EVALUATION OF THE MECHNICAL CLEANING OF THE PRIMARY SIDE OF THE STEAM GENERATOR FOR WOLSONG NUCLEAR POWER PLANT-2

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Abstract

Mechanical cleaning of the primary side of the WNPP-2 Steam Generator was carried out with AREVA SIVABLAST in December 2010 during a plant outage. All industrial plants undergo changes with time and nuclear plants are no exception. CANDU undergoes increased hydraulic resistance due to redistribution of iron in the HTS. Dissolution of iron and flow accelerated corrosion occur in the outlet feeders. The magnetite layers cause fouling inside the steam generator tubes, leading to reduced heat transfer, as well as increased hydraulic resistance in the steam generator tubes and inlet feeders. These developments have negative effects on the core flow and inlet header temperature and consequently adversely affect the CCP. Before 5,000 EFPD, WNPP-2,3,4 will undergo analysis of the ROP trip setpoint. WNPP-2 will arrive at 5,000 EFPD in 2012. For maximizing the ROP trip setpoint, we are carrying out numerous studies and actions. As a counter action, the present cleaning operation was performed at the optimal time and excellent results were achieved.

1. INTRODUCTION

This paper reports the effects of mechanical cleaning of the primary side of the Steam Generator for Wolsong Nuclear Power Plant-2(WNPP-2). Mechanical cleaning results in increased flow of the heat transport system (HTS) and potentially impacts channel flows and Critical Channel Power (CCP), one of the major components in the Regional Overpower Protection (ROP) system. Critical channel power is defined here as the channel power at which the fuel elements experience dryout conditions.

All industrial plants undergo changes with time and nuclear plants are no exception. CANDU experiences increased hydraulic resistance due to redistribution of iron in the HTS[1]. Dissolution of iron and flow accelerated corrosion (FAC) occur in the outlet feeders. Iron is removed from the outlet feeders and deposited in the cold part of the circuit of Primary Heat Transport System, including the cold leg of the Steam Generators, the inlet feeders, and possibly the first section of the channel. The magnetite layers cause both fouling inside the steam generator tubes, leading to reduced heat transfer, and increased hydraulic resistance in the steam generator tubes and inlet feeders. This has negative effects on the core flow and the Reactor Inlet Header (RIH) temperature, and consequently has adverse effects on the CCP. Before 5,000 Effective Full Power Day (EFPD), WNPP-2,3,4 will undergo analysis of the ROP trip setpoint. WNPP-2 will arrive at 5,000 EFPD in 2012. For maximizing the ROP trip setpoint, we are carrying out numerous studies and actions. The steam generator mechanical cleaning is one of the counter actions. The WNPP-2 was carried out with AREVA SIVABLAST in December 2010 during a plant outage.

2. CANDU-6 REACTOR SYSTEM DESCRIPTION

Wolsong Nuclear Power Plants are CANDU 6 Pressurized Heavy Water Reactors (PHWRs). They have 380 horizontal fuel channels surrounded by a cool low pressure heavy water moderator. Each fuel channel is six meters long and contains twelve fuel bundles within a pressure tube. A bundle is made up of 37 elements, which contain natural uranium in the form of compacted sintered cylindrical pellets of uranium dioxide (UO_2). Each channel has an End Fitting at each end, which allows for the Fueling Machines to be attached, facilitating power refueling. Coolant enters the channel from an inlet feeder pipe that is connected to the inlet end fitting. The coolant then enters the fuel string, flowing within the channels between the fuel elements inside the pressure tube. The coolant leaves the channel via the outlet feeder pipe, which is attached to the outlet end fitting. The coolant enters the channel at about 11 MPa and 263 ^{o}C. It leaves at slightly above 10 MPa and 310 ^{o}C.

When a channel is fueled, its power is increased and the coolant at the end of the channel contains D_2O vapor. As the fuel in the channel burns up, the channel power decreases, and the length of the boiling region decreases. When the power has reduced sufficiently, boiling in the channel drops out until it is refueled again.

