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AGING MANAGEMENT OF ONTARIO POWER GENERATION'S DRY STORAGE CONTAINERS FOR USED FUEL

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ABSTRACT

Ontario Power Generation uses Dry Storage Containers (DSCs) to store used CANDU fuel, following initial cooling in irradiated fuel bays. DSCs are subject to an aging management plan to ensure their 50-year design lives. This paper provides an overview of an aging management procedure developed by Ontario Power Generation's (OPG's) Nuclear Waste Management Division (NWMD) for managing its nuclear waste assets. Details of an aging management plan specific to the DSCs are highlighted, including the outcome of on-going inspections and activities that have been defined by the plan.

1. INTRODUCTION

Ontario Power Generation (OPG) uses Dry Storage Containers (DSCs) to store used fuel generated by CANDU nuclear reactors, after the fuel has been initially cooled underwater in irradiated fuel bays. DSCs are individual free-standing, steel-clad, reinforced high density concrete containers that are intended to provide containment, shielding and passive heat dissipation of the used fuel for a 50-year design life. To ensure this design life, and the potential for life extension beyond 50 years, DSCs are ideal subjects for assessment and monitoring via an aging management program.

2. OVERVIEW OF AGING MANAGEMENT PROCEDURE

Aging is adequately managed if its effects are understood and controlled, and if aging-related degradation is mitigated through implementing appropriate corrective actions to prevent the loss of an asset's primary functions. Thus, the purpose of aging management is to define, as early as possible in an asset's service life, the components critical to its primary functions, and to determine potential degradation mechanisms that could lead to its deterioration. To this end, aging management at NWMD-OPG has been established as "a systematic approach to enhancing and integrating existing programs and activities that address the life cycle of OPG's nuclear waste assets, and their associated systems, structures, equipment and components (SSECs)". This approach is important as some degradation mechanisms are difficult to detect via routine inspection and maintenance programs, particularly, if the mechanisms are slow to develop and act over long periods of time. As a result, aging management activities are implemented that will provide timely detection, and minimization and mitigation of aging degradation, before an asset's safety margins and reliability are degraded to the extent that its primary functions are compromised.

The Aging Management procedure at OPG-NWMD has been modelled on EPRI guidelines for managing the aging of nuclear power plants [R-1, R-2] and has been formalized into the following major steps:

- Identification of Systems, Structures, Equipment and Components (SSECs) Subject to Aging Management

- Identification and Evaluation of the Aging of Components

- Assessment and Recommendation of Aging Management Practices at the System Level

- Aging Management Planning and Implementation

The first step involves identifying the systems, structures, equipment and components that are crucial to maintaining the primary functions of an asset. The primary functions of an asset are those functions that must be maintained at all times during its service life to fulfill its life cycle requirements. Primary functions are to be derived from information on the original design basis, operating history, safety analyses, and licensing conditions.

The second step involves the preparation of a "Condition Assessment Report" in which applicable stressors, aging mechanisms, and aging effects are identified for each component. Aging management is required if the aging effects will result in a loss of the asset's intended function. Thus, aging effects must be assessed by taking into account design, environmental, and operating conditions, as well as, consideration of the severity of impact and risk associated with each.

In the third step, applicable aging management practices are identified and prioritized at the system level, and are to be integrated with any existing inspection and maintenance activities. The review of system performance involves a review of the system operation, inspection and maintenance history. A set of "baseline" inspections may also be undertaken in this step.

In the fourth step, the Aging Management Implementation Plan is developed and sets forth a management strategy and timeframe for the implementation of inspection, maintenance, and any other activities (e.g., mitigation, remedial and replacement) that are required to control potential failure mechanisms. The Aging Management Plan is to be periodically reviewed and updated to account for significant changes in condition or in response to any significant modification to the system.

3. DRY STORAGE CONTAINERS

The Dry Storage Containers used at OPG (Figure 1) were designed and developed by OPG. Currently, approximately 350 DSCs are in-service at OPG's Pickering Used Fuel Dry Storage Facility, which has been in operation since 1995. In addition, there are approximately 70 DSCs in storage at OPG's Western Used Fuel Dry Storage Facility located at the Bruce Nuclear Power Development. This latter facility has been in operation since 2003.

