BRUCE B UNIT 6 DIVIDER PLATE SEALING SKIN INSTALLATION

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Abstract

Bruce Unit 6 went into service in 1984, since its initial startup reactor inlet header temperatures have risen steadily. In 1999 reactor inlet header (RIH) temperatures had risen to the point that extraction steam to both high pressure feed water heaters had being valved out of service in an effort to keep boiler pressures above the units safe operating margin and RIH temperatures low. It was projected if no action was taken to reduce RIH temperature levels unit derating would start in 2000 and continue at a rate of 0.8% reactor power per year (-5.7Megawatts).

Experience gained from the Bruce A units and other CANDU stations with segmented divider plates pointed to two main contributors to RIH temperature increases, divider plate leakage and boiler tube ID fouling. Divider plate leakage is a measurable condition, with proven results if corrected. Boiler tube ID fouling on the other hand was a measurable condition via eddy current and oxi-probe inspections, however only limited data existed at that time as to its effect on RIHT. In addition the effectiveness of ID cleaning was unknown and the equipment and process needed conversion and qualification for Bruce units. The decision was made to reduce the divider plate leakage now, and later perform an ID clean if the process proves beneficial. For reasons of cost, time (design and installation), dose and remaining boiler life, Bruce B design engineering decided that sealing the divider plates best suited the stations needs.

During the last few years of Bruce A'S operation a design was developed that would seal the existing divider plates rather than replacement. The sealing design consisted of a thin stainless steel sealing skin that covered the entire segmented divider plate plus all peripheral seams. Thicker stainless steel clamping plates covered the sealing skin panels to hold them in place and provide erosion protection. The sealing skin and clamping plates were held in place by utilizing the bolt patterns of the original divider plate design. No welding was required. The installation process proceeded as planned, actual installation time was approx. 20 days including opening, decontamination, installation and closing of all 8 boilers. The cost was approx. $2M. Dose received during the installation was 20 man Rem. On return to full power station thermal performance staff reported a 3 to 4 deg C reduction in RIHT levels. Boiler pressures had risen from 4120kpa before the outage to 4400 kpa. Gross power production had increased by 20 Magawatts.

Introduction

All CANDU stations are experiencing a common problem, rising Reactor Inlet Header Temperatures (RIHT). Rising RIHT is a multi-mode problem, the main contributors are assumed to be boiler tube ID fouling and divider plate leakage. Physical evidence and engineering analysis to date has proven a link between divider plate leakage, increasing RIHT and loss in generation output. Other CANDU stations with a similar multiple component divider plate configurations have corrected divider plate cross flow leakage and achieved reduced RIHT values.

The divider plates separate the inlet and outlet heavy water flows on the primary side of the steam generators. Heavy water is forced to flow through the steam generator tubes by the divider plates. The original design basis configuration (Figure 1) of the divider plates consists of a multi-panel lap joint bolted design, resting and supported by lap joint seat bars. Both seat bars are welded to the primary head bowl and the tube sheet. The bolted joint design is prone to leakage across the joints, diverting flow that would otherwise pass through the tubes. Resulting in a reduction in steam generator (SG) heat transfer efficiency.

Bruce Unit 6 went into service in 1984, since its initial startup reactor inlet header temperatures have risen steadily. Divider plate leakage was suspected as the root cause of RIH temperature increase. In 1995 Ontario Hydro Technologies developed a process to measure divider plate leakage.

