newfoundland labrador hydro

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December 21, 2021

Board of Commissioners of Public Utilities
Prince Charles Building
120 Torbay Road, P.O. Box 21040
St. John's, NL A1A 5B2

Attention: Ms. Cheryl Blundon
Director of Corporate Services & Board Secretary

Dear Ms. Blundon:

Re: Allowance for Unforeseen Items Account – Holyrood Thermal Generating Station Unit 3 Boiler Tube Failure – Final Report

On October 12, 2021, Newfoundland and Labrador Hydro's ("Hydro") notified the Board of Commissioners of Public Utilities of its intent to use the Allowance for Unforeseen Items account to complete a level 2 inspection and associated repairs to the Holyrood Thermal Generating Station ("Holyrood TGS") Unit 3 boiler tubes which were immediately required for safe and reliable operation of Holyrood TGS Unit 3. Repairs were completed and Unit 3 was returned to service on November 21, 2021. Attached is Hydro's final report in relation to this work, as required under the Capital Budget Application Guidelines.[1]

Should you have any questions, please contact the undersigned.

Yours truly,

NEWFOUNDLAND AND LABRADOR HYDRO

Shirley A. Walsh
Senior Legal Counsel, Regulatory
SAW/kd

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[1] "Capital Budget Application Guidelines," The Board of Commissioners of Public Utilities, October 2007 (originally issued June 2, 2005).

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Holyrood Thermal Generating Station
Unit 3 Boiler Tube Failure

Final Report

December 21, 2021

A report to the Board of Commissioners of Public Utilities

Contents

1.0 Introduction

The Holyrood Thermal Generating Station ("Holyrood TGS") consists of three thermal generating units; Units 1 and 2, each providing a capacity of 170 MW, and Unit 3, providing a capacity of 150 MW. Each thermal generating unit is supplied with steam generated by a dedicated boiler for each unit. Each boiler contains boiler tubes which carry high-pressure steam throughout the boiler.

The boiler tubes are exposed to multiple degradation mechanisms such as creep due to high temperature, fatigue cracking due to cyclic stress as a result of starting up/shut down, corrosion due to water chemistry, corrosion fatigue cracking due to the combined action of cyclic stress and corrosion, and erosion due to water flow at high pressure inside the tubes.

Newfoundland and Labrador Hydro ("Hydro") conducts asset management activities to proactively identify, replace, repair, or refurbish equipment to minimize the disruption of service and avoid unsafe working conditions due to equipment failure. Generally, Hydro identifies the required refurbishment and replacement work in time for inclusion in its capital budget applications; however, there are situations where unforeseen failures occur and require immediate refurbishment and replacement work to maintain safe and reliable operations.

1.1 Unit 3 Boiler Tube #5 Failure

On September 11, 2021, while Hydro was in the process of returning Holyrood TGS Unit 3 to service following a planned maintenance outage, a rupture on boiler tube #5 occurred on the east waterwall of Unit 3 boiler. A section of the tube (approximately 13.5 inches tall by 3 inches wide) was ejected during the rupture resulting in the release of steam into the powerhouse. The rupture occurred on the side of the tube that is facing the boiler insulation and cladding (cold side) as shown in the picture in Figure 1; therefore, it is referred to as a cold side rupture.