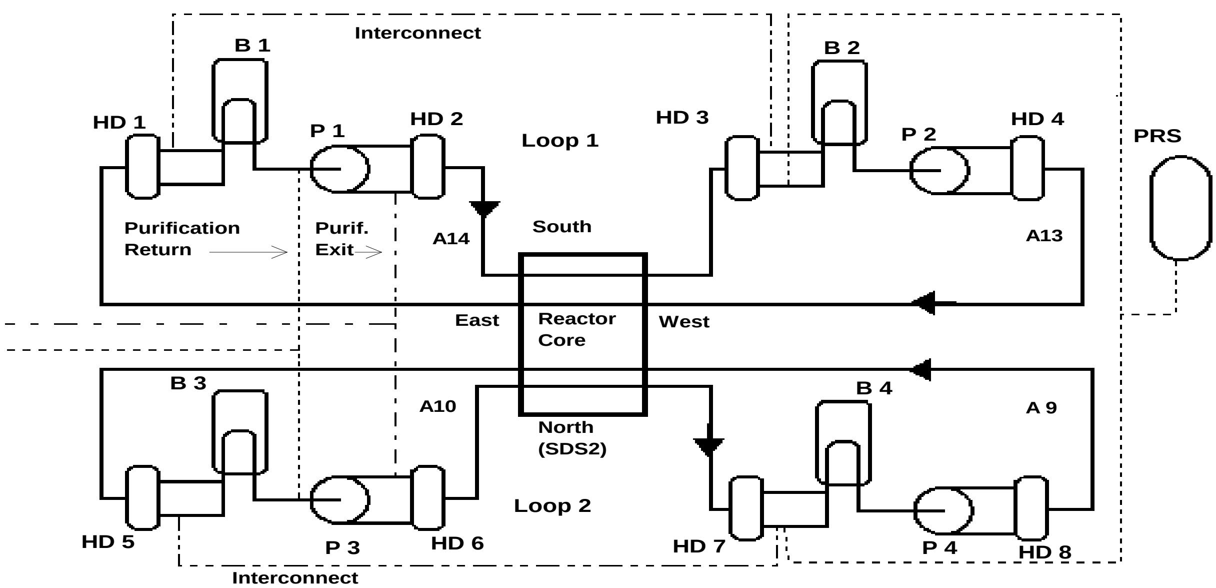

Figure 1. CANDU Simplified Circuit Diagram

Figure 1 shows a simplified overview of the HTS. The core is subdivided into two symmetrically located figure of eight loops. Each loop consists of two core passes of 95 channels each. Each pass contains a pump that feeds an inlet header, which is connected to 95 inlet feeders that connect to the channels as described above. The 95 outlet feeders connect to an outlet header. Two riser pipes connect the outlet header to the hot leg side of a steam generator. Coolant flows through the vertical steam generator u-tubes to the steam generator outlet, where it flows to the pump suction line of the pump in the other core pass in the loop. Because it goes through a figure of eight loop, flow in channels in one core pass is in the opposite direction to the other flow. As the channels in each core pass are laid out adjacently, it follows that the flows in adjacent channels are in opposite directions, forming a checker-board pattern. The two HTS loops are connected at each end of the reactor through the pressurizer interconnect line and the purification and feed interconnect lines. The pressurizer is connected to the discharge pipes of outlet headers 3 and 7. The purification feed flow is associated with inlet headers 2 and 6, while the purification return flow enters the HTS at the suction of pumps 1 and 3. The HTS also contains stability pipes that connect outlet headers 1 and 3 in loop 1, and outlet headers 5 and 7 in loop 2.

The intent of the reactor design was to have the flow rates in each channel be proportional to power. Channels in the central region of the core have a higher time average power than those near the periphery, and hence require higher flows. Required flows are achieved by use of different diameter feeder pipes, and through the use of flow restriction orifices in the inlet feeders of channels in the outer core region.

The design utilized the NUCIRC computer program together with an appropriate CCP model. NUCIRC models the various steady state homogeneous thermalhydraulic processes that take place in the HTS. Through the use of CHF correlations based on out-reactor testing, the channel power at which fuel goes into dryout can also be predicted. The modeling associated with NUCIRC (Hartmann, 1987, Soulard, Hau, 1991, Soulard, Dam, et al, 1995, and Harvel, Soulard, 1996) has been improved over the years.

3. CANDU HTS AGING

The following is a list of the currently known ageing processes in CANDU that are occurring within the HTS and can affect CCP:

- Increase in pressure tube diameter due to irradiation creep. This reduces the hydraulic resistance in the channel, and hence increases flows. However, it causes the coolant to preferentially bypass the interior channels of the bundle, reducing the CCP. Because there is more creep in the higher power channels, there is a flow redistribution effect whereby some of the flow from the outer low power channels is redirected to inner channels. This mitigates the effect of pressure tube diametral creep on the CCP for the central, ROP most limiting channels.