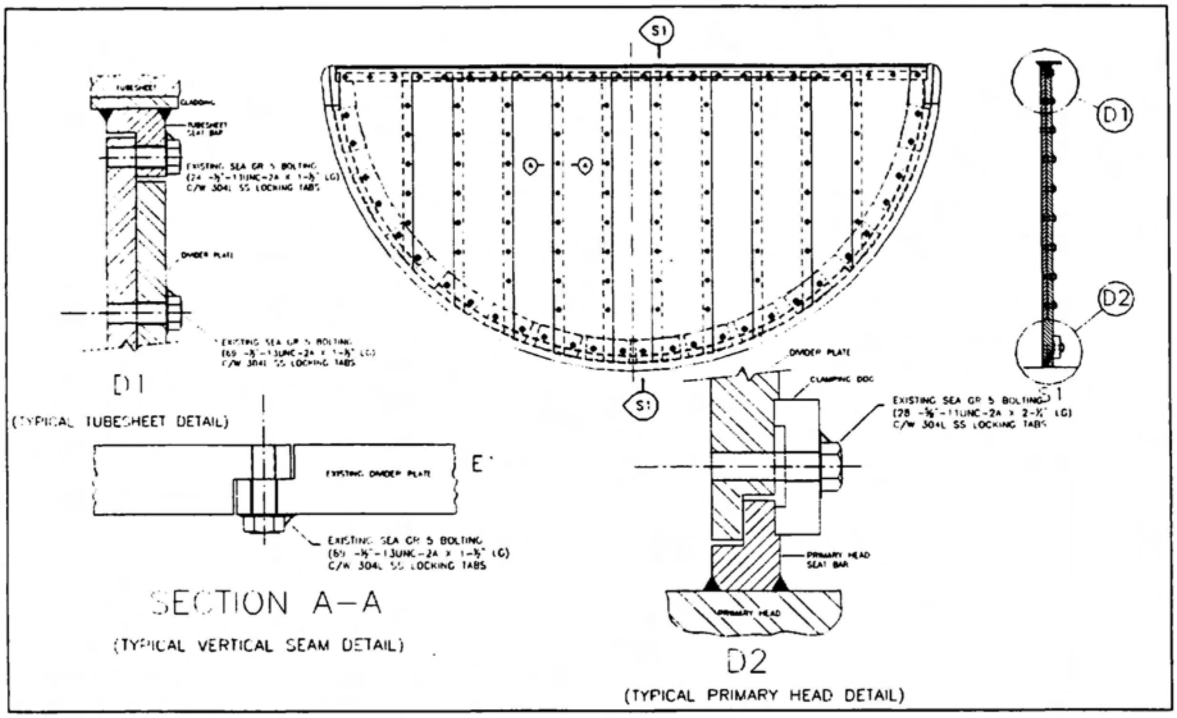

Figure 1 Bruce B Divider Plate Original Configuration

The process known as 'ALIS' measured sound energy leaking through the divider plate. An ultra sonic sound source was placed on one side of the divider plate and a microphone was move in a path following all the bolted joint seams on the other side. Using the 'ALIS' process an estimate could be made to determine the leakage area. In 1997 when Unit 6 was the first to inspected the findings were dramatic. It was estimated that SG 3 and SG 6 had leak path areas equivalent to 120 and 100 square centimeters. Figures 2 shows the results of Unit 6 Steam Generator 3 'ALIS' first inspection. Leakage paths of this magnitude were estimated to cause a bypass leakage in the range of 10% of total flow and be responsible for up 4 deg C of RIH temperature rise. Between the 1997 inspection and 1999 the Bruce Unit 6 RIHT levels had increased to the point that both interim measures to reduce RIH temperatures were exhausted, boiler pressure reduction and isolation of extraction steam to the HP heaters. If no action was taken reactor power deratings would be required, in order to operate the unit within current operational limits. Once deratings start it was estimated to continue at a rate of 0.8% reactor power (5.7 megawatts) per year. With both high pressure feed water heaters out of service Unit 6 was already incurring a gross electrical production loss of 15 to 20 Mwe. In addition the unit was being operated with secondary side pressure very close to the current safety analysis lower limit of 4000 Kpa (g) pressure.

Pre 1999 Acoustic Leak Test Results

Leak testing of the Bruce B SG divider plates have shown significant leakage area and some rudimentary tests done at Bruce A in 1997 indicated similar leakage. Based on supporting evidence from other CANDU stations, reducing or stopping the cross flow divider plate leakage will result in significant RIHT reductions. Acoustic leak inspections of the Bruce B divider plates have estimated leakage areas as follows.

Unit 6 steam generators B03 and B08 have leakage areas of 120 to 100 CM^2 equating to leakage volumes of 10 and 8% of total PHT flow. RIH temperature increases of 4.1 deg C outer zone (OZ) and 3.3 deg C inner zone (IZ) were estimated as a result of the bypass leakage. Tables 1 and 2 show pre 2000 inspection results.

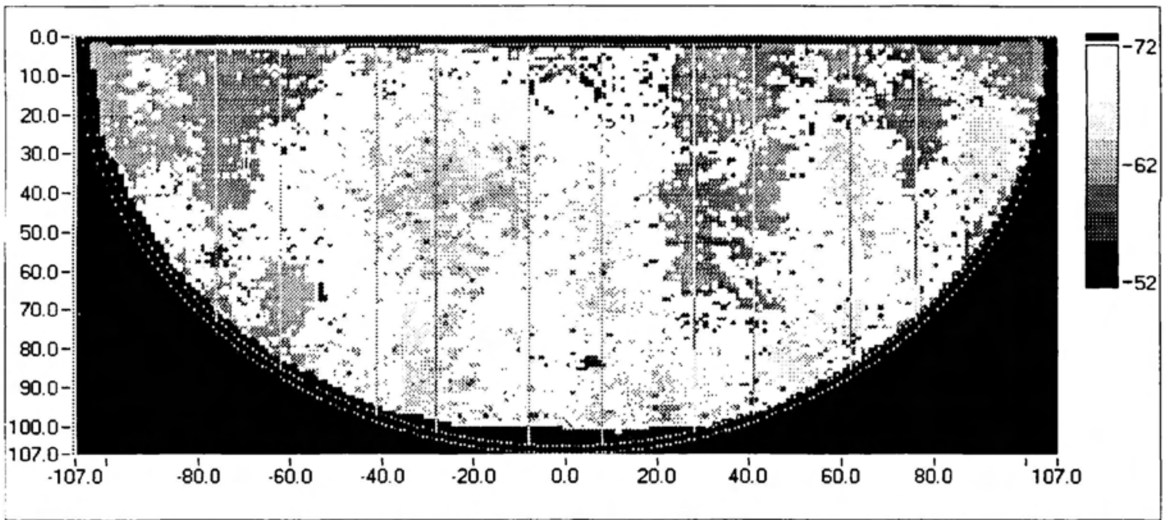

Figure 2. Unit 6 Sg3 ALIS Inspection Plot - Leakage Estimated at 120 sq cm.

Note: Light areas indicate leakage, Red equals highest, dark area indicate least, Blue equals least.

Unit/ Boiler	B01	B02	B03	B04	B05	B06	B07	B08
U5	90_{99}	70_{99}	60_{96}	50_{96}				
U6			120_{97}			100_{97}		
U7				20_{98}				40_{98}
U8		50_{98}						30_{98}

Table 1. Bruce B Divider Plate Acoustic Leakage Inspection Summary

LEGEND: TABLE DATA FORMAT (Leakage Area CM^2)($_{YEAR}$)

UNIT	STEAM GENERATOR	AREA (cm^2)	LEAKAGE FRACTION	OZ RIHT (°C)	AFFECT ON IZ RIHT (°C)
5	3	60	0.048	1.8	1.6
5	4	50	0.038	1.4	1.3
6	3	120	0.102	4.1	3.7
6	6	100	0.085	3.3	3.0

Table 2. Leakage Area, Leak Volume, and Resulting RIHT

Options

Elevated RIHT levels are controllable with out physical modification. By reducing Reactor Power and steam pressure on the secondary side, RIHT levels can be controlled, however with each reduction the available energy to produce power at the turbines is reduced. Controlling RIHT by secondary side pressure reduction is therefore not an economically acceptable option.

