AGING MANAGEMENT APPLIED TO STORAGE OF BULK ION EXCHANGE RESIN IN EPOXY COATED CARBON STEEL CONTAINERS

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ABSTRACT

Ontario Power Generation (OPG) began in-ground storage of spent ion exchange resins in the 1980s using epoxy coated carbon steel containers. In 2001, a sequence of aging evaluation activities based on EPRI guidelines was used to assess the current conditions of the stored containers. The evaluation concluded that the containers (also known as resin liners) may fail during the 50 years interim storage period due to fabrication defects and the storage environment. Risks to container integrity were then assessed through field activities which included ultrasonic measurements of the container wall thinning and characterization studies of the waste resins. While results confirmed that containment had not been breached and no resin leakage from the containers was detected, localized wall thinning and pits especially on the inner surfaces of the resin liner, were evident. The carbon steel liners were replaced by stainless steel 316L liners, during 2003, to provide enhanced resistance to pitting corrosion. A plan to "overpack" the carbon steel liners in stainless steel overpacks has been developed. Overall, the aging management approach applied has been effective in assessing age related risks of the critical systems, structures, equipment and components (SSEC) for resin storage, and defining the appropriate remediation strategy.

1 INTRODUCTION

Spent ion exchange resins, containing ionic impurities removed from CANDU reactor water systems, are stored in bulk storage tanks at the nuclear generating stations. Spent resins may be stored up to ten (10) years at the station prior to being transferred to the waste management facility for long term storage. Resins are dewatered in the 3m ^{3} containers or resin liners and stored in in-ground storage structures known as ICs for a period of fifty (50) years. Currently, the waste site maintains and operates approximately 140 ICs with a capacity of over 600 resin liners. To ensure safe containment of resins during the storage period, an aging evaluation was conducted in 2001 to assess the performance of the stored resin liners after 20 years in storage.

The aging evaluation procedure used was a step-by-step approach established based on EPRI guidelines [1]. The assessment process began by estimating the current condition of the key system components based on available design and operational data. Components critical to meeting design objectives were identified and were the subject of further examinations. Further examinations generally consisted of field verifications and sample analyses of the identified critical components.

The evaluation assesses the overall impact of aging mechanisms on the critical components of the storage system, IC and identified the resin liners as one of the critical components that might fail prematurely. The resin liners were then subjected to a series of field investigations which included ultrasonic wall thinning measurements, chemical analysis of water obtained from the resin liners, and characterization studies of the aged resins. Controls and monitoring measures to mitigate or delay the age-related deteriorations were evaluated and finally a plan was developed for implementation of aging management activities necessary to preserve the system primary functions.

2 AGING MANAGEMENT

Assets subject to aging management within OPG are mainly the systems, structures, equipment and components (SSEC) that bear significant safety or licensing implications. With the key objective to ensure the primary functions of the SSEC being evaluated are maintained, the aging management process yields a program to ensure all critical functionalities are maintained. The aging management process consists of steps and outputs as listed in Table 1.

Table 1: Aging Management Steps and Outputs

Step	Output
1. Identification of Critical SSECs	System and Structure Report
2. Assessment of System Conditions and Aging Management Strategies	Condition Assessment Report
3. Aging Management Planning and Strategies Identification	Aging Management Plan

2.1 Identification of Critical SSECs

This step begins by assessing the primary functions of the assets or systems being evaluated. Long lived and passive components [1] that might jeopardize the system design functions are identified as critical SSECs. Design documents, operations / maintenance history as well as performance reports of the ICs were reviewed in the 2002 evaluation. The resin liners have been identified as a potential critical SSEC which might affect its design functions within the intended 50 years storage life, as documented in the "System and Structure Report".

2.2 Assessment of System Conditions and Aging Management Strategies

Condition assessment, typically, is conducted on the component level with an objective to detect potential age-related failures. The assessment examines the impacts of time-limited parameters such as design life and physical or radiochemical causes of degradations such as number of stress cycles, corrosion, or accumulated radiation doses, on each of the studied SSECs. The resin liners, being identified as a critical SSEC, were evaluated specifically for the effects of corrosion. To confirm the potential premature failure risks of the resin liners, non destructive examinations (NDE) including ultrasonic wall thinning measurements and detailed characterization studies of the waste resins were performed. Assessment results and recommendations are discussed in the "System Condition Assessment Report".

2.3 Aging Management Strategies and Plan

The last step of the aging management process integrates the condition assessment results and recommends strategies to implement the controls necessary to prevent the loss of system primary functions. The "Aging Management Plan" for the ICs recommended the epoxy coated carbon steel resin liners be replaced by stainless steel 316L resin liners.