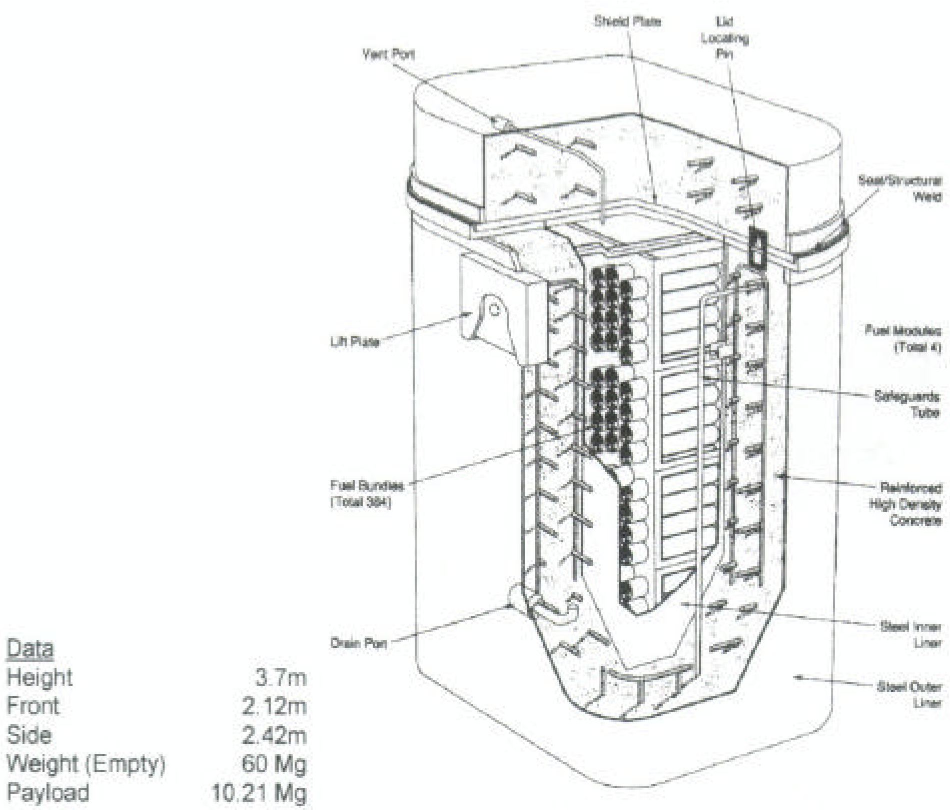

Figure 1
Dry Storage Container

The DSC is a reinforced concrete container designed for storage and transportation of used CANDU fuel. The concrete walls comprising the base of the DSC and its concrete lid are encased in a carbon steel inner liner and outer shell. The thickness of both the liner and shell is 13 mm, and the 0.52 m space between them is filled with high density reinforced concrete. The overall outer dimensions of the DSC are 2.12 m x 2.42 m in plan, and 3.7 m high (including lid). The DSC holds 384 used CANDU fuel bundles in four storage modules (long or standard).

The DSC containment boundary consists of the inner liner, the bottom plate of the lid, stainless steel vent and drain tubes, and three nuclear-grade closure welds. The lid closure weld is a full penetration groove weld between the 32 mm thick base plate of the lid and the flange at the top of the base. The weld is designed to provide the DSC with the required structural strength to keep the lid secure and to provide a seal for the containment barrier. Stainless steel shielding plugs are inserted into the vent and drain ports and then seal welded to complete the containment boundary.

The outer steel shell facilitates lifting and handling and protects the concrete from external mechanical and chemical agents. The outer shell also facilitates decontamination following wet-loading of the fuel. A high performance epoxy-based protective coating system is applied to the steel shell to further ease decontamination and to provide corrosion protection.

The DSCs are stored indoors in passively ventilated buildings that are intended to limit exposure to outside ambient conditions.

4. AGING MANAGEMENT PLAN FOR DSCs

4.1 Identification of SSECs Subject to Aging Management

In accordance with OPG's Aging Management procedure, key "systems" comprising the DSC system were first identified. These systems were the outer steel shell, high density reinforced concrete, inner steel liner, and the fuel storage modules. Each system was in turn broken down into its key components. Each of these components was then analyzed for mechanisms that could potentially result in early failure of the DSC's primary functions (e.g., corrosion of the seal welds resulting in a loss of containment). To determine the overall risk to system failure, each mechanism was ranked in terms of its severity (consequence) and likelihood (probability of occurrence). Those mechanisms with the highest risk were subjected to further detailed evaluation to determine if appropriate aging management activities were required to provide timely detection of the aging effects. Various mitigation and remedial actions were also recommended, if needed.