- Increase in hydraulic resistance due to redistribution of iron in the HTS. Dissolution of iron and FAC occur in the outlet feeders. Iron is removed from the outlet feeders and deposited in the cold part of the circuit, including the cold leg of the steam generators, the inlet feeders, and possibly the first section of the channel. The magnetite layers cause both fouling inside the steam generator tubes, leading to reduced heat transfer, and increased hydraulic resistance in the steam generator tubes and inlet feeders. These factors have negative effects on the core flow and RIH temperature, and consequently on the CCP.

- Leakage across the divider plate in the steam generators. This was a more significant concern before the plates were replaced with an all welded design in Pt. Lep (PLGS) and G-2. This leakage allows a portion of the flow to bypass the steam generators, resulting in reduced heat transfer and increased delta pressure.

- Erosion of the edges of flow reducing orifices. This can lead to relative flow redistribution from the inner to outer core.

Other potential ageing mechanisms, such as fouling on the external surface of steam generator tubes and HTS pump impeller wear, have been shown to have negligible effects up to this point in time.

4. WNPP-2 STEAM GENERATOR MECHANICAL CLEANING EFFECT

Subtle changes have occurred within the HTS at the WNPP-2 over the 15 years that the station has been in operation. The most visible changes in the HTS are a increase in RIH temperature and a decrease in the inlet outlet header delta pressure that have taken place over time, as shown in Figures 2 and 3. All CANDU reactors experience dissolution of iron and FAC in the outlet feeders and some plants (PLGS and G-2) have experienced leakage across the divider plate in the steam generators. PLGS and G-2 showed increased inlet outlet header delta pressure with an increase in RIH temperature. After the divider plates in the steam generators were replaced with an all welded design, the PLGS and G-2 inlet outlet header delta pressure dropped and maintained same trend as WNPPs, as shown in Figure 4[2].

We wish to confirm that RIH temperature increase does not originate from the leakage. Before the steam generator mechanical cleaning, we reviewed the HTS conditions for WNPPs last year [3]. There was no evidence of leakage across the divider plate in the steam generators, as shown in Table 1 and Figure 5.

Table 1. RIH temperature change in CANDU

FPD	T_{RIH} (℃)					
	WS1	WS2	WS3	WS4	G-2	Pt. Lep
500	259.46	263.22	262.33	262.52	263.74	263.69
1000	261.65	263.07	262.36	263.04	264.32	264.72
1500	262.00	263.78	263.33	263.32	265.63	265.49
2000	262.15	263.79	263.79	263.76	266.85	265.51
2500	262.94	263.67	264.42	264.25	266.82	266.46
2755	262.67	264.33	264.56	264.69	268.04	266.32
3000	262.05	265.02	264.56	265.04		266.65
3354	262.94	265.26	264.43	264.85		267.20
3500	263.13	265.22	264.37	264.36		
4000	263.50	265.7				
Increasing Rate(℃/day)	0.000864	0.000768	0.000813	0.000779	0.001844	0.001111

Before 5,000 EFPD, WNPP-2,3,4 will undergo analysis ROP trip setpoint. WNPP-2 will arrive at 5,000 EFPD in 2012 and in the subsequent consecutive years WNPP-3,4 will arrive at 5,000 EFPD. For maximizing the ROP trip setpoint, we are carrying out numerous studies and actions. As a counter action, the present cleaning operation was performed at the optimal time and excellent results were achieved, as shown in Table 2.

We used the averaged value of each RIH of temperature from the control data and achieved differential pressure data from Shutdown System #2. We conducted the comparison at a 100% Full Power condition and performed the evaluated based on the Design Manual [4].

- RIH temperature effect
  -2.1℃ * -0.89%/℃ = +1.87%
- Differential pressure effect
  +57KPa * 0.037%/KPa = +2.11%
- Total effect
  +3.98%

As shown in Tables 2 and 3, the effects of the mechanical cleaning of the primary side of steam generator for WNPP-2 are very similar to those reported for WNPP-1. The differential pressure is almost the same and the RIH temperature showed a greater decrease of 0.7℃ than WNPP-1. These factors resulted in 0.4% more increased reactor power relative to WNPP-1.

