The Experience of Safety System Refurbishment in Wolsong Unit 1

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Abstract

Wolsong Unit 1 is a CANDU-6 type nuclear power plant designed by Atomic Energy of Canada Limited (AECL) in Canada. Wolsong Unit 1 has been operating successfully since 1983, and its design life will be expired in November 2012. To renew its operational license for another 10 or 20 years, several refurbishment projects including Periodic Safety Review (PSR) Safety Improvement and Safety System Refurbishment were suggested by Korea Hydro and Nuclear Power Company (KHNP), and have been performed by several domestic organizations and AECL. The PSR Safety Improvement, which includes 2 refurbishment items, has been performing by Korea Power Engineering Company (KOPEC) since December 2007. The Safety System Refurbishment, which includes 15 refurbishment items, has been performing by KOPEC since January 2008. Each refurbishment item and its workscope are briefly summarized herein. These refurbishment items include various engineering works such as fluid systems design, mechanical design, I&C design, civil design, piping design, electric design, procurement support, safety analysis input, licensing support and so on. It is expected that the PSR Safety Improvement and the Safety System Refurbishment could be contributed to the improvement of the safety and reliability of Wolsong Unit 1.

1. Introduction

Wolsong Unit 1 is a 600 MWe-class CANDU-6 type nuclear power plant which uses D_2O as coolant and moderator. Wolsong Unit 1 has been operating successfully since the commercial operation in 1983, and its design life will be expired in November 2012. Currently, series of refurbishments are in progress in Wolsong Unit 1.

The purpose of Wolsong Unit 1 Safety System Refurbishment is to prepare for its continued operation by refurbishing safety systems to meet the latest technical requirements for the life extension for another 10 or 20 years. The preliminary safety evaluations related to Wolsong Unit 1 Safety System Refurbishment were performed by Korea Electric Power Research Institute (KEPRI) in May 2006, and the Preliminary Safety System Refurbishment was done by KOPEC in November 2006. AECL also participated in walkdown activities for the Preliminary Safety System Refurbishment. KOPEC made a contract with KHNP for the PSR Safety Improvement in December 2007 and for the Safety System Refurbishment in January 2008. Both refurbishments will be conducted until 2010 and 2013, respectively.

The PSR Safety Improvement consists of 3 refurbishment items, while the Safety System Refurbishment consists of 17 refurbishment items. Most of those items will be refurbished during the grand overhaul period from April 2009 to October 2010 except for 3 items; “Modification of Emergency Core Cooling (ECC) Tank Heating and Recirculation Flow Path”, “Installation of Hydrogen Control System in Reactor Building”, and “Connection Demineralized Water to D_2O Recovery Tank”, that are planned during the plant outage in 2012. Refurbishment performed by PSR Safety Improvement and Safety System Refurbishment are scheduled to be completed between November 2009 and May 2010, but 2 refurbishment items, the Removal of 3.45 kPa Blow-out Panel and the Installation of Fixed Fire Extinguishing System in Reactor Building, have been completed in April 2009.

This paper presents summarized information on the PSR Safety Improvement and the Safety System Refurbishment by describing work contents and workscopes for each refurbishment items.

2. PSR Safety Improvements

2.1 Removal of 3.45 kPa blow-out panel

The blow-out panels with two different set points (3.45 kPa and 6.9 kPa) were installed on several compartments in reactor building of Wolsong Unit 1. This blow-out panel provides isolating functions (including classifying of D_2O vapor area and non-D_2O vapor area in the view of D_2O Steam Recovery) among the compartments during normal plant operation, and all blow-out panels will be ruptured to internally circulate the vapor in the reactor building atmosphere when an accident occurs and to effectively circulate the cooling water in the Primary Heat Transport System (PHTS) during the low pressure operation of ECC.