3 LONG TERM STORAGE OF WASTE RESINS

3.1 Design of the In-Ground Storage Structures (ICs) and Environmental Conditions

The design of the IC utilizes its surrounding till material and a concrete shell along with a top concrete cap as a primary means to shield radioactivity from the waste resins. Resin liners, once filled with used resins, are stacked 4 to 6 high inside an IC with an intended design storage life of 50 years. This in-ground storage arrangement provides a relatively stable environment, with a maximum temperature fluctuation of less than 10^{o}C, throughout the year as it is isolated from the exterior weather. Groundwater infiltration into the ICs was estimated to be minimal based on the site hydrogeological studies. Figure 1 illustrates the design details of an IC.

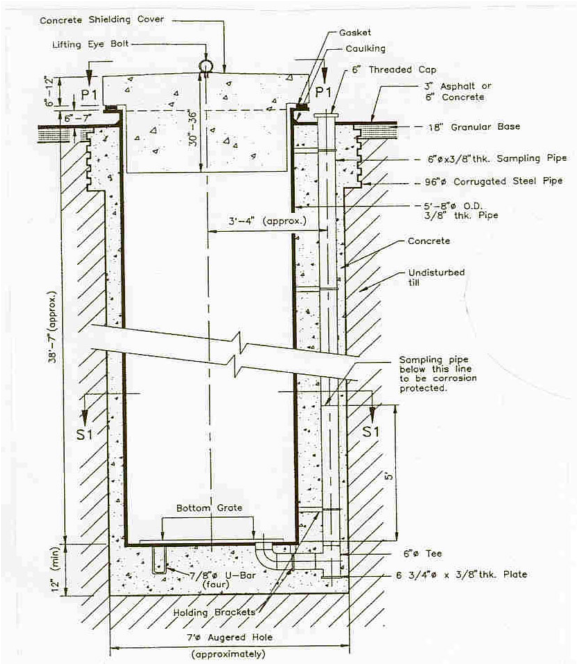

Figure 1: *Typical in-ground storage structure IC.*

3.2 Design of the Resin Liners and Resin Types

Resin liners used for in-ground storage of the spent resins are of a capacity of $3m^3$, with an overall height of 71" and 64" in diameter. The liners placed in service in the 1980s are made of ASTM A36 or A285 Grade C carbon steel with a 6.35mm thick side wall and 7.94mm thick top and bottom end shells during fabrication. The container surfaces were cleaned using abrasive blasting and 2 coats of epoxy were applied to give a dry film thickness of 375 µm for the interior surface and 250µm for the exterior surface of the liners. An internal filter manifold was provided for resin dewatering and free water content as low as 20% (volume) was achieved via the hydrosphere filter. A typical resin liner is shown in Figure 2.

Figure 2: *$3m^3$ Resin liner*

Three types of resins namely (i) moderator resin which consists of strong acid / strong base mixed bed resins in the H/OH- form; (ii) heat transport resin which consists of strong acid / strong base resin in the Li^{+}/OH^{-} form; and (iii) CANDECON resin which consists of strong acid resin in the H^{+} form, are stored in the resin liners. The resin environment is known to be complex with the presence of sulfuric acid, chloride, and traces of nitric acids reported in various studies. More detailed characterization data is provided in Section 4.2.

4 AGING EVALUATION OF THE RESIN LINERS

The non destructive examinations (NDE) performed to examine the integrity of the resin liners included (i) ultrasonic wall thinning measurements and (ii) chemical, radiochemical and microbiological characterization of the resin liner contents.

4.1 Wall Thinning Measurements

4.1.1 Ultrasonic Scanner System

The 2002 inspection campaign used an ultrasonic scanner system consisted of an automated scanning rig, a wet (water cushion) ultrasonic transducer and the Winspect™ data analysis software [2]. The scanner system was designed with the following requirements:

- Performs C-Scan (thickness monitoring) of the resin liner surface via a remote operated control;
- Detects a minimum 10% wall loss and corrosion pits of diameter > 4 mm
- Scans in annular space of 38 mm
- System can be set up in < 15 minutes to limit worker exposure to radiation from the resin liners.

Figure 3 shows the ultrasonic wall thickness mapping system used in the inspection campaign.