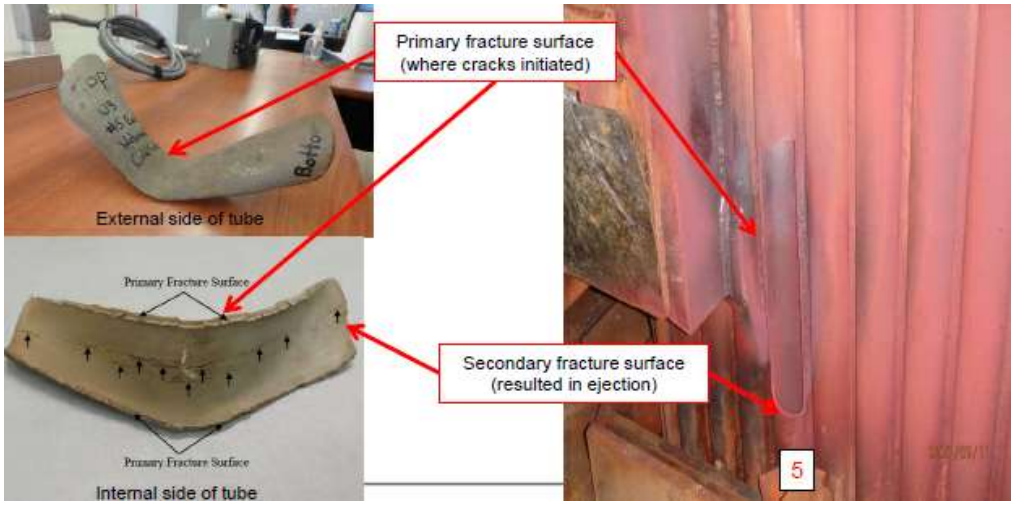

Figure 1: Boiler Tube #5 Rupture on the East Waterwall of Unit 3 Boiler

The released high-pressure steam blew out a part of the insulation and cladding. A cold side rupture of this nature is a rare occurrence. This incident is only the second occurrence in the Unit 3 boiler's 40 years of operation with the first occurring in 1993. A rupture of this nature has never occurred on Units 1 and 2.

At the time of the rupture event, Unit 3 was in the process of increasing load from 30 MW up to 70 MW. The unit tripped and Holyrood TGS was safely evacuated. Figure 2 shows debris and steam on the floor and cladding damage on Unit 3 boiler as a result of the tube rupture. The incident was a high-potential near miss which did not result in any injuries.

Figure 2: Debris, Released Steam and Cladding Damage on Unit 3 Boiler

A section of the ruptured tube was sent to an engineering consultant (Wayland Engineering Ltd) for investigation and evaluation of the degradation mechanism. The physical, chemical, and metallurgical evidence indicated that the primary degradation mechanism responsible for this cold-side rupture is consistent with corrosion fatigue which initiated from the internal surface of the tube. Fatigue due to thermal cyclic loads causes cracks to develop and propagate over years of the tubes service life. These cracks grow to a critical size (length/depth) at which point the tube is no longer able to withstand the applied stresses due to thermal cyclic loading and internal steam pressure. Due to the nature of the corrosion fatigue failure mechanism and the risk of additional failures on the Unit 3 waterwall boiler tubes, Hydro initiated a level 2 condition assessment to ensure all waterwall tubes on all sides of the boiler that are at risk of failure are fit for service. The inspection method was developed in consultation with General Electric ("GE"), B&W Engineering ("B&W") and Wayland Engineering.

In correspondence dated October 12, 2021,[1] Hydro notified the Board of Commissioners of Public Utilities ("Board") of its intention to utilize the Allowance for Unforeseen Items Account to fund costs associated with completing the work necessary to safely return Unit 3 to service.

2.0 System Overview

2.1 Existing System

Units 1 and 2 boilers were designed by Combustion Engineering Company (currently GE) and placed in operation in 1969 and 1970, respectively. The Unit 3 boiler was designed by B&W and placed in operation in 1979.

2.2 Operating History

2.2.1 Inspection and Test Plan

Hydro maintains an Inspection and Test Plan for all pressure parts at the Holyrood TGS, including boiler tubes, and completes tube thickness measurements annually in addition to other assessments such as tube samples which are taken from each boiler (typically every three years) and sent to an engineering company for analysis. Sample locations are chosen based on high heat and stress areas. Additional inspections are performed under the boiler condition assessment capital work program.

[1] "Unit 3 Boiler Tube Failure – Allowance for Unforeseen Items Notification," Newfoundland and Labrador Hydro, October 12, 2021.

