Steam Generator Leak Detection at Bruce A Unit 1

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ABSTRACT

A new steam generator leak detection system was recently developed and utilized at Bruce A. The equipment is based on standard helium leak detection, with the addition of moisture detection and several other capability improvements. All but 1% of the Unit 1 Boiler 03 tubesheet was inspected, using a sniffer probe which inspected tubes seven at a time and followed by individual tube inspections. The leak search period was completed in approximately 24 hours, following a prerequisite period of several days. No helium leak indications were found anywhere on the boiler. A single water leak indication was found, which was subsequently confirmed as a through-wall defect by eddy current inspection.

INTRODUCTION

During 1996 operation, a small (~0.5 kg/hr) D_2O leak was detected on Bruce Unit 1 Boiler 03. The leak rate persisted at this level until a scheduled Unit outage in Spring 1997. Due to the difficulty in locating small boiler leaks with fluorescein solution, a more sensitive leak detection technique was sought and developed for field use on CANDU units. The method, called Helium Leak Detection (HLD), is an established technique for locating leak paths in a wide variety of industrial and commercial applications, including boilers. [1]

Past experience at Bruce A involved locating boiler tube leaks using fluorescein solution. In this method, the boiler secondary is filled with a fluorescein dye solution and pressurized to 200 psig (1.3 MPa). Leaks are then found by a manual visual inspection of the primary side tube sheet with the aid of a black light. The practical sensitivity limit for fluorescein leak detection is estimated at approximately 2 kg/hr of D_2O, which exceeded the actual D_2O leak rate on Unit 1 in this instance. Given this situation, the more sensitive HLD capability was then developed. At present, HLD has an estimated sensitivity which corresponds to D_2O leak rates of 0.01-0.1 kg/hr under typical CANDU operating conditions. The helium tracer gas is completely inert and does not pose any boiler or reactor chemistry consequences. This paper describes the particular HLD system which was designed at Ontario Hydro Technologies (OHT). Also described are the leak search results and experiences from Bruce A in Spring 1997.

HLD METHOD

The HLD method as applied to steam generators involves the detection of helium gas leaking across the primary-secondary boundary of the boiler. In the OHT system, pressurized helium gas in the boiler secondary flows through the leak path to the primary side. The primary side of the tube bundle is purged with air so as to flush any helium gas toward a detector probe placed in the primary head of the boiler. A "sniffer" probe is positioned within the primary head and is manipulated by a robotic arm around the tubesheet. The sniffer samples the air from each tube in the boiler and a helium detector measures the helium concentration in this air. A leaking tube is signaled by a helium concentration well above background levels. Similar HLD systems have been developed elsewhere and are in use globally. [2] The system utilized at Bruce A had several unique features which augmented the capabilities of the HLD method. These were:

- Buoyancy control of helium gas
- Primary-side moisture detection
- Phased leak search

Each of these is discussed more fully in sections below, as well as an explanation of the various leak detection equipment installed on the Unit.

HLD PRIMARY SUBSYSTEMS

Figure 1 contains a diagram of the various HLD subsystems which were installed on Bruce Unit 1 during the Spring 1997 outage and prior to the leak search. An air purge system was located in the reactor vault at the primary head of the boiler under test. The air purge direction was from the primary outlet toward the primary inlet, although the opposite purge direction was judged to be equally satisfactory. Service air was used to purge the tube bundle through the cold leg manway at a rate of approximately 1500 L/min (53 cfm). A simulated leak was also installed at the primary outlet into one of the boiler tubes. A small flow of helium gas could be introduced into this tube to act as a diagnostic aid for the leak detector. At the primary inlet manway was placed the tubesheet sampling system. This consisted of a sampling sniffer probe which was manipulated according to a predetermined pattern across the tubesheet in search of helium gas leaking through from the secondary side. The helium detector was a commercial mass spectrometer instrument which had been modified for plant use. The sniffer probe was manipulated remotely across the tubesheet by a Zetec SM-23 robotic arm. No boiler entries were required using this method.