Table 2. Evaluation of the cleaning of the primary side of steam generator at 100% data for WNPP-2

	Differential Pressure(kPa)						Power Recovery(%)
	SG1(4→1)	SG2(2→3)	SG3(8→5)	SG4(6→7)	Avearge	Difference	
2010.11(Before)	1237.6	1266.4	1243.8	1223.6	1242.85	–	–
2010.12(After)	1286.0	1322.6	1301.3	1289.4	1299.83	57.0	2.11
	RIHT(℃)						
	SG1(4→1)	SG2(2→3)	SG3(8→5)	SG4(6→7)	Avearge	Difference	
2010.11(Before)	266.05	265.71	266.82	265.53	266.03	–	–
2010.12(After)	264.38	263.87	264.44	263.03	263.93	−2.1	1.87

Table 3. Evaluation of the cleaning of the primary side of steam generator at 80% data for WNPP-1

	RIHT (℃)	Differential Pressure(kPa)						Power Recovery(%)
		SG1(4→1)	SG2(2→3)	SG3(8→5)	SG4(6→7)	Avearge	Difference	
2003(Before)	262.73	1168.6	1217.2	1175.0	1188.4	1187.3		
2003(After)	261.34	1237.1	1275.9	1244.3	1245.0	1250.6	63.3	3.58
2004	261.67	1221.9	1259.6	1224.5	1229.6	1233.9	−16.7	2.67
2005	262.24	1174.1	1222.6	1183.1	1193.8	1193.4	−40.5	0.66

5. FUTURE ACTIVITIES

Without replacement of the pressurized tube, we could not fully recover the fresh status. At the present status, the following aspects should be considered.

- ROP analysis methodology change
- Fuel bundle design change
- Ultrasonic flow measurement and calibration.

6. CONCLUSION

Before 5,000 EFPD, WNPP-2,3,4 will undergo analysis of the ROP trip setpoint. WNPP-2 will arrive at 5,000 EFPD in 2012. For maximizing the ROP trip setpoint, we are performing numerous studies and actions. The mechanical cleaning of the primary side of WNPP-2 Steam Generator is one of the

counter actions. We determined that this counter action was performed at the optimal point in time as there is no outage between this outage and the next outage, and we achieved excellent results..
We obtained about 4% more reactor power than before cleaning of the primary side of the WNPP-2 Steam Generator. Economically, this will yield a gain of about 0.97 million CAD in the first year. The effects of the cleaning of the primary side of the WNPP-2 Steam Generator will be decreased in the future. We will carry out this project for Wolsong 3,4 in 2011 and 2012.

7. REFERENCES

[1] W.J. Hartmann, M. Cormier, B. Willemsen, T. Whynot, P.D. Thompson “Plant Aging Adjustments to Maintain Reactor Power at the Point Lepreau Generating Station”, 5th CNS, Canada, Nov 2000.
[2] Sung Min, Kim ” The appropriateness review for the Cleaning of the First Side of Steam Generator for WNPP-1,2” TRA06-W0-Safety-60000-005, Mar 2006.
[3] Sung Min, Kim ” ROP Trip Setpoint Recovery Method” NETEC TC-Safety Analysis Team-S2009-76, July 2007.
[4] WS2,3,4 Shutdown System No.1 Part 1 General Requirement and Overview” 86-68200-DM-001 Rev.8, Dec 2000.