Experience gained from COG studies, Bruce A , acoustic testing of Bruce B SG divider plates and other CANDU stations identified rising RIH temperature as a multi-mode problem caused largely by steam generator tube ID fouling and divider plate leakage. Divider plate leakage is a measurable condition, with proven results if corrected.

All CANDU 600 stations that had segmented divider plate designs replaced with a welded floating design achieved significant RIH temperature reductions. Pt Lepreau NGS and Hydro Quebec have both replaced the segmented divider plates in the CANDU 600 type SG's and have achieved at least 3 deg C of RIH temperature reduction.

Boiler tube ID fouling is a measurable condition via eddy current and oxi-probe inspections, however only unsubstantiated data existed at the time as to its effect on RIHT. In addition the effectiveness of steam generator tube ID cleaning was not fully known, the process was not qualified or designed for the Bruce steam generators.

The decision was made to reduce the divider plate leakage now, and later perform an ID clean should the technology proves successful. For reasons of cost, time (design and installation), experience, dose and suspected remaining boiler life, Bruce B design engineering decided that sealing the divider plates best suited the stations needs.

Preliminary Design and Concept Testing

During the last few years of operation of the Bruce A Units 1-4, similar problems were being experienced. Units were being derated as a result of increasing RIHT levels. During that time a challenge was put to the Bruce Projects and Modifications Boiler Design Team, to develop a cost effective method of sealing the divider plates. The design was to have significant cost savings over the current practice of divider plate replacement. The design team developed an all metal sealing membrane, designed to cover the entire divider plate and all peripheral seams. Figures 3 and 4 show preliminary sketches of the sealing skin installed on the Bruce B divider plates. During early design review meetings with Babcock&Wilcox, Ontario Hydro Nuclear Technology Services, Ontario Hydro Technologies and Bruce A station staff, concerns were raised as to the effectiveness of the sealing skin to seal around the periphery of the divider plate. It was pointed that the sealing skin was not likely to seal if the seat bar was not flat or level. Ie. When the seat bars were installed the divider plate sealing surfaces were machined flat and planar and the exposed seat bar surfaces were left in the as installed condition. The exposed seat bar surfaces were likely uneven and not planar due to weld distortion. A new design requirement was imposed, the sealing skin edge seal would have to accommodate dimensional differences between the divider plate and peripheral seat bars.