HLD SECONDARY SUBSYSTEMS

The eight boilers on the Unit were drained of water to the best extent possible. Due to the large volume of the boiler secondary system and the difficulty in isolating the boiler under test from the remaining boilers and steam drums, pressurization of the secondary side was achieved with a combination of air and helium/argon mixture. An air compressor was attached near the main steam balance header at 1-45210-NV88. A helium injection system was attached to the boiler wet storage recirculation system at valve 1-36320-V10. Pressurization of the boiler secondary system proceeded by first pressurizing to 500 kPa (60 psig) with air, followed by the injection of a gas mixture containing approximately 5% helium and 95% argon through the boiler blowdown piping. The gas was commercially supplied premixed from a gas tube trailer parked just outside the Unit. The argon used was standard Ar-40, a stable isotope which presents no radiological hazards. Argon-40 is present in air at a concentration of 0.9%. No significant amount of the argon added to the boiler can migrate into the primary side. Activation of the argon to Ar-41 is therefore not a possibility.

To confirm the presence of sufficient helium gas in the boiler secondary, samples of boiler secondary gas were continually flowed through an automated helium analysis system located in the Unit 1 West boiler room. The analyzer was attached to the boiler secondary through two water lancing ports (flanges C26 and C28). This helium analysis system was also fitted with an oxygen sensor to confirm that the helium and argon mixture had displaced the air in the boiler secondary.

The central control for the leak detection system was located within a portable office trailer near the Unit. All subsystems were connected electronically to the control system with signal cables routed to each of the remote locations. In the case of the air purging and tubesheet sampling systems, these cables were routed through penetrations installed in the boiler bellows area. The control system allowed remote data logging and control of field devices using a digital network and a personal computer.

BUOYANCY CONTROL OF HELIUM GAS

For a successful leak search, the helium in the boiler secondary must remain there for the duration of the test. Helium is a light gas which, due to buoyant forces, tends to rise when placed in air. Therefore, maintaining a uniform helium charge in the boiler secondary poses difficulty. The use of diaphragms or baffles to isolate the boiler from the steam drum is undesirable for several reasons, including the need for steam drum entry and possibly also boiler modifications. However, when helium is pre-mixed with a heavy carrier gas, the mixture is negatively buoyant in air and will remain fixed within the boiler secondary. This was the rationale and the advantage of using argon as the carrier gas, as opposed to air or pure helium. No boiler isolation devices need be installed with this method. There is a gradual loss of helium from the boiler due to diffusion, but this process is manageably slow under the leak search conditions of 500 kPa. The gas composition of 5% helium/95% argon was arrived at through consideration of buoyancy and leak detector sensitivity.

PRIMARY-SIDE MOISTURE DETECTION

Before the leak search, the boiler secondary was drained of water to the best possible extent. However, at the tubesheet, several inches of water were still present during the leak search. In cases where the through-wall defect is above water, helium will readily flow through the leak path to the primary side and be detected by the helium detector. For leaks below water however, the helium cannot permeate through the water layer and such leaks would remain undetected by this technique. To detect tube leaks below the water line near the tubesheet, the leak detection system was equipped with an additional mode of detection, a moisture detector (dew point meter). The dew point meter measures the water concentration in the purge air emerging from the tube under inspection. For leaks located under water, moisture from the secondary flowing through to the primary side (due to the 400 kPa pressure differential) will evaporate, registering as a rise in dew point. For leaks above water, the dew point may again register an elevated reading, depending on the humidity of the gas in the boiler secondary. The characteristics of the helium and moisture detection methods are summarized in Table 1, which indicates the detectability of defects above and below water. From these characteristics, it is evident that a leak indication which registers *only an elevated dew point* must be an under water defect. For cases where a helium indication is measured, the leak must be above water, *regardless of the dew point reading*.

PHASED LEAK SEARCH

In preparation for the Bruce Unit 1 leak search, pressurization of the secondary system to 500 kPa was completed in approximately two hours. The charging of Boiler 03 secondary with the helium mixture then proceeded over a second two hour period. Once the boiler was filled with the helium mixture, the leak search commenced. Throughout the leak search period, a slow flow of helium/argon was maintained to counteract diffusional losses of the helium from the boiler. To maximize efficiency, the leak search was divided into two phases-survey and detailed search. The survey covered all of the tubesheet and was intended to localize the leak within a subsection of the tubesheet. The survey phase was conducted with a funnel device fitted to the end of the SM-23 manipulator arm installed in the

Table 1 Detectability characteristics of helium and dew point detectors.