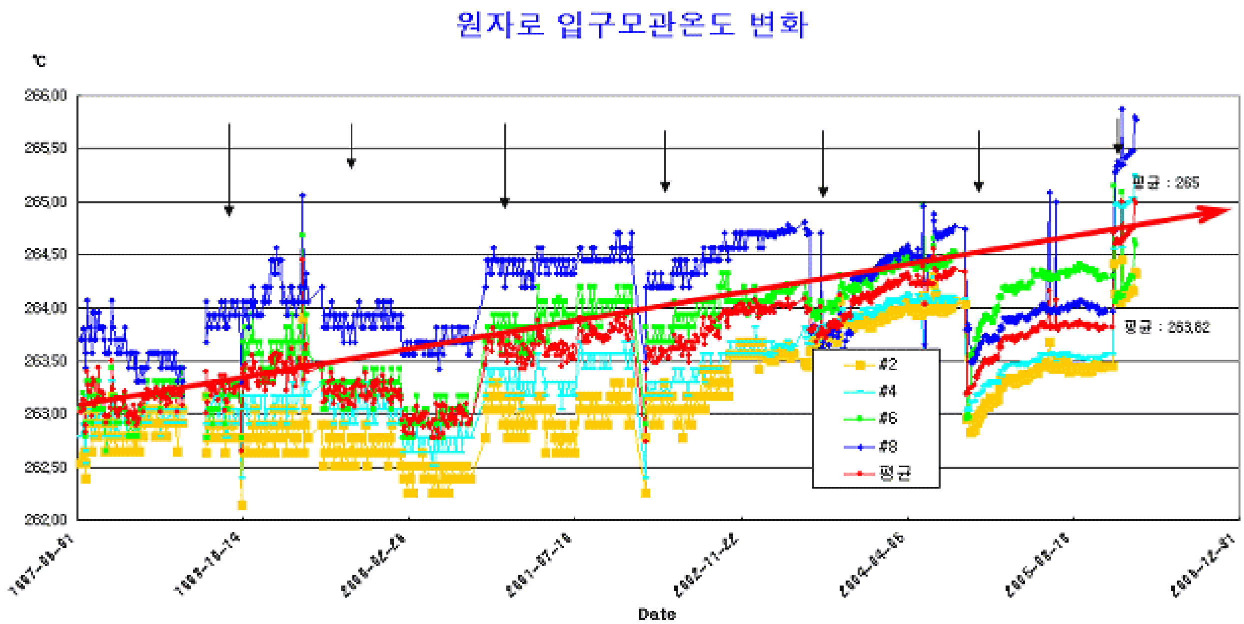

Figure 2. WNPP-2 RIH temperature trend

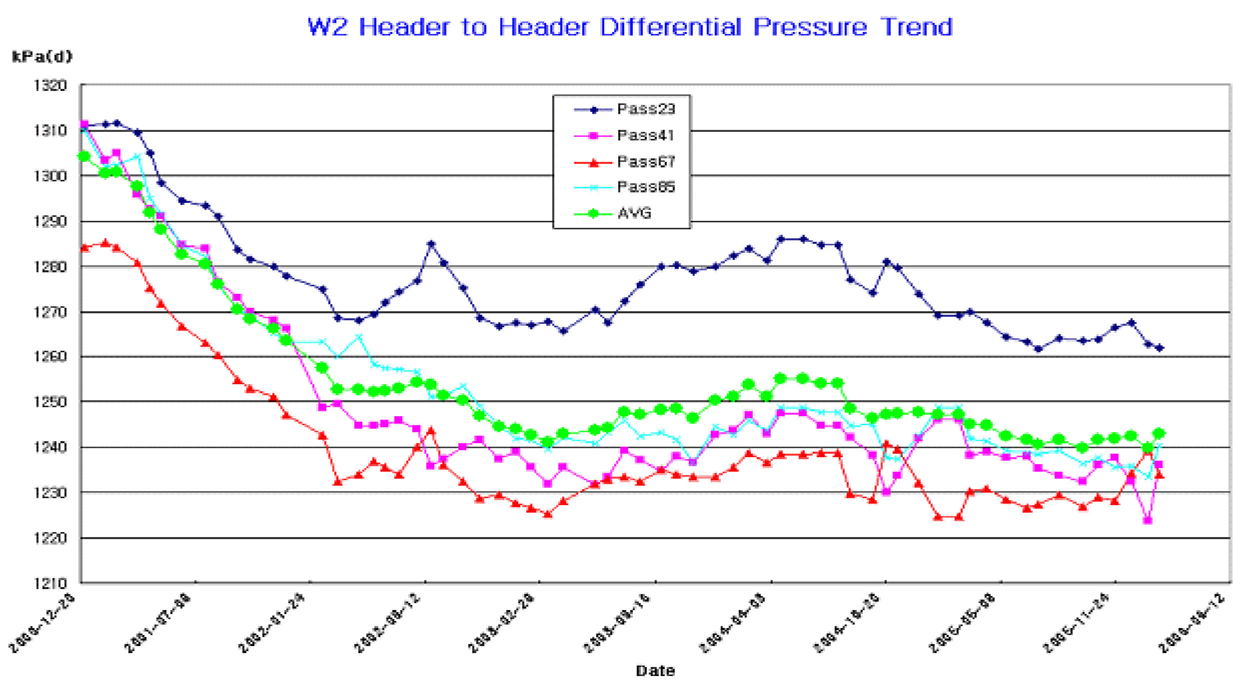

Figure 3. WNPP-2 differential pressure trend