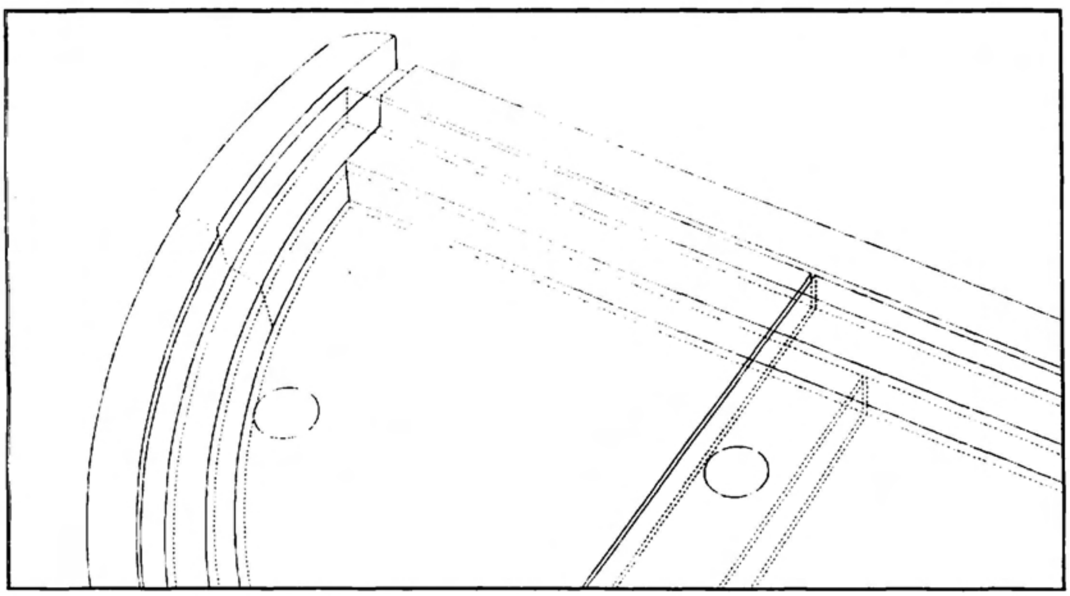

Figure 3. Divider Plate , Original Configuration

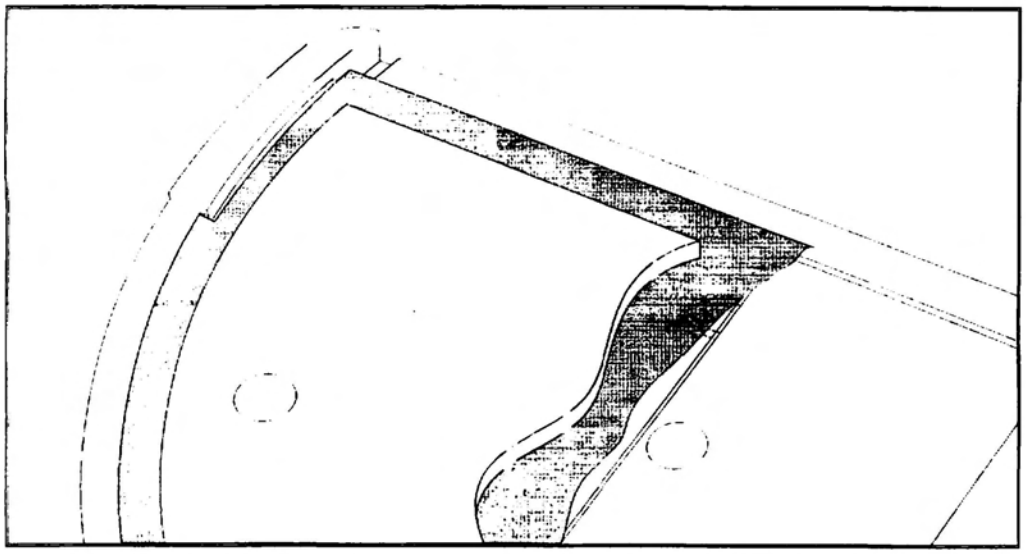

Figure 4. Divider Plate Showing Clamping Plate covering sealing skin as installed

A simple test was developed to determine if the sealing skin peripheral edge could or would conform to seat bar surface imperfections. A small section of the sealing material was fabricated with a bent edge to seal at the seat bar area and a covering clamping plate. These components were then bolted to a divider plate / seat bar mockup. The seat bar portion was a 1/8" x 1" flat bar which was bent and twisted to produce a sealing condition much worse than could exist in the field. The bent sealing material easily conformed and sealed the gaps. The conclusion was that the sealing skin assembly could easily seat and conform to any dimensional differences between the divider plates and seat bar. Figures 5, 6 and 7 display edge seal proof of principle test.