4.2 Condition Assessment Report

The results of the condition assessment are given in Table 1, where the DSC's primary functions, components critical to those primary functions, and potential degradation mechanisms assessed to have the highest risk are given. As a general finding, there were no mechanisms that were obvious routes to early failure of the DSC. However, it was recommended that the mechanisms and affected components listed in Table 1 be subject to further monitoring and possible mitigating actions, as precautionary measures to ensure service life. The mechanisms and components recommended for monitoring are those that are critical to the containment and mechanical integrity functions of the DSC.

Table 1
Condition Assessment of the DSC

Primary Function	Critical Components	Potential Degradation Mechanisms
Containment - radiological and helium atmosphere	- lid closure, vent and drain seal welds, and their heat-affected zones (HAZ)	- corrosion, possibly enhanced by stress corrosion cracking and residual stresses
Shielding	- high density concrete	- no life limiting mechanisms identified
Heat Dissipation	- no special heat dissipation features	- n/a
Mechanical Integrity - for handling and transport	- outer shell - exterior protective coating	- corrosion (corrosion of base plate possibly enhanced by atmospheric chlorides) - damage during handling
Fuel Retrievability	- ensured, if mechanical integrity maintained	- n/a

4.3 Planning Aging Management Practices and Implementation

Monitoring of the "higher risk" mechanisms (listed in Table 1) was planned via a series of aging management activities discussed below. These activities were comprised of regular inspections and monitoring of key components of the DSC (see Figure 2). Not only were these activities specified to provide timely detection of deterioration, it was also expected that the data gathered could potentially provide information on the rates of each mechanism. This latter information would be important in formalizing and planning any necessary mitigating interventions, to slow the aging process, or remedial actions, to substantially reduce or eliminate an aging mechanism, thereby ensuring life expectancy.

- General visual checks

  - assess the general condition of the DSC and area immediately around it during regular "walk downs"
  - focus on the condition of the protective coating and any potential corrosion occurring around the lid closure weld, drain/vent seal welds, and their HAZs

- Remote visual check of the DSC base plate

  - use of a high resolution camera to inspect the underside of the base plate of selected DSCs, while the DSC is suspended above the ground
  - monitor for potential corrosion and condition of coating

- Chloride Sampling and Analysis

  - monitor and ensure that the presence or build-up of atmospheric chlorides does not significantly enhance the potential or risk of corrosion

Complementing these monitoring activities, potential mitigating and remedial activities include repairing any damaged or deteriorated coating (particularly in the area of the seal welds), eliminating sources of water that could contact the base plates, and maintaining the building envelop in good repair.

5. IMPLEMENTATION OF DSC AGING MANAGEMENT PLAN

The Aging Management Plan for the DSCs has been recently implemented.

Routine general visual checks have not revealed any damage to accessible areas of the DSCs' exterior shell and coating. Initial chloride "swabs" have been taken from the lid and walls of selected DSCs. Currently, the measured levels of chlorides do not pose a risk for early failure of external steel components due to corrosion. Potential chloride build-up will be assessed based on comparison with these initial results.

To date, the aging management and mitigation activities have been principally focused on the base plates of the DSC, as these components are not readily accessible for inspection and evaluation. A "baseline" series of remote visual checks has been completed and an assessment of additional means to mitigate damage to the base plates is underway. Results of these latter activities are discussed below.