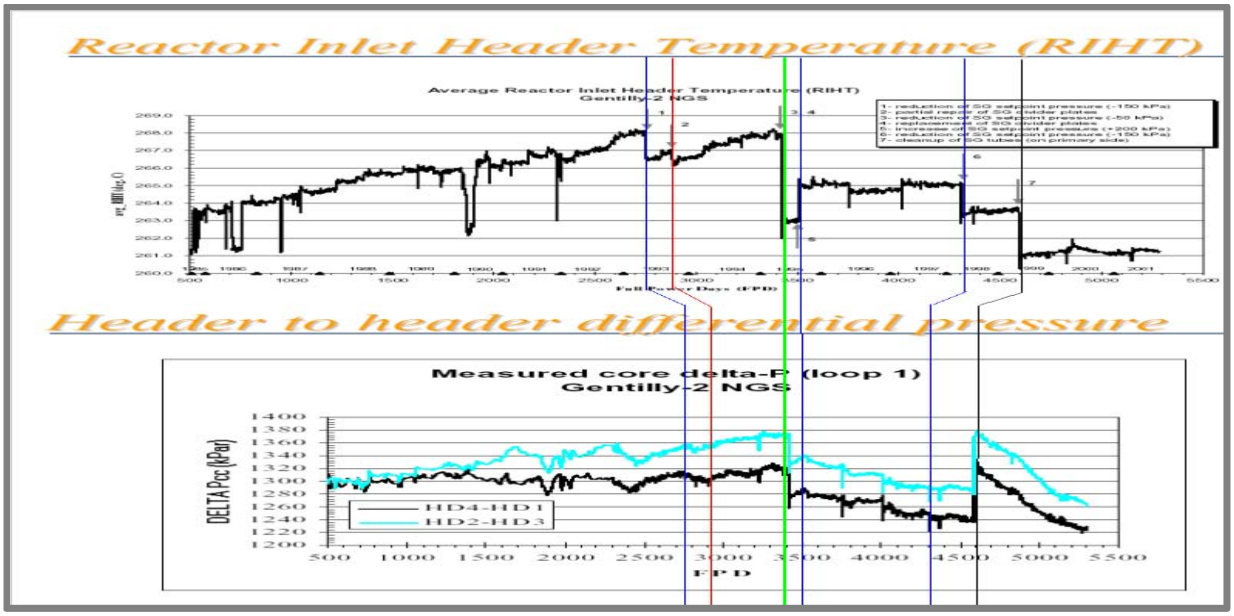

Figure 4. G-2 Differential pressure and RIH temperature trend

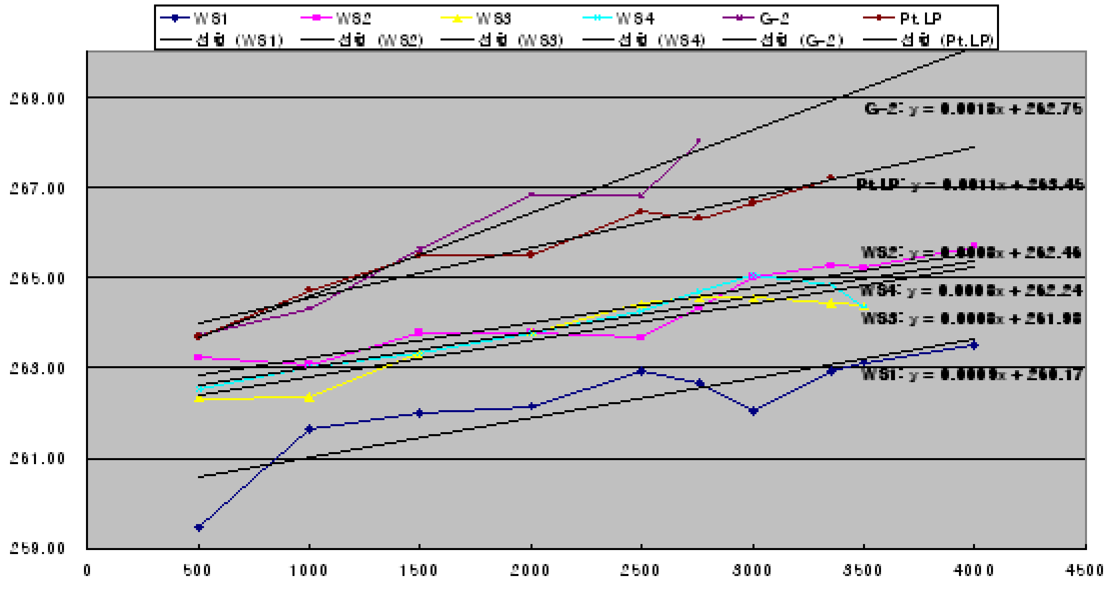

Figure 5. RIH temperature change in CANDU