In case of Wolsong units 2, 3, 4, all blow-out panels with 3.45 kPa set point were removed when they were constructed, but for Wolsong Unit 1, the installed blow-out panels have been maintained. Therefore, if a small LOCA, a relatively small size rupture, or a Loss of ECC water injection occurs in Wolsong Unit 1, blow-out panels may fail to rupture in the reactor building and interrupt the internal circulation. As a result, a localized increase in hydrogen concentration will occur. In addition, blow-out panels which failed to rupture can interrupt the gathering of cooling water in the sump of reactor building basement during the low pressure operation of ECC.

Therefore, in order to minimize the possibility of the deflagration or detonation caused by a local increase in hydrogen concentration in the reactor building as well as to effectively circulate the cooling water released from the ruptured region of PHTS during the low pressure operation of ECC, blow-out panels with 3.45 kPa set point, which are installed between fuel exchange room(R-107/108) and moderator room (R-111) and between fuel exchange room (R-107/108) and steam generator room (R-501), were evaluated to be removed.

Also, the investigation of the appropriate duct flow and the flow-path change on the D_2O vapor recovery system, when 3.45 kPa blow-out panels were removed, confirmed that they had no adverse effects.

2.2 Addition of moderator high temperature trip parameter on SDS #1

In Wolsong Unit 1, if the temperature of moderator is increased, a manual trip is initiated by operator's decision, but to coincide with the latest licensing requirements for heavy water reactors, the high temperature trip on Shutdown System (SDS) #1 should be added. That is, it is desirable that the reactor is tripped before rupturing the moderator rupture disk by detecting the high temperature of moderator in advance.

The high moderator temperature trip function provides protective measure to prevent the loss of cooling water in the moderator heat exchanger. Three new thermowells were mounted on the main pipe of moderator pump, and three temperature measurement loops (D, E, F) were provided for this trip parameters. In addition, design changes for logic circuits and control panels were performed.

3. Safety System Refurbishments

3.1 Automation of ECC low pressure injection

The current Wolsong Unit 1 requires operator's action when transferring from medium pressure operation to low pressure operation of ECC. During medium pressure operation of ECC, the dousing tank isolation valves (3432-PV10/PV11) are opened, and sump isolation valves (3432-PV1/PV2) in reactor building are closed (Figure 1). When low dousing tank level is indicated, operator’s action is required to manually open sump isolation valves (3432-PV1/PV2) to ensure continuous flow of ECC. The operator must immediately close the dousing tank isolation valves (3432-PV10/PV11) manually to prevent air from entering the ECC pump suction, which can lead ECCS unavailability due to ECC pump failures. Also, operator must open Raw Service Water (RSW) isolation valves (7131-PV506#1/PV506#2) of ECC Heat Exchanger (HX) secondary side manually (Figure 1).

This refurbishment improves the reliability of ECC by automating logic on the opening of sump isolation valves (3432-PV1/PV2), the isolation of dousing tank isolation valves (3432-PV10/PV11, 3432-PV162/PV163), and opening of RSW isolation valves (7131-PV506#1/PV506#2/ PV505#1/PV505#2) of HX secondary side when low dousing tank level is indicated (Figure 1). The dousing tank isolation valves (3432-PV162/PV163) are newly installed as mentioned in Section 3.2 “Redundancy of ECC medium pressure isolation valve”, and the RSW isolation valves (7131-PV505#1/PV505#2) of heat exchanger secondary side are also newly installed in front of the heat exchanger as mentioned in Section 3.3 “Parallel redundancy of ECC heat exchanger inlet valve”. As the automatic transfer of ECC operation from medium to low pressure operation eliminates the need of operator’s action, which is required within 15 minutes after a Loss of Coolant Accident (LOCA), the unavailability related to the operator’s action can be minimized.

The loop for level measurements of a dousing tank was triplicated, and the level measurement method was changed to a wet type from a dry type. The design changes for the additional installation of control logic cabinet and main control board of ECC were also carried out.

