface pre-shipment and during annual maintenance.	Passive, long-lived
Cask Body ● Inner Shell	Containment, structural support	Limited visual inspection of internal surface pre-shipment and during annual maintenance.	Passive, long-lived
Cask Body ● Depleted Uranium Segments	Shielding	No direct inspection possible.	Passive, long-lived

The results of this part of the aging management process were documented in a System and Structure Report. An additional benefit of this work was that gaps and inconsistencies in the existing periodic maintenance and inspection practices became apparent. Appropriate corrective actions were taken.

3.2 Assessment of Package Aging Mechanisms and Management Measures

The next step in the Aging Management Procedure was to determine the aging mechanisms that could affect the components described in the System and Structure Report. OPG-NWMD drew upon external expertise in metallurgy and corrosion for this work. Service environments, potential stressors and associated degradation mechanisms were identified. Wherever possible, readily-detectable (e.g. visual) indicators of the presence and action of degradation mechanisms were identified. In some cases mitigating factors from existing operational or maintenance practices were found. Management measures were proposed. A risk ranking for the degradation mechanism was then developed based on the consequences of its effects, if left unchecked, and when these effects would occur and become significant. An example of this process is described below for the RRTP Cask Body, the most important and only long-lived component of the package.

The stainless steel outer shell of the Cask Body is exposed to the natural environment on its exterior surfaces and the depleted uranium shielding segments on its interior surfaces. The stainless steel inner shell of the Cask Body is exposed on its inner surface to radiation from the payloads carried, elevated temperatures due to the decay heat of the contents, and possibly moist air due to some payloads having residual water. Again the outer surface of this component is exposed to the depleted uranium shielding segments contained within the annulus of the Cask Body. The depleted uranium is fully enclosed by the stainless steel shells with a small volume of air trapped at the time shells were welded together. All of these components are exposed to the normal vibrations and shocks from road transport and handling of the package.

The possible stressors acting on the Cask Body components were found to include:

- Outer shell – chemical stressor due to chlorides from road salt corroding the exterior surface of the outer shell.
- Inner shell – chemical and mechanical stressors due to combined effects of nitric acid (from radiolysis of moist air) and fretting from contact with basket.
- Depleted uranium segments – chemical, mechanical and radiological stressors due to oxidation of the depleted uranium segments plus differential thermal expansion between the depleted uranium and stainless steel, plus radiation-induced embrittlement.

The degradation mechanisms and consequences for these stressors (if unchecked) are identified as:

- Stress Corrosion Cracking (SCC) of the Outer Shell allowing ingress of air to the depleted uranium in the Cask Body annulus (with follow-on effects) and reduction of load-carrying capability.
- SCC of the Inner Shell that could result in a reduction in containment effectiveness plus similar problems as described above for the Outer Shell.
- Distortion or cracking of the depleted uranium segments due to oxide buildup, over-stressing or embrittlement resulting in a reduction in shielding effectiveness.

The anticipated indicators for these degradation mechanisms would be:

- Rust spots, cracking and pitting for SCC of the Inner and Outer Shells
- Distortion of the Cask Body and increases in external radiation levels for changes in the depleted uranium.

It can be seen that there can be multiple indicators for a single degradation mechanism and this may necessitate the use of multiple inspection techniques to ensure the earliest detection and effective monitoring.

Mitigating factors against SCC of the Outer Shell included the use of a lacquer coating on the external surface and the weather enclosure of the Roadrunner trailer (visible in Figure 1). Measures proposed to manage the aging effects included:

- SCC of Outer Shell: periodic inspection of the lacquer on the and immediate repairs of chipping and scrapes that penetrate the coating
- SCC of Inner Shell: periodic cleaning and use of liquid penetrant inspection, particularly at welded joints.
- Depleted uranium oxidation and distortion: periodic gamma-scanning and precision measurements of Cask Body dimensions to check for distortion.

When the risk rankings were assigned, only SCC of the Outer Shell and SCC of the Inner Shell were determined to be “High Risk” with the likelihood of unchecked effects becoming significant after approximately five years based on a possible corrosion rate of 0.2 mm per year. Oxidation and distortion of the depleted uranium was assigned a “Low Risk” ranking and it was concluded that these effects would not become significant for at least ten years of service. These results formed only a portion of the evaluation contained in the Roadrunner Transportation Package Condition Assessment Report

3.3 Future Work: Aging Management Plan for the Roadrunner Transportation Package

In 2005 OPG-NWMD intends to develop and implement an aging management plan for the Roadrunner Transportation Package. It is likely that it will result in an enhanced periodic inspection and maintenance program for the package plus changes in business planning to fund the additional work. In the meantime improvements derived from knowledge gained through the aging management identification and assessment phases are being incorporated in existing inspection and management program. For example the relevant procedures are being re-written to ensure the use of chloride-free cleaners, lubricants and non-destructive examination agents. The benefits of aging management are already becoming apparent.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Aging management can make several valuable contributions to the operation of radioactive materials transportation packages including preserving design margins, maximizing the service life, improving inspection and maintenance and ensuring orderly "no surprises" business planning for expenditures on the packages. The application of aging management principles requires a methodical and detailed examination of the package design and service conditions as well as a consideration of the risks and costs of taking various alternative actions.

Aging management is especially important for high-value packages where the cost of replacement or extended unavailability due to repairs would be unacceptable.

Aging management should be applied as early in the service life of a transportation package as possible. Ideally at the design stage consideration will be given to aging management to eliminate or minimize stressors and to facilitate inspections and management measures throughout the service life of the system. Logically the periodic inspection and maintenance procedures for a package should be based on a preliminary form of the identification assessment and planning phases of aging management to ensure that all possible threats to the package's service life are addressed before the package makes its first shipment.

5.0 REFERENCES

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