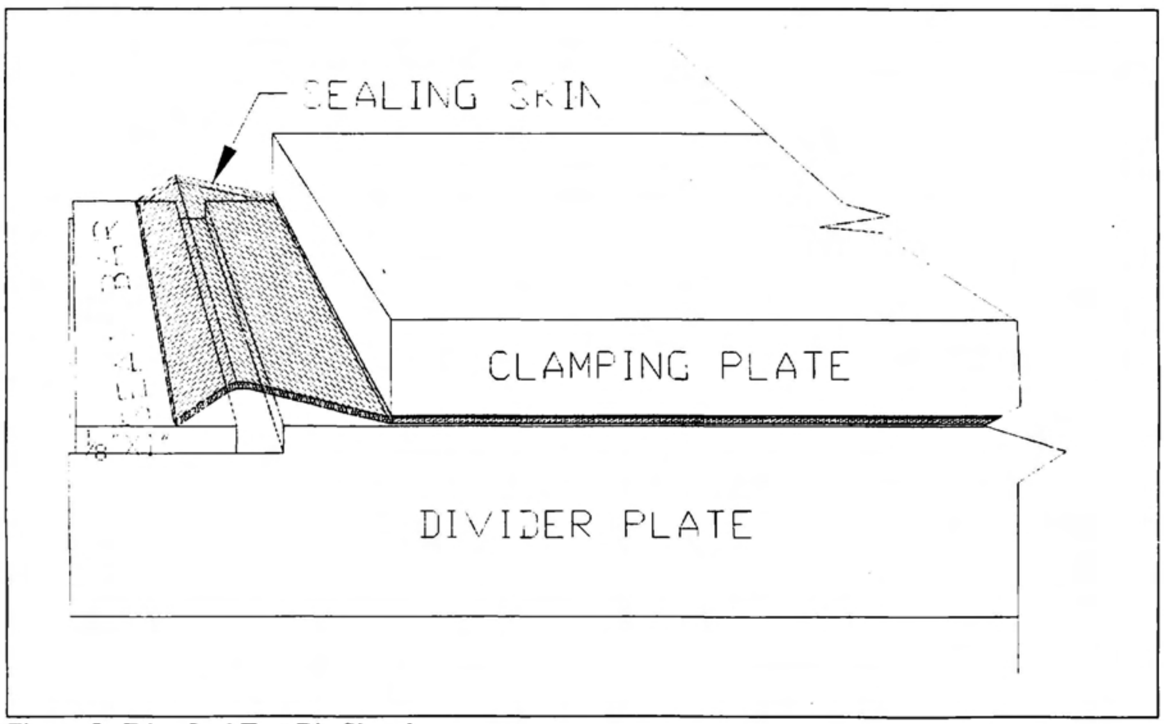

Figure 5. Edge Seal Test Rig Sketch

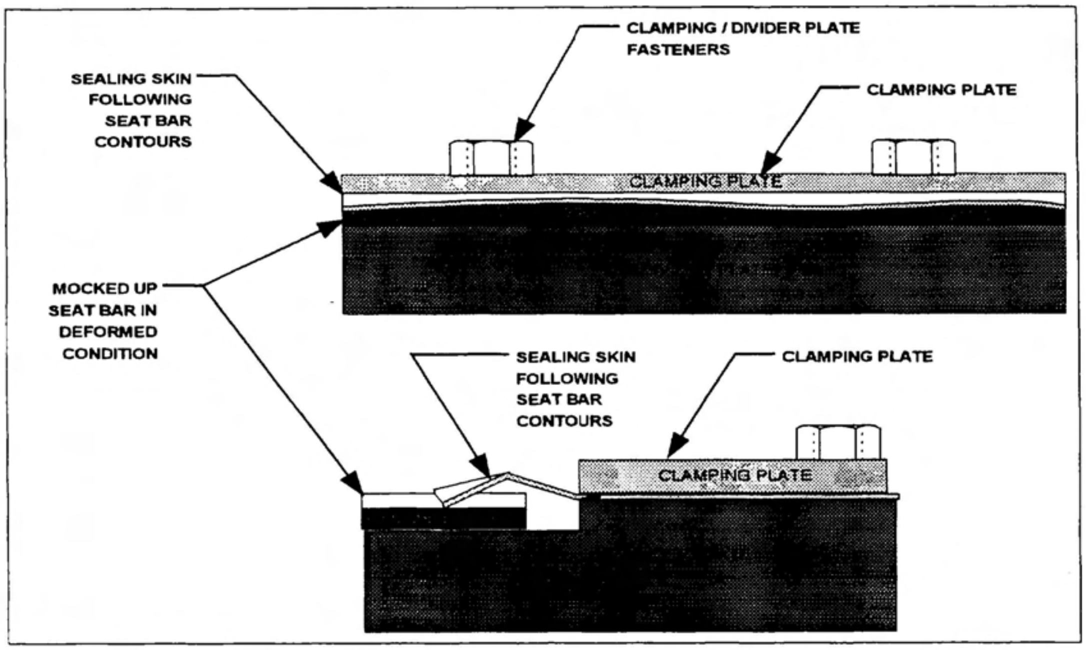

Figure 6. Edge Seal Test Results - sketch

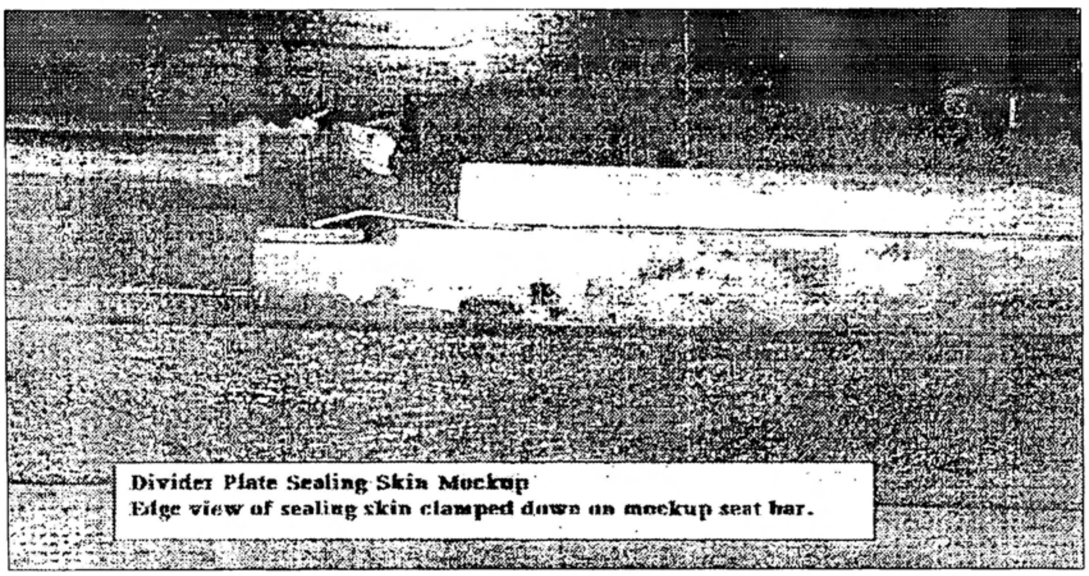

Figure 7. Edge Seal Test Rig Photo

To further prove the effectiveness of the sealing skin leak testing technologies were developed and a full scale mockup was tested with a preliminary and final sealing skin design installed.

In 1997 a full scale mockup of the Bruce A preheater primary head complete with segmented divider plate was tested for leakage using air supplied by a blower. The first step was to measure the back pressure of the seal created by the divider plate in the original design configuration. Second was to install a sealing skin mockup without the bent peripherial edge and perform the test again. The simple test demonstrated that the sealing skin could reduce cross flow leakage by at least 50%.

In 1999 the test was repeated using a refined set of sealing skins with bent edges, proper clamping plates and the 'ALIS' acoustic divider plate leak measurement equipment from OHT.

The results clearly demonstrated a 10 times reduction leak path area. Original configuration leakage area was 30sq cm, with the sealing skins installed the leakage area dropped to 3 sq cm. Figures 8 and 9 show before and after Mock-up testing results as measures by 'ALIS'.

Additional concerns were raised as to the actual installation time and experience required to perform the sealing skin installation work. The concerns were resolved in light of the experience gained during the Bruce 'A ' May 1995 Unit 4 outage. Prior to the outage a suspected