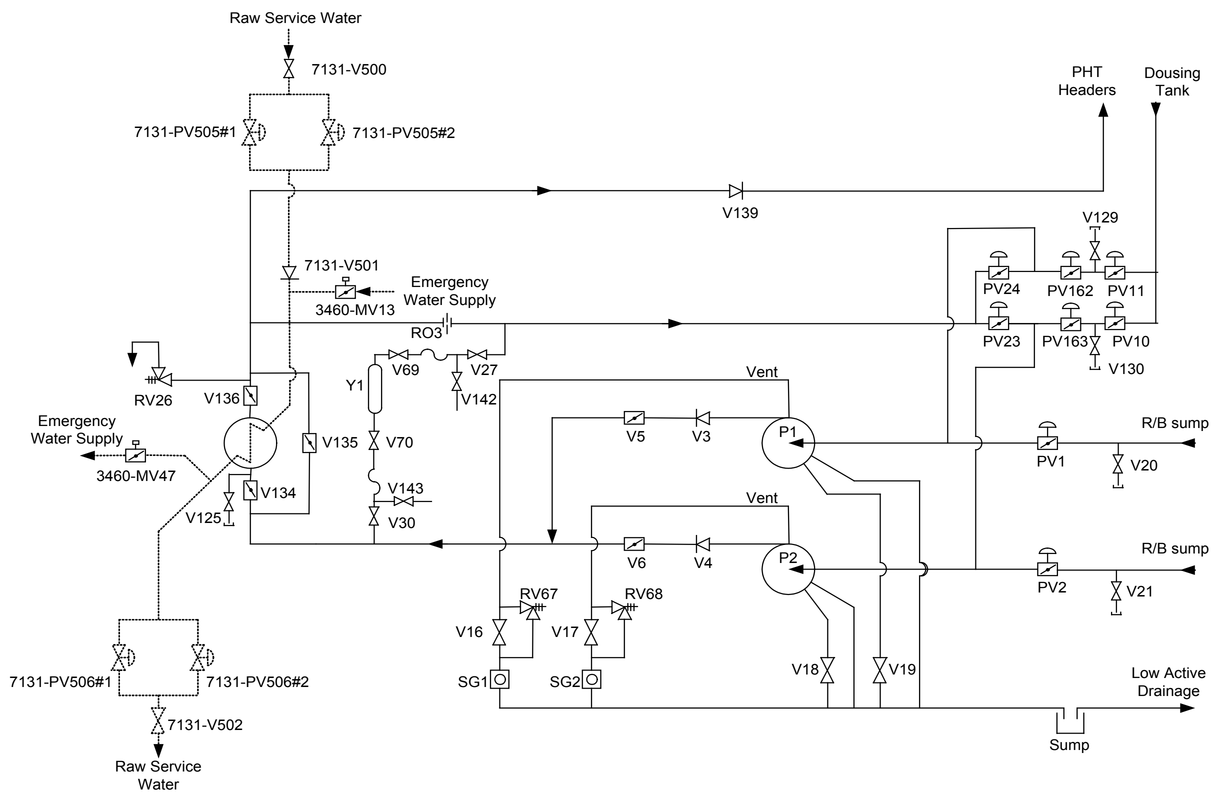

Figure 1. ECCS Mid and Low Pressure Injection Design Change

3.2 Redundancy of ECC medium pressure isolation valve

The redundancy of ECC medium pressure isolation valves is to minimize the possibility of air inflow from dousing tank that can be induced during the transferring period from medium pressure operation to low pressure operation. If air enters from the dousing tank into ECCS because the medium pressure isolation valves are not installed in duplicates, the ECC pump can be damaged.

That is, the newly installed isolation valves (3432-PV162/PV163) at the outlet of dousing tank isolation valves (3432-PV10/PV11) between dousing tank and ECC pump are to prevent the ECC pump damage due to the air inflow that can be induced by single isolation. During ECC low pressure injection, the dousing tank isolation valves (3432-PV10/PV11) are designed to be closed automatically (Figure 1).