Figure 3: *Ultrasonic Wall Thickness Mapping System.*

4.1.2 Inspection Findings

Ultrasonic scans over the resin liner surface (global scan), followed by detailed scanning over targeted areas of the resin liners (local scan e.g. 250mm x 250mm) were concluded to be successful. Wall thinning, mostly in the form of pits of various deteriorated depths, was noticed on all inspected resin liners. Among the inspected resin liners, more significant deteriorations were noticed in the CANDECON resin containing liners with the most wall thinning observed in wet CANDECON resin liners (i.e. CANDECON resin liners with free water). While through wall pits were not detected, wall thickness reductions were found to range between 20-60% at various spots on the inspected liners. The pits, as detected in the scans, further indicated that the bottom seam weld located approximately 100mm from the bottom of the resin liner is particularly susceptible to pitting corrosion due to potential defects in the epoxy coating. A review of the resin liner design had noticed that defected coating can easily result near the circumferential welds during the fabrication process. Such a finding is also consistent with previously observation that the lifetime of the resin liners could be severely shortened if the epoxy coating is defective. In order to gain further understanding on how the resin types affect the rates of localized corrosion and the corrosion behavior of epoxy coated carbon steel, characterization studies of the aged resins, headspace gases and water samples retrieved from the resin liners were carried out at the same time as the ultrasonic inspections.

4.2 Chemical, Radiochemical and Microbiological Characterization Studies

4.2.1 Characterization of Resins

The physical condition of the resin was assessed visually using optical microscopy for the fracture of the resin beads. All examined resins showed cracking but remained in a free-flowing and unagglomerated state. The observed condition suggested that the resin liners have been continuously exposed to a moist environment since the onset of the storage period.

The chemical constituents of the resins, analyzed by Induction Coupled Plasma Mass Spectrometry (ICP-MS), were found to be dominated by iron, sulfur, and nickel. Sulfuric acid, chloride, and traces of nitric acid were detected in resin leachate. The radiochemical constituents, determined using gamma spectrometry and scintillation counting, were found to be dominated by Cs-137, Co-60, C-14 and H-3. Dissolved or suspended organic content, up to 1850 ppm, was measured. Such a high level of dissolved organics suggested that various forms of organic acids are likely to exist in the waste. A consistent chemical composition was detected (i.e. Fe, S, and Si) in free water samples retrieved from the bottom of the resin liners. A pH value of 3 was detected in the free water samples. Microbial activity was observed in some of the resins examined and both anaerobic bacteria and aerobic bacteria were observed in such cases.

All findings resulted from the characterization study consistently indicated that the presence of various acids, metal ions, as well as radiolysis products inevitably form a complex and potentially corrosive environment for the carbon steel resin liners.

4.2.2 Headspace Gases

Headspace gas samples were analyzed for combustible contents (i.e. CH_4, CO, H_2, C_2H_6, C_2H_4, and C_2H_2) and air constituents (i.e. O_2, CO_2, and N_2) using gas chromatography. Concentration of carbon 14 (in the forms of CO_2 and non-CO_2) and tritium (in HTO and non HTO forms) were measured using liquid scintillation counting.

Oxygen depletion was noticed in all examined liners. The depleted O_2 level condition, often caused by corrosion, oxidation of the organic resins and /or biological consumption [3], also suggested that the carbon steel liners are exposed to corrosion. The headspace gas sample analysis results showed a gas composition consisted mainly of hydrogen, followed by methane, carbon dioxide and nitrogen. The high hydrogen level is likely generated during the carbon steel corrosion process, as suggested by Pillay [4], and/or from the radiolysis effect on the ion exchange resins. Carbon dioxide and methane are both potential products of radiolysis and/or biodegradation of the resins.

5 CONCLUSIONS

The Aging Management procedure followed by OPG to evaluate the integrity of the in-ground storage structures was concluded to be an effective approach. This procedure systematically identified the areas of concern, thus allowing further investigations to be efficiently conducted on the critical components. The aging evaluation performed on the waste resin storage system in 2002 concluded that the carbon steel resin liners may fail prematurely.

While through-wall penetrations and/or leakages of resins have not been detected after 20 years in service, the resin liners assessed in this aging evaluation were found to be deteriorated mainly by pitting corrosion due to the corrosive resin environment. Despite the good corrosion protection provided by the epoxy coating, a flawless coat is known to be difficult to achieve. A review of the resin liner design further confirmed that coating defects particularly near the seam welds are often unavoidable during the fabrication process. Potential weakening of the integrity of the containers together with other outcomes resulted from the NDE and characterization studies have led to the development of a remediation program.

These plans involve retrieving and "overpacking" the carbon liners in new 316L stainless steel containers in order to enhance pitting corrosion resistance. Resin liners made of stainless steel 316L have also been placed in service since 2003 in order to ensure safe storage of future waste resins.

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