2.2.2 5-Year Unit 3 Boiler Tube Failures History and Correction Actions

Beginning in September 2016, B&W completed a detailed assessment of the Unit 3 boiler tube sections that were assessed by AMEC Foster Wheeler (currently Wood Group) in their August 2016 report as being at risk of failure. B&W utilized their patented NOTIS[2] system to complete this assessment. This system non-destructively measures the thickness of the tube sections and the thickness of the internal oxide scale to predict tube remaining life. The detailed assessment by B&W found that tube condition was better than expected, but resulted in recommendations for inspecting boiler tubes and bends at specific locations. All of these inspections have since been completed. The area of Unit 3 boiler tubes related to the September 2021 failure had not been identified by AMEC Foster Wheeler as being at risk of failure.

In 2017, an ultrasonic thickness ("UT") survey was completed on all 60 of the reheater bends at the ninth floor and any bend that was measured below the acceptance criteria (21 total) was repaired by applying a pad weld.

In 2018, all of the sections recommended by AMEC Foster Wheeler were inspected and tube thickness was measured to predict tube remaining life. There were no concerns identified in any of the recommended sections to be inspected with the exception of the reheater bends at the ninth floor of the powerhouse. In this area, ten tubes were inspected and there were two tube bends identified that were slightly below the recommended acceptance criteria based on thickness; however, all were determined to be in good condition based on predicted remaining life.

On November 15, 2018, there was a waterwall boiler tube failure on Unit 3 that resulted in a steam leak that forced the unit out of service for five days. The failed tube was replaced and sent to a metallurgical lab for analysis. Corrosion fatigue cracking resulting from external stress applied by the structural attachment was confirmed as the failure mechanism. To determine the condition of other similarly attached tubes, B&W formulated a plan to complete inspection of all windbox corner attachment tubes during the 2019 planned outage for Unit 3 using a borescope. As the damage propagates from the inside of the tube, external inspection does not identify this problem. Other non-destructive techniques such as x-ray and ultrasonic had been attempted without success. The borescope inspection was also not successful because the borescope had difficulty reaching the areas of concern from the top opening of

[2] NOTIS ("Non-Destructive Oxide Thickness Inspection Service").

the tubes in the steam drum due to the length of the tubes and associated bends. Additionally, the resolution of the borescope was not sufficient to detect minute flaws.

In 2019, a UT thickness survey was completed on 39 of the 60 reheater bends and 18 pad welds were applied. In 2020 pad welds were applied to all remaining bends that had not been previously pad welded. Re-inspection was recommended for 2023.

To resolve the issue and reduce the risk of similar tube failures, it was decided that B&W would complete a redesign of the windbox structure to reduce stress on the tubes and that all corner attachment tubes would be replaced to remove any existing damage. This work was not performed in 2020 as the design was not completed until after the 2020 outage for Unit 3 was finished.

In 2020, Hydro engaged B&W to perform an engineering study to mitigate thermal cyclic stresses. The study recommended tube replacements and installation of expansion folds in the windbox to reduce the loads on tubes attached to the windbox due to thermal expansion. The B&W study was completed near the end of 2020. During the 2021 outage, 12 tube replacements approximately 10 feet in length (6 at the South West and 6 at the South East corners of the windbox high stress areas) were completed along with the installation of expansion folds recommended in the B&W study (Figure 3).

Figure 3: New Expansion Folds in the Windbox

In January 2021 a tube leak occurred on the west waterwall which was similar to the May 2018 failure that occurred on the south waterwall. The tube was replaced again and sent to a metallurgical lab for analysis with the same results.

3.0 Alternatives Considered

3.1 Deferral

Unit 3 could not be returned to service until the correction actions were completed. This unit is critical to the provision of reliable service for the upcoming winter season. Given Hydro's commitment to have the Holyrood TGS fully available for generation until March 31, 2023, deferral of this project was not viable.

3.2 Replacement

This alternative involves the replacement of the damaged section of tube #5 in Unit 3 boiler. Other work is required to gain access to this damaged tube section such as scaffolding and the removal of insulation and cladding. This option would not include inspections of other waterwall tubes, and therefore would not address the risk of additional failures which could pose an unacceptable safety risk.