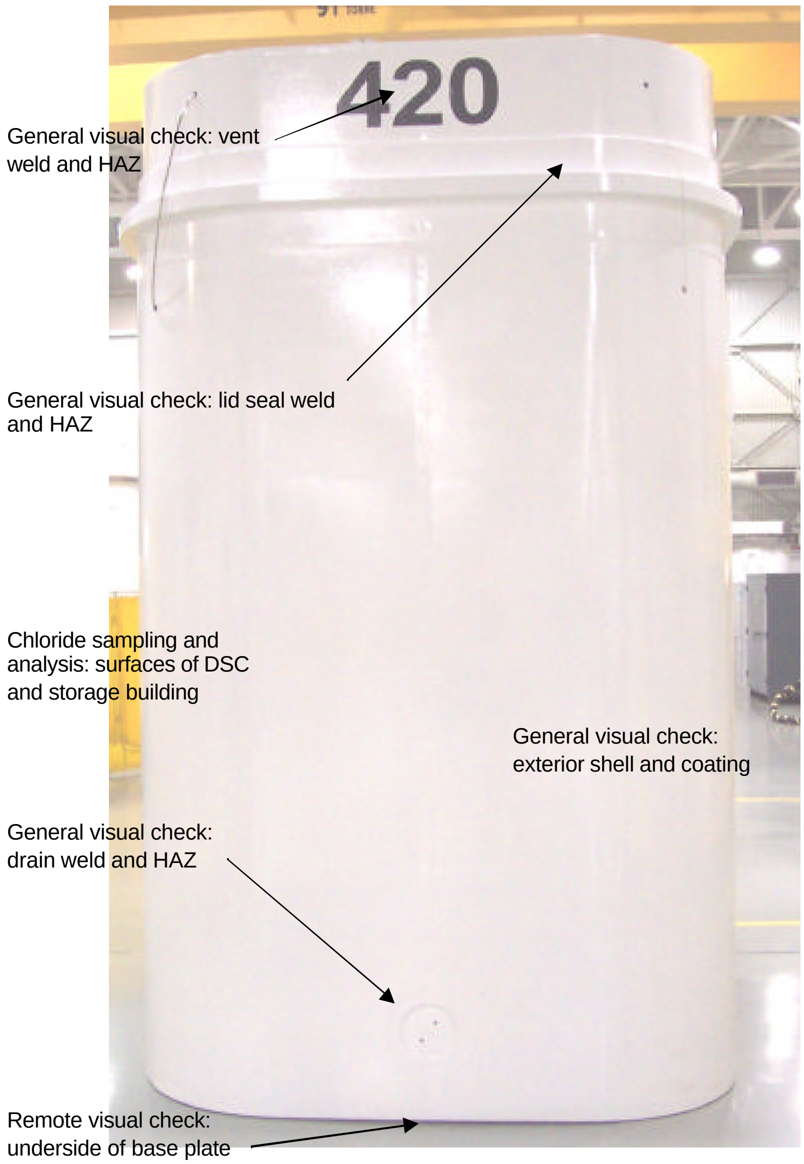

Figure 2
Aging Monitoring of DSCs

5.1 Remote Visual Checks of DSC Base Plate

To monitor the potential high risk degradation mechanisms – corrosion of the base plate and damage to the protective coating – that could potentially affect mechanical integrity, remote visual inspections of the base plate of selected DSCs have been conducted. These inspections were carried out with the use of a high-resolution digital camera that could be maneuvered to any point under the DSC, while it was suspended above the ground (Figure 3). A portable grid system comprising of aluminium sheets with grooves was used to define the path for the camera to travel as it was passed from one side of the base to the other. Each inspection was recorded onto a digital video disc (DVD) and filed for future reference. This storage format, combined with the grid system, allows for accurate and reproducible resolution of any location on a base.

To date, the bases for 15 DSCs have been inspected. These DSCs will form part of a “baseline” population that will be re-inspected at future dates to monitor for any changes in their condition and performance over the long term. These fifteen DSCs were selected based on: time in storage, history of known prior damage to the base coating, and exposure to factors likely to result in coating damage and corrosion (e.g., multiple movements of the DSC, history of standing in water). This selection process was considered to be conservative, as DSCs with pre-existing conditions that would predispose them to the effects of corrosion were included in the baseline population. As storage of used fuel continues, additional DSCs will be added to the baseline population.

Figure 3
Remote Visual Inspection of DSC Base Plate
(- digital camera being guided underneath the base plate)

The principal finding from the inspections was that very little evidence of corrosion was seen. The most common defect was localized removal of the coating system’s top coat, exposing the primer below, which is likely to have occurred during handling and movement of the container (Figure 4). The most significant damage to the coating in terms of the potential for corrosion, generally occurred near the edges of the base, where local areas of both the top coat and primer were completely removed exposing the carbon steel substrate. At these latter locations, a superficial corrosion product layer was observed on the steel (Figure 5). There appeared to be no correlation between DSC condition and age in storage. The oldest container inspected had been in storage for eight years and was in a condition similar to more recently stored DSCs.

5.2 Mitigating Activities

To mitigate damage to the DSC base plates, an investigation of options to protect the base plates was undertaken. Potential means of protecting the base plates were reviewed with the intent to minimize damage to the coating during handling, processing and storage, and, if damage has occurred, to limit further deterioration of the damaged coating or base plates. Options considered included the use of a mat or pad material placed under the DSC, temporary application of a protective material during handling and processing, and the use of alternative coatings that are more impact resistant and/or corrosion inhibitive.

The alternative selected for potential implementation was use of a "set-down" mat under each DSC to minimize impacts during placements, to elevate the DSC above potential pools of water, and to be of an "open" design to allow water to drain and air to circulate. The use of a temporary protective material was not selected, as it was considered to be limiting in terms of the effort required to apply and remove the material. In terms of alternative coatings, though a number of impact resistance and corrosion inhibitive systems are available, it was expected that their use would still not match the benefit of using a set-down mat.