3.3 Parallel redundancy of ECC heat exchanger inlet valve

This refurbishment is to increase the reliability of ECCS by installation of duplicate valves for ECC HX by using RSW as cooling water for ECC HX cooling. The secondary outlet valves of ECC HX have already incorporated the duplicate valve design in parallel in Wolsong Unit 1. The

HX inlet valve added by this refurbishment is designed to be opened automatically by the Section 3.1 “Automation of ECC low pressure injection”.

Therefore, two pneumatic operating valves (POVs) are added in parallel at valve 7131-V500 outlet, and the existing manual valve (7131-V500) is changed to normal open. The installed POVs are automatically opened at the start of ECC LP injection (Figure 1).

Also, in this refurbishment, the methods for a leakage protection should be considered to prevent an ECC heat exchanger from corrosion caused by leakage of seawater from the newly installed POVs during normal plant operations. During the plant walkdown, it was also discovered that at least 11 adjacent pipes should be transferred to other areas because the installation area was too narrow to install those valves.

3.4 Change of signal set point for high pressure condition of ECC in reactor building (3.45 kPa → 1.0 kPa)

The ECCS for Wolsong Unit 1, when an LOCA occurs, eliminates the residual and decay heat by injecting ECC water into PHT systems. The ECCS is designed to be operable for the final protective operation by using the onset and conditional parameters. The high pressure conditional signals in reactor building, together with PHT low pressure signals, are critical factors that are used in determining an out-core LOCA.

In this refurbishment, the signal set point for injecting ECC water at high pressure condition in the reactor building is changed from 3.45 kPa to 1.0 kPa to secure the fuel integrity when a small LOCA accompanied with the loss of class IV power occurs.

3.5 New ECC TSP canister installation

After a LOCA, pH value for the sump water must be maintained greater than 10 in order to control the radioiodine release below 0.1% which is derived from the safety analysis from the reactor building sump during the low pressure injection operation of ECCS. Therefore, the TSP (trisodium phosphate) is provided in five canisters (each 20kg) which are installed around the reactor building sump.

3.6 Removal of pump interlocking logic for maintaining alternative flow path of ECC pump

The ECC pump can be initiated when dousing tank isolation valves are opened because the ECC pump initiation is interlocked with the opening of dousing tank isolation valves (3432-PV10/PV11). This is to essentially secure the suction flow when ECC pump is started. The ECC pump does not start when the dousing tank isolation valves are closed. To protect the ECC pump from being unavailable, the interlock between the ECC pump and the dousing tank isolation valve was eliminated by using the secured alternative flow (Figure 1).

3.7 Modification of SDS #2 high log rate set point

For each accident that requires the operation of shutdown systems, each of shutdown system must be provided with at least 2 trip parameters. The PHT high pressure trip is used as an auxiliary trip parameter for the PHT pump seizure or Loss of Regulation event, but it is not effective at any power levels. To reinforce the ineffective power range for the PHT high pressure trip, the trip coverage must be extended by lowering the set point of high log rate trip. Therefore, the trip set point for the high log rate in SDS #2 was adjusted from 25%/sec to 15%/sec.

3.8 Addition of SDS #2 coolant high pressure trip instrumentation

Wolsong Unit 1 has 4 outlet headers in the PHT system. But only outlet header No. 1 and No. 5 are designed to detect the PHT high pressure trip (Figure 2). Hence the trip coverage is considerably limited to the PHT high pressure trip. The addition of PHT high pressure trip instruments to outlet header No. 3 and No. 7 enables the detection of all four (4) outlet headers. Therefore, the trip coverage is expected to be immensely improved for the partial flow loss.

To add the PHT high pressure trip, twelve (12) transmitters were installed by sharing the existing pressure measurement taps on SDS #2 (extra taps will not be additionally installed), and the provision for a new transmitter room on SDS #2 was necessary.