3.3 Detailed Inspections and Replacement

This alternative involved detailed inspections of Unit 3 boiler waterwall tubes at risk of failure and replacement of tube sections as required. The detailed inspections require cutting a number of waterwall tube sections to allow for utilizing a specialized inspection tool that is inserted inside the tubes for inspection and thickness measurements.

4.0 Project Description

4.1 Chosen Alternative

Given the risk of additional boiler tube failures and the risk to the necessary operation of Unit 3 for the winter season, as well as the safety risk associated with boiler tube failures, Hydro determined that detailed inspection of the Unit 3 waterwall tube sections were required prior to returning Unit 3 to service. Hydro determined that the most prudent alternative was to proceed with replacement of the damaged section of tube #5 as well as detailed inspections of Unit 3 boiler waterwall tubes with replacement of any other Unit 3 boiler waterwall tube sections, as required. As Holyrood Unit 3 is

required to provide sufficient generating reserves for the 2021–2022 winter season, Hydro determined that it could not delay this work and proceeded with the full scope under the Allowance for Unforeseen.

4.2 Project Scope

External boiler scaffolding and asbestos abatement hoardings were constructed. External insulation and cladding were removed and internal boiler scaffolding was built to provide access to inspection locations for contractor personnel.

To provide access to the inside of the waterwall tubes for inspection, 71 tube sections (totaling approximately 200 feet of tube) were removed to allow a specialized probe (custom made to fit for Unit 3) to be inserted inside of at risk tubes to perform inspections (Figure 4).

Figure 4: Portion of Removed Waterwall Tube Section on Unit 3 Boiler

A specialized boiler tube inspection company, TesTex, was engaged to perform the inspections. Large structural attachments welded to the external surface of the waterwall tubes are used to support the windbox and upper header vestibule. Tubes were recommended for internal inspection based on high-stress areas around the structural attachment locations. Tube inspections started in the high-stress areas and moved outward along the waterwalls until no corrosion fatigue indications were detected in three consecutive tubes, as recommended by GE. The inspections discovered 8 corrosion fatigue indications, which were removed. With all inspection complete, the 71 tube sections previously cut from

the boiler waterwalls to provide access for inspection equipment were replaced by Hydro's boiler contractor, GE.

4.3 Project Timeline

The project milestones and completion dates are listed in Table 1.

Table 1: Project Timeline

Milestone	Completion Date
Waterwall Tube Failure	September 11, 2021
Scaffolding/Abatement Completed	September 28, 2021
Inspections Completed	October 17, 2021
Tube Welding Completed	November 11, 2021
Service Pressure Test Completed	November 15, 2021
Unit 3 Returned to Service	November 21, 2021

5.0 Project Costs

The current expenditures for this project are shown in Table 2. The original preliminary estimate was $1,800,000. Current estimated actual expenses are approximately $2,225,275, as a result of the specialized engineering required to inspect the Unit 3 boiler tubes and the magnitude of work required to remove, inspect, and replace the boiler tubes. Project expenditures provided in Table 2 reflect costs reported to date. This value may change marginally as Hydro receives final invoicing from all contractors. Actual final costs will be reported in Hydro's Allowance for Unforeseen Capital Expenditures Monthly Reporting.[3]

Table 2: Project Expenditures ($)

Project Expenditure	Cost
Internal Labour	70,000
Boiler Tube Removal, Installation and Engineering	1,681,059
Non Destructive Inspections	36,000
Specialized Boiler Tube Inspections	260,162
Insulation Removal/Insulation	178,054
Total	**2,225,275**

[3] Filed with the Board on the tenth business day of each month.

6.0 Conclusion

On September 11, 2021, a rupture on a boiler tube occurred on the east waterwall of the Unit 3 boiler. A section of the tube was ejected during the rupture which resulted in the release of steam into the powerhouse and damage to the boiler insulation and cladding. Hydro determined that detailed inspections and replacement work was the most prudent alternative. The work was completed on Unit 3 boiler tubes in October and November 2021 and the Unit was released for service on November 21, 2021.