Detector Type	Defect Above Water	Defect Under Water
Helium	Yes	No
Dew Point	Yes[#]	Yes

[#]Depends on boiler secondary humidity

primary inlet head. The funnel, which allowed simultaneous inspection of seven tubes, was moved to each desired location around the tubesheet and held there for approximately 15 seconds. This allowed a sample of air to be obtained from the group of seven tubes which was analyzed for helium content by the leak detector and for water content by the dew point meter. The helium concentration, dew point, SM-23 arm location and other data were continually logged to disk. If a leaking tube was among the tubes being sampled, the location was flagged for closer examination in the detailed search phase. Air samples were also obtained on a periodic basis from the boiler head (both hot and cold legs) and the purge air. These were routed to the leak detector through a gas manifold, which was part of the tubesheet sampling system. These measurements established the helium and moisture background concentrations in the boiler primary head.

Following the leak survey phase described above, the detailed search commenced. Its purpose was to positively identify any leaking tubes within the subsections already flagged in the survey phase. The detailed search phase was performed with a single tube probe (ie. individual tube inspections). Each tube in the flagged subsection was individually checked by moving the sniffer probe (using the SM-23) in close proximity to the tubesheet plane at the tube exit. The detector signals were recorded for each tube before moving to the next tube. Once the leaking tube had been located, its identity was carefully confirmed by noting the present SM-23 position on the computer monitor. The leaking tube location was also later confirmed by a careful review of a videotape produced from the SM-23 camera during the leak search.

At the completion of the leak search, the boiler secondary helium/argon gas was flushed out by opening the main boiler blowdown valves. Following this, the secondary system was depressurized by opening the relief valves on the steam drums. The leak detection equipment was then removed from the Unit to permit subsequent inspections of the boiler.

TUBESHEET SURVEY RESULTS

In this phase, 99% of the tubesheet was inspected (a total of 4163 tubes) over a period of approximately 24 hours. The 37 tubes not inspected were all located in Rows 1 and 2. Obstructions near the boiler divider plate prevented the funnel sniffer probe from reaching these tubes. The dew point data for the survey is shown in Figure 2 as a tubesheet map. The ambient dew point in the boiler primary head was around -21°C, which indicates that the boiler was well dried by the air purge prior to the leak search period. The tubes marked as leak indications correspond to elevated dew point readings. The threshold utilized for a leak indication on this map was -19°C, approximately 3σ above the mean value of -21°C. When an elevated reading was obtained using the 7 tube funnel, all 7 tubes being inspected were logged with the same elevated dew point reading. The localization of the actual tube leak indication was performed with the single tube probe (described below).

Approximately 120 tubes were flagged for individual inspections. The tubes in the vicinity of rows 10-20 and columns 89-91 were chosen on the basis of elevated dew point readings. Most of the other tubes among the 120 were selected on the basis of suspected small variances of helium signals.

DETAILED SEARCH RESULTS

Following the tubesheet survey, the 7-tube sniffer probe was removed and replaced with a single tube probe. The 120 flagged tubes were inspected individually to localize and confirm any possible leak indications. The dew point readings for the individual tubes included one prominent leak indication located at R16 C90 with a dew point of -4 to -3°C. The dew point indication for this tube was much larger than with the 7 tube funnel (approx. -17°C) because the wet air from the leaking tube was no longer diluted with dry air from the 6 other tubes under the sniffer funnel. No helium leak indications were found amongst the 120 tubes flagged from the tubesheet survey. The boiler was therefore considered leak tight to helium gas.

SUBSEQUENT NDE INSPECTIONS

After the leak search was conducted, Non-Destructive Examination (NDE) via boiler tube Eddy Current (ECT) was employed to inspect tube R16 C90 (identified as the leaker), as well as other tubes in the immediate area of this tube. ECT analysis results confirmed tube R16 C90 to have a 100% through-wall crack at the boiler inlet (hot leg) tubesheet. This tube sample was removed for metallurgical examination, which also confirmed the leak search conclusions. The tube removal also confirmed the existence of water on top of the tubesheet, which would have prevented the helium from permeating to the crack, and through to the inside diameter of the tube.

Additional ECT in Boiler 3 also reported a number of tubes which contained 100% through-wall crack indications similar in location to R16 C90. These tubes, (R22 C82, R18 C90 and R34 C58) were also removed from the boiler, and the 100% through-wall indications were confirmed by metallurgical examination. The existence of these tube cracks in this area of Boiler 3 then led to a concentrated effort of inspecting all the tubes in all the boilers in both Unit 1 and in Unit 4, to ensure that additional crack indications were not present.