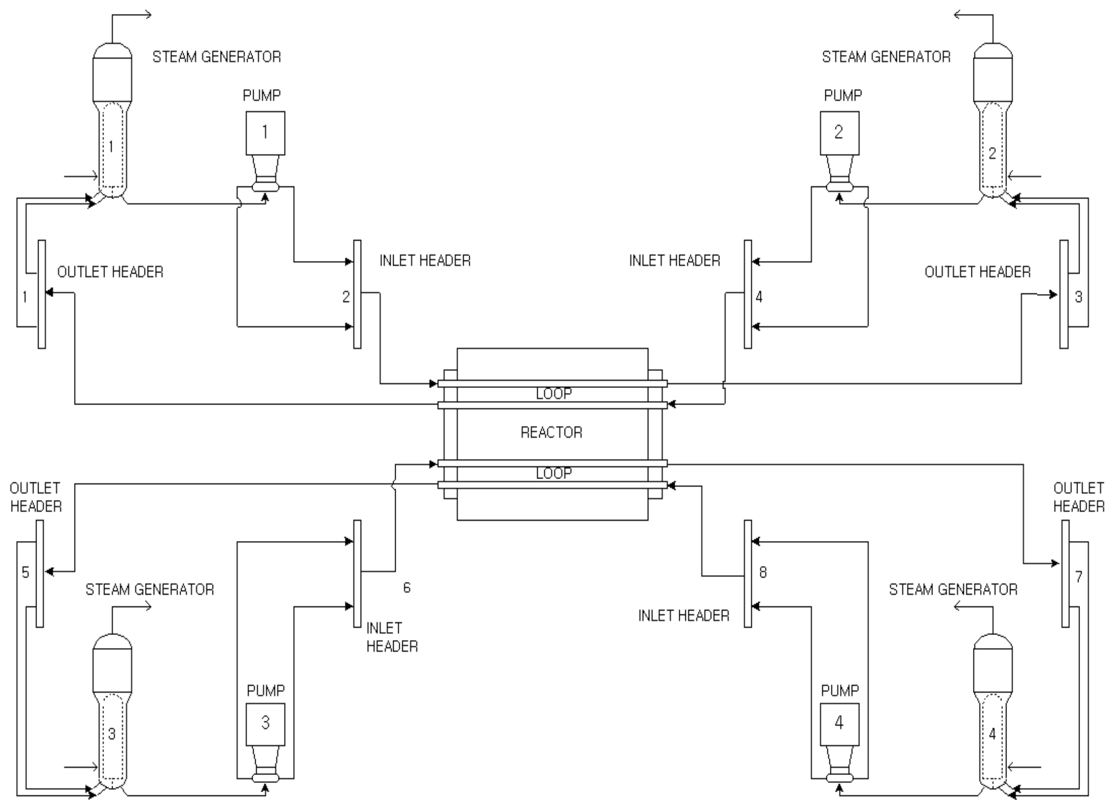

Figure 2. Primary Heat Transport System (PHTS)

3.9 Moderator sub-cooling margin improvement

If the pressure tube is in contact with the calandria tube caused by expansion or extension, a dryout can occur in the calandria tube. To prevent pressure tube from contacting with calandria tube, the moderator temperature is needed to be maintained at an appropriate sub-cooled state condition.

Main Moderator System (MMS) in Wolsong Unit 1 consists of two (2) pumps with 100% capacity, two (2) heat exchangers with 50% capacity, and valves. Each heat exchanger is designed to remove 60 MW(th), and the outlet temperature in calandria has to be maintained at 74℃(At the time of construction, the outlet temperature in calandria was designed to be 77℃. It was changed at site later.). At the height of "Row B", the moderator temperature in steady state is 88℃, and the saturation temperature is 109.5℃. Hence, 21.5℃ of sub-cooling margin can be secured.

The current sub-cooling margin for Wolsong Unit 1 is estimated that it cannot ensure the integrity of fuel tube for a part of DBA, so that the sub-cooling margin needs to be increased. Therefore, the moderator sub-cooling margin will be improved by changing the outlet moderator temperature from 74℃ to 69℃ to maintain the sub-cooled state.