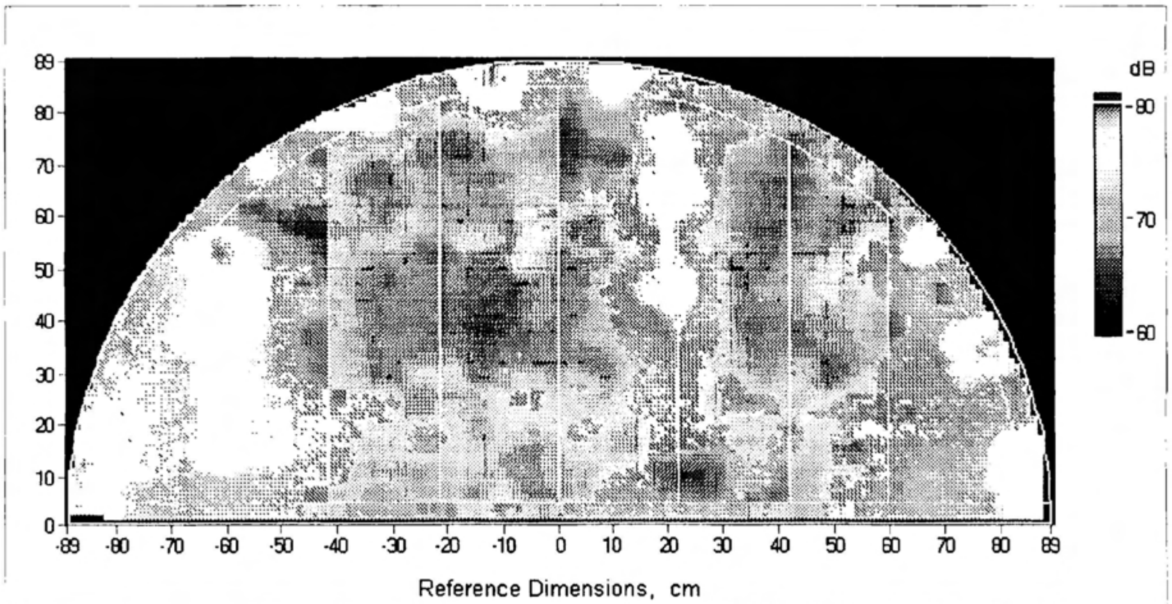

Figure 8 Test 3: Skins Removed and Two Joint Bars Shimmed by 1 mm. Estimated Total Leak Area: 30 cm^2

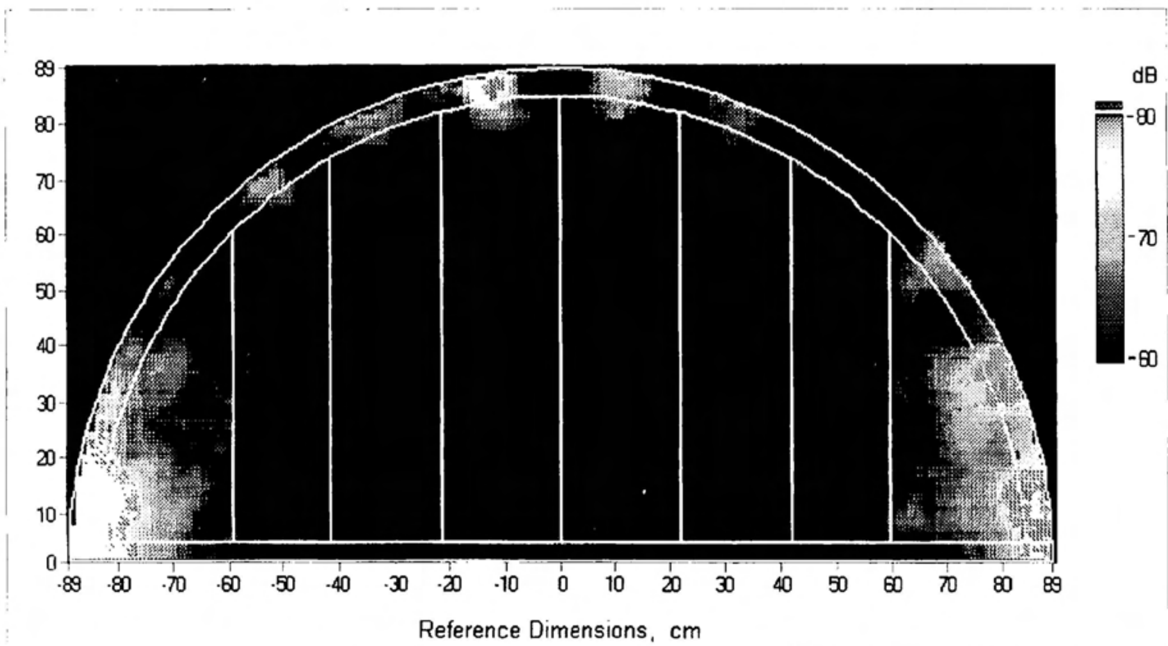

Figure 9 Test 4: Skins in Place "Replicate Condition" Estimated Total Leak Area: 3 cm^2

hydrogen explosion blew out several preheater divider plates forcing a full scale replacement. Based on the man power, dose and work experience of that job a sealing skin design appeared well within the capabilities of the on site work force and supervision.

Final Design and Details

Based on the Bruce A preheater divider plate site experience, low estimated dose levels, suspected remaining boiler life and performance testing of mock-ups with the design installed, funding was approved to proceed with the final design.

As proposed during the Unit 6 outage a thin metal membrane (Sealing Skin) of 0.030in thick 304L SS would be installed over the existing divider plates on the hot leg (inlet) side of all eight Unit 6 steam generators. Utilizing the existing divider plate bolting pattern, selected bolts would be removed and replaced with longer fasteners. The sealing skin structure was designed to utilize the longer fasteners for attachment to the inlet side of the divider plates. For each of the 8 steam generators all 68 of the ½" divider plate vertical seam inter-segment bolts would be removed and replaced with longer bolts. Sixteen (16) of the 28 primary head clamping dog bolts would be replaced with longer bolts and none of the 24 – ½" tube sheet seat bar bolts would be replaced.