The metallurgical examinations revealed that all tube cracks were very tight. These would tend to exhibit small leak rates under operation, a fact which was borne out by the D_2O leak rate on this boiler remaining stable and small (< 1 kg/hr) throughout more than a year of Unit operation. The position and characteristics of these tube cracks made their detection very difficult. The defects were located at the top of the tubesheet and submerged in water at the time of the leak search, thereby negating any possibility of detection with helium. The moisture detection capability was not sufficiently sensitive to detect three of the four tube cracks, under the conditions used for this leak search.

CONCLUSIONS

The leak detection equipment functioned reliably throughout its field use and was successful in locating one through-wall tube defect near the tubesheet. The presence of both helium and moisture detection capabilities was essential for a complete boiler leak search. Optimizing the moisture detection sensitivity is a future development priority.

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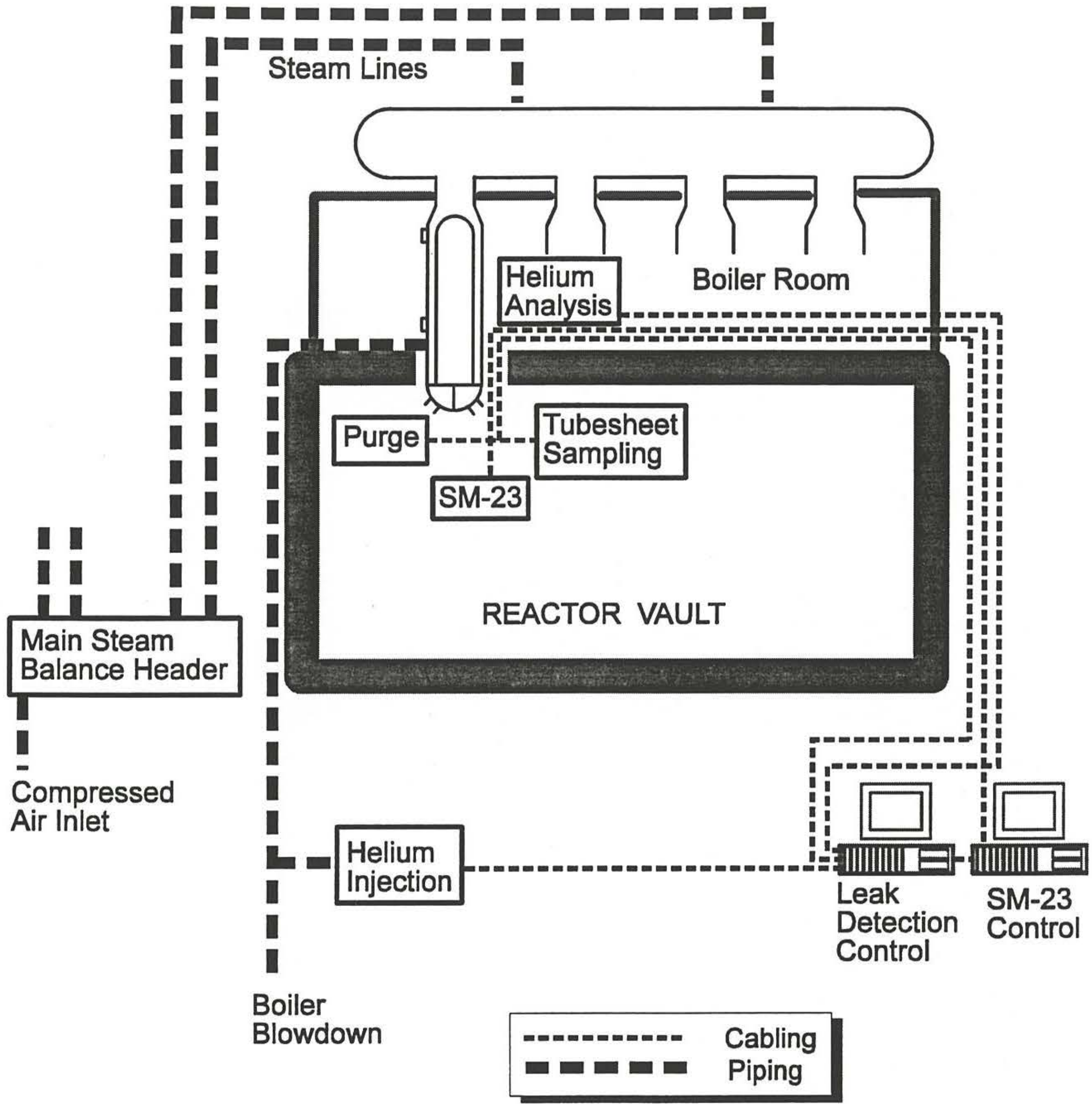
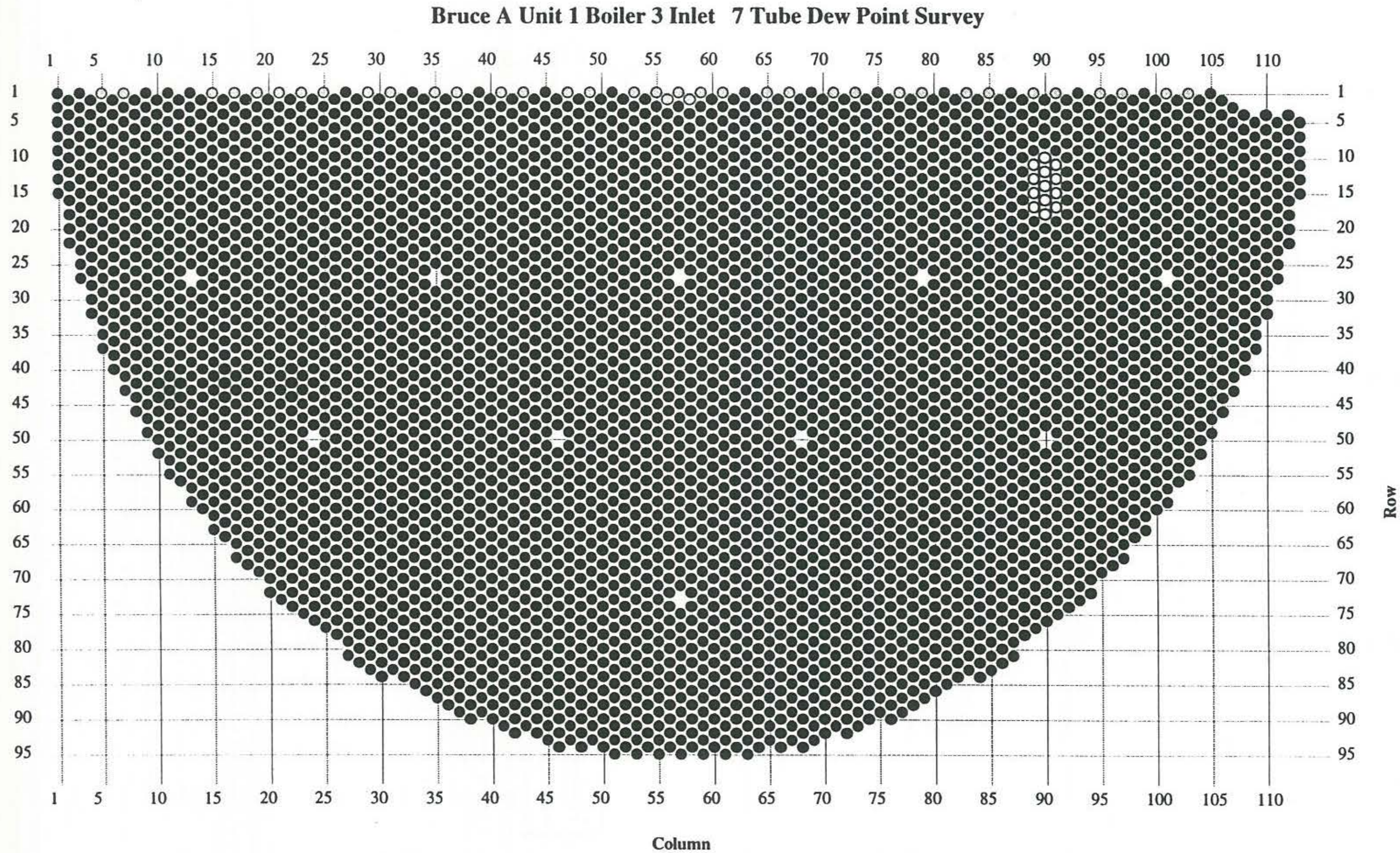


Figure 1 Overview of the major components of the helium leak detection system.



Type	Total	% of Total
○ Not Inspected	37	0.88
● No Leak Indication	4150	98.81
O Leak Indication	13	0.31

Figure 2 Dew Point tubesheet map for survey phase of leak search