3.10 Monitoring on poison tank level

To maintain the equilibrium between the inner pressure of calandria and the Liquid Injection Shutdown System (LISS) pressure in a steady state, the helium supply-headers on Moderator Cover Gas System (MCGS) and LISS are connected with each other. The valve 3471-PV55 is installed at the connection piping (Figure 3), and the valve opens to maintain the pressure balance between MCGS and LISS in steady state. However, the high pressure helium is discharged from poison tank when the reactor is tripped, causing the pressure of helium supply-headers to be over its set point during the discharge of poison from calandria, and the LISS closes the valve 3471-PV55.

If the valve 3471-PV55 is closed due to malfunction during normal plant operation, the differential pressure is likely to build up between the LISS and the MCGS. In this case, the level of poison tank will be raised slowly by reversing flow from the LISS. Therefore, if an accident necessitates the injection of poison, the time for injection into calandria will take longer. As a result, the malfunction on SDS #2 may be induced.

Therefore, the valve 3471-PV55 should be monitored during normal plant operation because it is a leading indicator of level rising in the poison tank. If the valve is closed or high poison tank level is indicated during normal plant operation, the operator is required to take appropriate actions or should trip the reactor to prevent the functional deterioration of SDS #2. For this reason, the provisions for monitoring the valve 3471-PV55 status and gadolinium storage tank level are newly furnished.

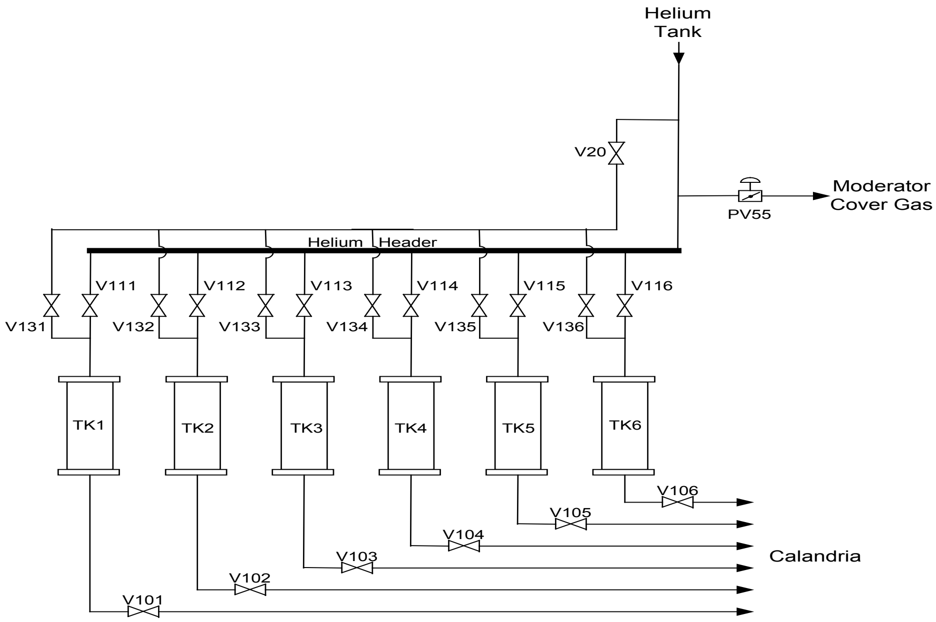

Figure 3. Liquid Injection Shutdown System (LISS)

3.11 Automation of PHT pump trip

Following a LOCA, the PHT pump should be operated as long as possible. However, the vibrations induced by cavitation in the PHT pump impeller due to the increase in the steam ratio in reactor coolant can damage the integrity of equipment in Reactor Coolant Pressure Boundary (RCPB). Therefore, the PHT pump should be tripped to protect the pumps and adjacent piping when an excessive vibration is detected.