The 0.030" thick 304L SS sealing skin covers the entire divider plate surface plus the peripheral edge seams. All major leak paths previously identified using an acoustic leak detection method were sealed. A 3/16" thick 304L SS clamping plate was installed on top of the sealing skin. The clamping plate has multiple functions. First it holds the sealing skin tight to the surface of the divider plate and provides the force required to form a seal around the periphery of the plate. Second it covers and protects the entire sealing skin and divider plate from the primary heat transport (PHT) flow, except for a 1 inch band around the peripheral edge. The free edge is necessary to allow the sealing skin to conform to seat bar variations and flex during operation. The last function the clamping plate is to extend the leak path of the vertical inter-segment seams in the divider plates. This was accomplished by staggering the vertical seams of the divider plate, sealing skin panels and clamping plates. (See Figure 10.)

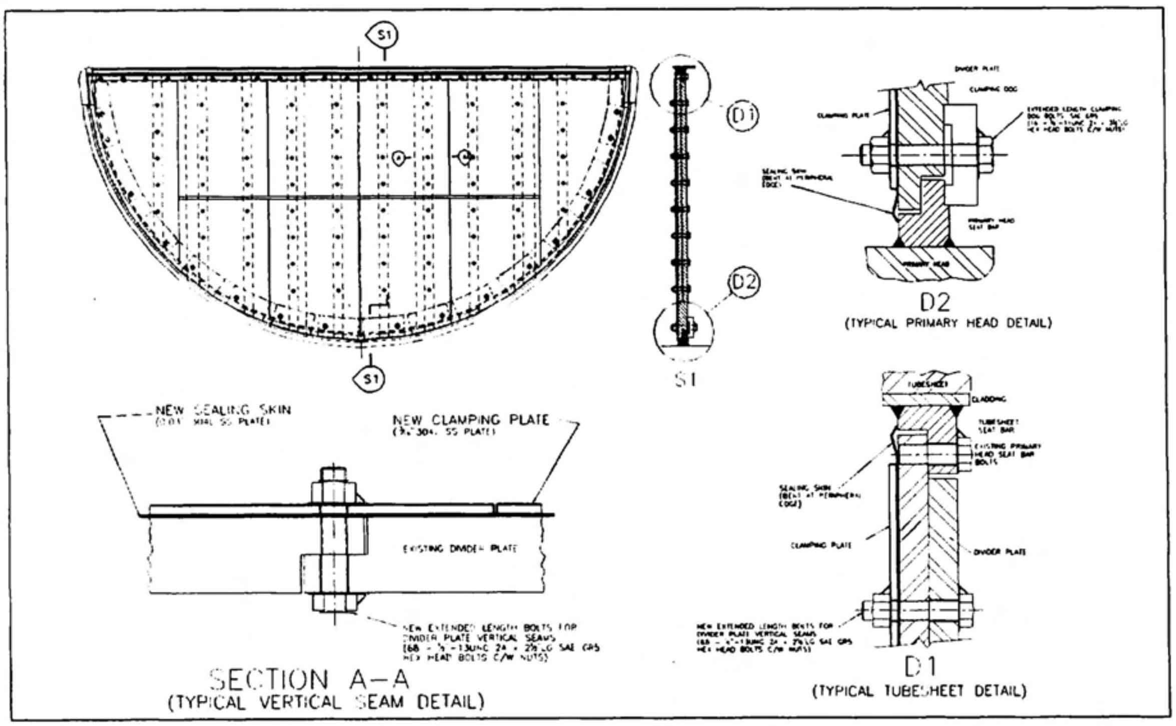

Figure 10. Final Sealing Skin Design as Installed

Technical Review

In keeping with the original assessment of the Bruce B Steam Generator divider plates, a Finite Element and thermal hydraulic modeling of the design was completed to assess the design integrity during a 200% PHT pipe suction line break event. This was necessary to ensure the design meets the Nuclear Safety assumption that the design does not impact public risk. The conclusion of the analysis was similar to the original assessment, no single divider plate panel is predicted to become an individual loose part which could potentially result in subsequent failure of HT pump seals. A technical review team was assembled to review the design and assess the analysis results. The team concurred that the analysis results were consistent with previous analysis and endorsed the proposed skin fix and its installation in Unit 6 during the February 2000 planned maintenance outage.

Installation and Tooling

During the early design development and planning of the project the need for special tooling and processes was recognized to reduce radiological dose levels. The following tooling and process were used.

1. Several divider plate mock-ups were used to develop and streamline installation techniques and test fit-up of the sealing skin design.
2. Boiler primary head decontamination was performed using a high pressure wash system achieving a reduction from ~100,000 counts loose to ~1000 counts.
3. Boiler tube sheet shielding was also used. A shielding frame was designed to hang from the geometry of the bowl, eliminating the need for legs and obstructions in the work area. General fields were reduced to 50-100mR from 150 to 300 mR.

The installation process proceeded as planned, actual installation time was approx. 20 days including opening, decontamination, installation and closing of all 8 boilers.

Post Installation Results

Using the acoustic leak detection and measurement method, two Unit 6 steam generator divider plates were inspected before and after the installation of the sealing skins. Steam Generators 3 and 8 were inspected before and after installation of the skin fix. An estimated 10 times reduction in leakage area was observed as a result of installing the divider plate sealing skins. Steam generator 3 and 8 estimated leakage areas before the sealing skin installation were 210 and 220 square centimeters respectively. Figure 11 shows the SG3 pre-divider plate sealing skin installation acoustic leak inspection results.