To date, two candidate polypropylene-based mats have been selected based on short-term static load capacity tests, their "open" design concept, and the material's expected physical and chemical durability. Tests are underway to evaluate the long term load carrying performance (i.e., creep) of the mats and a review to confirm that the potential fire hazards associated with their use and storage are low.

6. SUMMARY

Aging Management at OPG's Nuclear Waste Management Division has been implemented to provide timely detection, minimization and mitigation of aging-related deterioration of its assets. OPG uses Dry Storage Containers to store used CANDU fuel, following initial cooling in irradiated fuel bays. DSCs are subject to an aging management program to ensure their 50-year design lives.

Figure 4
Damage to Coating Topcoat (typ.)
(Scale: width = ~ 100 mm)

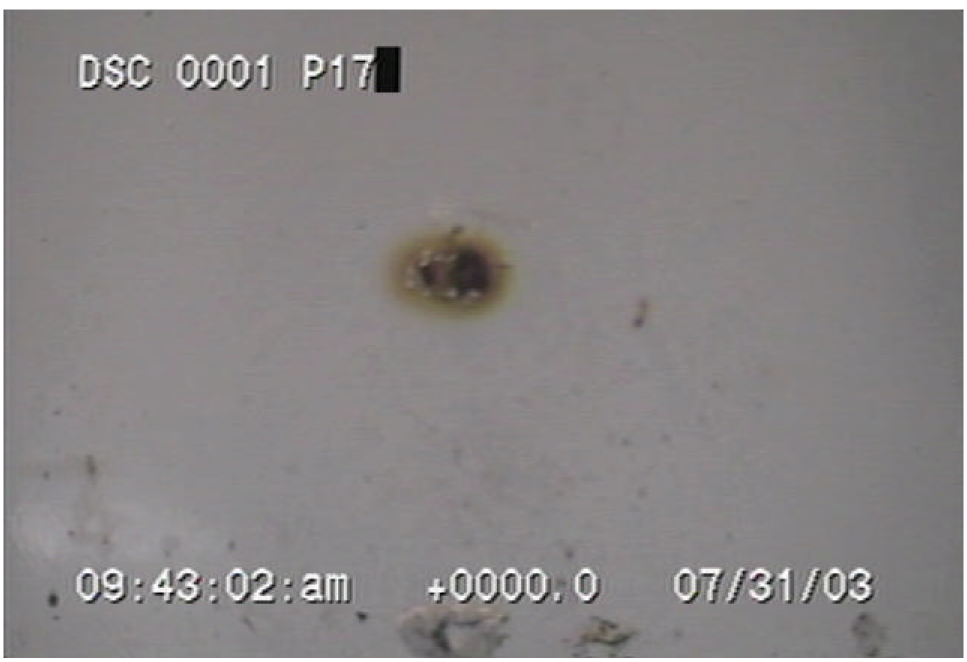

Figure 5
Surface Corrosion Where Coating Damaged to Steel (typ.)
(Scale: width = ~ 100 mm)

An aging management plan for the DSCs has been implemented. The plan is based on a condition assessment of the DSCs in which their primary functions, critical components, and potential degradation mechanisms were evaluated. While no long term service-life-limiting threats were identified, some key components were recommended for further monitoring. These components were (a) the lid, drain and vent seal welds on the exterior shell, and their heat-affected zones, (b) the exterior shell itself, (c) and base plate. The integrity of the coating and evidence of corrosion was to be monitored in these areas.

The principal effort, to date, has been the completion of a set of remote video inspections of the base plates for 15 DSCs. Very little evidence of corrosion was seen, with the most common defect being local removal or damage to the coating. These DSCs have been designated as the basis of a "baseline" population that will be re-inspected in future years.

Investigation of other means to protect the base plates has been completed. Two candidate polypropylene-based "set-down" mats for use under the DSCs have been identified. These mats are intended to protect the coating from damage and to elevate the DSC above potential pools of water. Investigation of the long term creep characteristics of these materials is underway.

References

R-1 EPRI TR-105090, "Guidelines to Implement the License Renewal Technical Requirements of 10CFR54 for Integrated Plant Assessments and Time-Limited Aging Analyses", November 1995.

R-2 EPRI 1007933, "Aging Assessment Field Guide, Final Report", December 2003.

Acknowledgement

The support of the staff at OPG's Pickering and Western Waste Management Facilities (WMFs) in developing the Aging Management Plan for the DSCs is gratefully acknowledged. Baseline video inspections of the selected DSC base plates and initial testing of the candidate set-down mat materials were conducted at the Pickering and Western WMFs, respectively.