To prevent an excessive vibration from the PHT pumps and adjacent piping, the Digital Computer Comparator (DCC) program was modified to add the logic that the PHT pump shall be tripped two (2) minutes immediately after the reactor power goes down below 10% FP with the pressure of the reactor outlet headers below 2.5 MPa(g).

3.12 Installation of fixed fire extinguishing system in reactor building

The fixed fire extinguishing system provides the reactor operators or fire fighters with extinguishing function when a fire breaks out in reactor building area. The fixed fire extinguishing system was designed in accordance with the requirements of the National Fire Safety Codes (NFSC) 102 and Fire Services Act. This is countermeasure for PSR and recommendation of regulatory agency for early implementation.

3.13 Incorporation of LISS waterhammer analysis results

When an in-core LOCA occurs, a reverse flow may occur in the moderator system due to the high pressure of moderator which can induce reverse flow to poison injection line. In this case, the LISS water level will be higher, and if poison injection is initiated by quick opening of quick opening valves, the possibility of waterhammer will be increased.

To prevent waterhammer, an analysis was performed by AECL using PTRAN code. Depending on the analysis results, the refurbishment was performed to decrease the possibility and impact of waterhammer. That is, to prevent helium from localizing to the first isolation valve of branch pipes connected to the poison injection piping, the following items in Wolsong Unit 1 were improved in the same manner as in Wolsong units 2, 3, 4 designs.

- Relocation of valve 3471-PV55, V20 within 1 ft to 3471-3H-161(Figure 3)

- Relocation of valve 3471-V131~136 within 20 ft to 3471-1H-111~116(Figure 3)

- Increase of design pressure on valve 3471-V131~136 from 13.78 MPa(g) to 25.51 MPa(g)(Figure 3)

- Reinforcement of related piping support and additional installation

To improve operational efficiency and decrease operator's exposure by reduction of periodical test time for the sampling of liquid injection system, recirculating sampling system for Wolsong Unit 1 LISS is newly installed. The system shall be the same as Wolsong Unit 2 provisions.

3.14 Refurbishment of LISS on-line poison monitoring

In Wolsong Unit 1, the poison concentration is periodically checked by sampling and analysis of the poison tank contents. But the latest licensing requirements for heavy water reactor prescribe that the poison concentration must be checked continuously on the SDS status.

Therefore, this refurbishment was done to enable on-line monitoring on poison concentration in poison tank of Liquid Injection Shutdown System (LISS). Also, if poison concentration in poison tank drops below the acceptable level, an alarm is automatically signaled to the Main Control Room. Six (6) conductivity probes for SDS #2 are installed beneath the poison tank in the poison injection line.

3.15 Addition of SDS #1 and #2 steam generator low level trip

SDS #1 provides the steam generator low level trip function for the steam generator Nos. 1 and 4, and SDS #2 for the steam generator Nos. 2 and 3, but these violate the diversity and redundancy of safety system. Therefore, this refurbishment improves its functions to be capable of low level trips for the steam generator Nos. 1 and 4 be actuated on SDS #1 as well as on SDS #2 (Figure 2).

For level taps to be added to steam generator, 6 holes in each steam generator should be newly made. New instrumentation room for SDS #2 is also necessary.

4. Major Implementation Activities

4.1 Walkdown

Walkdowns were carried out before and after the contract. The walkdowns were performed mainly to inspect installation spaces and interface items which are accompanied with the refurbishment, and to check access/exit spaces for equipment/components. Also, as the detailed design progresses, walkdowns associated with piping or electrical design took place whenever it was deemed to be necessary.

4.2 System design

AECL provided us with technical consulting services such as ten (10) design review meetings, LISS waterhammer analysis using PTRAN code, and preparation of technical report at AECL's facilities in Canada. AECL also participated in these refurbishments as a consultant or original designer of Wolsong Unit 1. The following design activities were conducted based on the walkdowns.