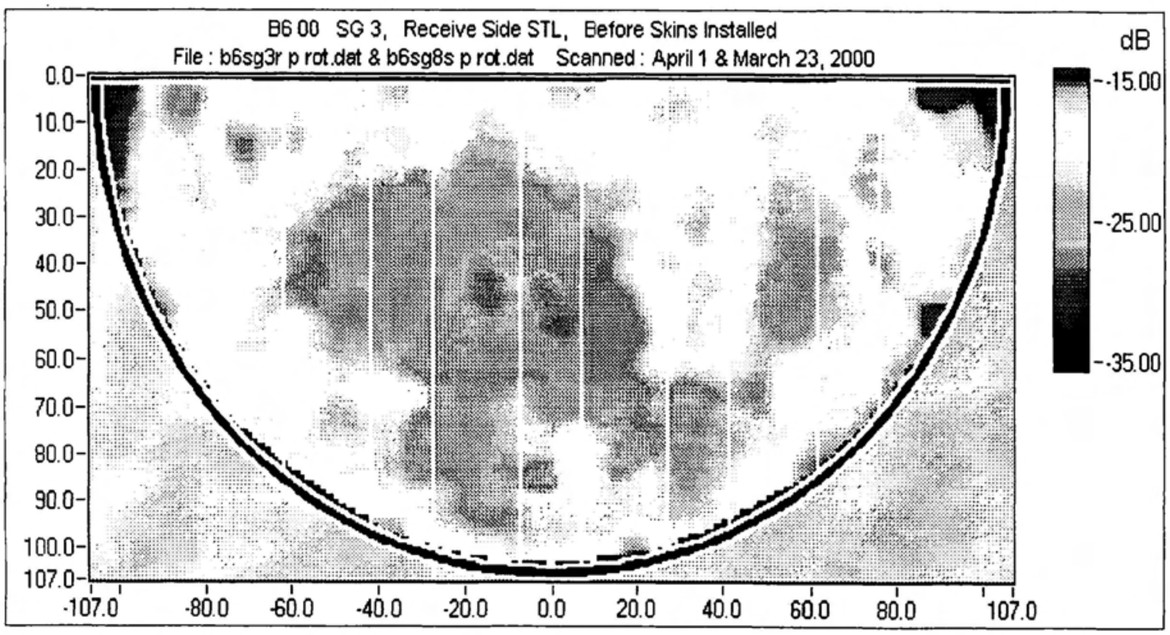

Figure 11 Bruce Unit 6 Sg 3 Before Sealing Skin Installed Estimated Leakage Area @ 210 sq cm

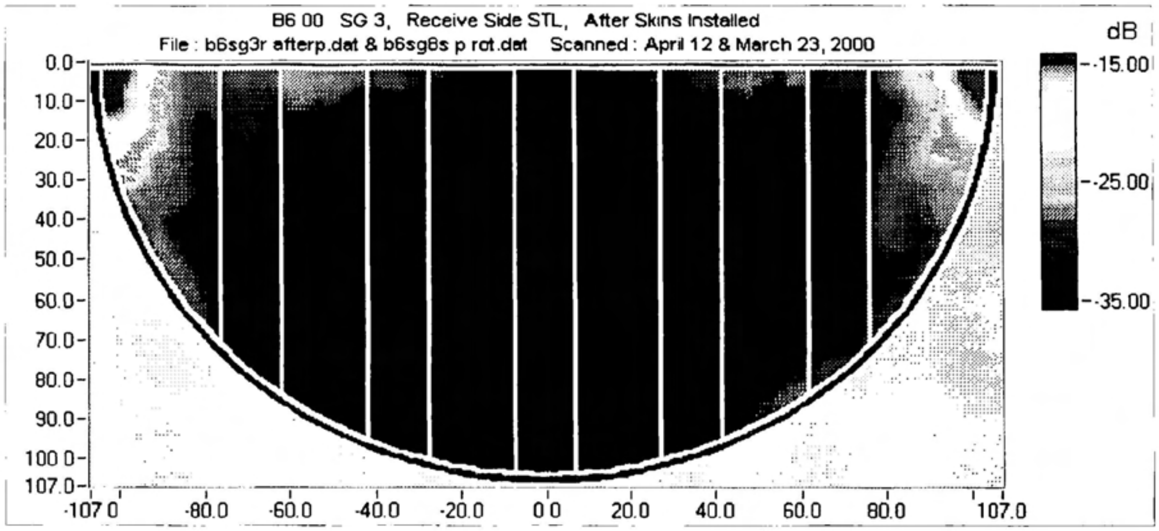

Figure 12 Bruce UNit 6 Sg 3, After Sealing Skin Installed, Leakage Estimated @ 20 sq cm

After installation of the sealing skin leakage areas were found to be reduced to 20 sq. centimeters. Figure 12 shows the SG3 post sealing skin installation acoustic leak inspection results.

Dose uptake for the installation was significantly less than anticipated. Actual dose uptake was less than 50% of the original estimate. The lower dose levels were a result of good work planning, shielding tooling and effective pre-job decontamination.

Current Unit 6 operational data is indicating a 4 degree C reduction in RIHT levels. This allowed both HP feed water heaters to be put back into service, steam generator secondary side pressure to be increased, and MWe output increased. The improvement in thermal performance produced gross electrical production improvement of 20Mwe.

Conclusions

- The divider plate sealing skin designs were successfully installed on all 8 of the Unit 6 steam generators.
- Cross flow divider plate leakage area was reduced by a factor of 10 as observed by acoustic inspection (ALIS).
- A significant reduction in RIHT was achieved 3 to 4 deg.
- Operational RIHT margins were restored. Unit 6 returned to normal operating conditions.
- As a result of using the decontamination spray tool, tube sheet shielding and mock-up training installation dose uptake was less than 50% of expected.
- A gross electrical production output gain of 20Mwe as achieved.

The divider plate sealing skin fix is a viable low cost method of reducing divider late leakage and restoring normal operating conditions.

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