4.2.1 Review of design documents

Various document reviews, such as original design data review on design documents and drawings, impact review for interface systems due to design change (e.g., electrical, air, water, air-conditioning, structure, etc.), and result of similar projects (e.g., environmental, seismic, etc.), were performed.

4.2.2 Review of operational and maintenance records

Limiting conditions for operation (LCO) and technical specifications (TS) of Wolsong Unit 1 were reviewed, and maintenance records were also investigated.

4.2.3 Review of the latest technical requirements

Design data and reference materials related to refurbishment, provided by KNHP, were studied, and the latest technical requirements associated with these projects were reviewed. Also, the latest techniques related to plant construction and equipment manufacture were reviewed. The human engineering design concepts were incorporated into the control provisions.

4.2.4 Preparation or revision of project deliverables

Flowsheets, Operating Flowsheets, General Arrangements, Isometric Drawings, Block Diagrams, Elementary Diagrams, and Piping Support Drawings for each refurbishment item were revised or prepared. Design Manuals, Operating Manuals, Stress Reports, Human engineering report, Operating/Test Procedures and Calculations were revised or prepared. Also, technical evaluation report, design change report, equipment specification, and construction design report were prepared after taking every aspect into consideration.

In addition, program specifications were revised or newly prepared after reviewing the DCC program changes, and IntEC/Load List was also incorporated into the specifications during the design change of electrical discipline.

4.3 Licensing support

To study the suitability of the design documents for the approval from Korea Institute of Nuclear Safety (KINS) in 2009, licensing and technical requirements including the domestic regulations for the Nuclear Act and the Fire Service Act were reviewed. Currently, the technical specifications and Final Safety Analysis Report (FSAR) were revised. Various licensing supports such as preparing answers for KINS questionnaire, having face-to-face meetings with KINS personnel, attending to licensing support meetings, and so on were conducted for KHNP. As a result, KHNP acquired operating license from MEST in December 2009 for all refurbishment items except for 3 items(“Modification of ECC Tank Heating and Recirculation Flow Path”, “Installation of Hydrogen Control System in Reactor Building”, and “Connection Demineralized Water to D_2O Recovery Tank”) that will be refurbished during the plant outage in 2012.

4.4 Safety analysis input

The revised design parameters needed for safety analysis for Wolsong Unit 1 were provided to KHNP, and the safety analysis results were used to revise the Chapter 15 in FSAR.

4.5 Procurement support

The material equipment specifications were prepared for the timely supply of materials and components. Most equipment specifications for foreign supplied items are already issued for procurement which is in initial phase, and the purchase order for domestic supplied items were placed by KHNP. The procurement support services such as reviews on the vendor documents were performed.

4.6 Site support

KOPEC provided site support services during installation and commissioning phases as requested by KHNP. Currently, installation works for most refurbishment items were completed or being completed except for 3 items(“Modification of Emergency Core Cooling (ECC) Tank Heating and Recirculation Flow Path”, “Installation of Hydrogen Control System in Reactor Building”, and “Connection Demineralized Water to D_2O Recovery Tank”) that will be refurbished during the plant outage in 2012.

5. Conclusion

The work contents and scopes of the PSR Safety Improvement and Safety System Refurbishment were introduced. The safety and reliability of Wolsong Unit 1 is expected to be immensely improved through these refurbishments.

These refurbishments are comprehensive engineering projects that cover various design fields such as fluid system, mechanical, instrumentation and control, piping, civil engineering, procurement support, safety analysis input, and licensing support. It shows that project management role is important in carrying out the work within limited schedule and budget. KOPEC has confidence in CANDU projects through a successful execution of these complicated projects. Also, this refurbishments hosted by KOPEC are being performed in collaboration with AECL. The accumulated experience through these refurbishments will be greatly helpful to performing large-scale engineering projects either home or abroad in the future.

6. References

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[4] Ministry of Government Legislation, “Fire Service Act”, June 2008.

[5] Ministry of Government Legislation, “National Fire Safety Codes (NFSC) 102”, December 2008.