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Liquid Relief Valves/Degasser Condenser Relief Valves Incidents and Countermeasures for CANDU 6 Nuclear Plants

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Abstract

Recent failures of Heat Transport (HT) system Liquid Relief Valves (LRVs) at several CANDU 6 plants resulted in heavy water spills. A multi-discipline KAERI task team along with AECL representatives was set up to assess the specific implications on the Wolsong 2/3/4 station. The study applied the knowledge gained from the generic study by conducting a fundamental review of the specific design of Wolsong 2/3/4. The purpose of the study was to demonstrate compliance with the relevant codes and licensing regulations and to identify the improvements to the design and operating procedures applicable to Wolsong 2/3/4. This paper presents the key recommendations of this study.

1. Introduction

In the past, CANDU stations have experienced a number of liquid relief valve (LRV) failure incidents. Some cases resulted in spills from the degasser condenser relief valves (RVs) and other incidents did not. There have also been cases of RVs opening with isolated degasser condensers, and in some of these cases the RVs failed to reseat due to damage.

Although all CANDU plants share a common design approach with respect to relying on the RVs as the final overpressure protection device for the HT main circuit, there are some design differences between various CANDU plants, and their system responses and event sequences following a LRV failure are expected to be somewhat different.

A station specific study was carried out for Wolsong 2/3/4. The purpose of the study was to apply the knowledge gained from CANDU 6 plant events, and other previous events by conducting a fundamental review of the CANDU 6 Pressure and Inventory Control (P&IC) system in order to demonstrate compliance with the relevant codes and licensing regulations and to identify improvements to the design and operating procedures applicable to Wolsong 2/3/4.

2. Pressure and Inventory Control System Design

2.1 System Description

The HT system which carries the heat generated in the reactor core to the steam generators, is a pressurized heavy water system with closed loops. The heat transport pressure and inventory control (P & IC) system for the Wolsong 2/3/4 NPP is designed to provide a means of pressure and inventory control for the closed loops as well as to provide adequate overpressure protection. The control of pressure and inventory is achieved using the unit computers. A simplified flow sheet of the P&IC system is shown in Figure 1.

2.2 Liquid Relief Valves (LRVs) and Relief Valves (RVs)

The LRVs on all CANDU plants are pneumatic actuated valves (air to close, spring to open). When the pressure in the outlet header rises to the valve relief setpoint, logic actuates solenoid valves that release the air from the actuators on the LRV. They are designed to fail open in order to ensure overpressure protection availability targets are met.

The RVs on all CANDU plants are spring-loaded safety valves, and in old designs have the pop open characteristics. The RVs are designed and manufactured to meet the ASME code requirements for *class 1* valves.

3. Recent LRV Failures and Lessons Learned

Under normal circumstances on CANDU 6 stations a spurious openng of LRV should not result in any D_2O spill, since the RVs are set at a pressure above the normal operating pressure of the heat transport system. For one of the spill incidents, the RVs opened one hour and forty seven minutes after the LRV failed open, resulting in a spill of heavy water coolant onto the reactor vault floor. It is suspected that the RVs opening was due to a reduction in the RV set pressure as the valve warmed up with the HT system at zero power hot conditions. There was no increase in HT system pressure to cause the opening.

Some of the root causes underlying the above heavy water spills are generically applicable to the CANDU 6 design. The most serious aspect of these incidents was the fact that the LRV diaphragm ruptured and the RVs malfunctioned causing damage, when required to function to provide overpressure protection for the vessel. Taking into account the pop-open characteristics of the RVs, their excess relief flow capacities, and associated piping configuration, the dynamic analyses indicated there may be an unacceptable risk that RVs in Wolsong 1 station can "chatter" with possible consequent damage to the valve internals and/or connecting piping. This risk exists in most of the unmodified situations that call for the RVs to perform their function. Changes were recommended to the design, design processes and operating procedures to ensure such incidents do not occur

4. Design Improvements

As soon as the events were fully understood, a potential need for Emergency Operating Procedure changes and design modifications for the station operators in case one or more LRVs fail open during operation at power exists.

4.1 Improvements that Prevent RV Opening

4.1.1 Automatic Setback

When an LRV opens, the HT system pressure drops, reducing the margin to dry-out. The drop in pressure following an LRV opening is not sufficient to require a trip to protect the fuel. If in the course of the incident the degasser condenser RV opens and does not re-close (effectively, causing a loss of coolant accident), in the absence of control system action, safety systems (SDS1, SDS2, and ECC) action becomes necessary to prevent fuel damage. Provision of a setback makes the safety system action unnecessary. Furthermore, the plant must be shut down in order to effect any repair. An automatic setback at 0.1%/s power on degasser condenser pressure exceeding 3.9 MPa(g) performs this function in an orderly manner - It is slow enough to avoid shrinking the HT sufficiently to cause a trip on low pressurizer level (the shrink caused by a setback at 0.1%/s corresponds approximately to the combined capacity of both feed pumps).

4.1.2 Pressure Setpoint Reduction

The margin between the HT operating setpoint of 9.89 MPa(g) and the RV setpoint 10.06 MPa(g) is too small to guarantee that the degasser condenser RV does not lift. Furthermore, the pressure setpoint must be reduced before the actual pressure rises above it, because once that happens, the degasser condenser is full and at the same pressure as the HT system, and there is no way of relieving the steam from the pressurizer. Reducing the setpoint early in the transient has the advantage of turning the pressurizer heaters off. A reduction to 9.4 MPa(g) provides a margin of 0.7 MPa to tripping and about 0.66 MPa to opening the RV in the degasser condenser.

4.1.3 Pressurizer Level Setpoint Reduction

The pressurizer level setpoint must be reduced in order to prevent compressing the steam in the pressurizer. If the pressurizer level is lowered and restored to its original value without venting steam, the pressure will rise above the initial value because the mass of steam increases when the level drops, but does not recondense quickly when the level rises. The amount of reduction is a compromise between a trip and ensuring that the steam space compression does not cause the degasser condenser RV to lift. Providing at least 0.5 m to the trip assures margin for errors on power measurement in estimating the pressurizer level setpoint calculated by the shutdown systems.

4.2 Improvements that Ensure Adequate Degasser Condenser RV Performance

The original design of the degasser condenser RVs in Wolsong 1 plant did not consider the dynamic behaviour of the RVs (i.e., valve chattering), and its impacts on the design of associated piping and supports. Repetitive oscillatory motion of the RV from fully or partially open to fully close position (i.e., valve disc collides with the nozzle/seat) at high frequency is defined as "RV Chatter". Due to the violent contact between the disc and the nozzle/seat, it is known that chattering can cause damage to the valve disc and seat, and it can result in severe dynamic/waterhammer loads on the associated piping and supports. Therefore, it is important to design the RVs and their installation properly to ensure stable operation of the RVs.

4.2.1 RV Chattering

RV chatter is due to hydraulic instabilities in the piping and the RVs. When the pressure upstream of the degasser condenser RV reaches its setpoint, the RV opens initiating a flow in the relief line, which in turn causes a net pressure drop in the line. The magnitude of this net pressure drop depends on the piping configuration (i.e., length and diameter, and number of fittings), the RV characteristics (i.e., pop open/close or proportional), and the system transient (i.e., the pressurization rate). Most of the existing RV designs for operating stations, incorporate relatively long inlet lines to the RVs (15 to 35 ft, except Wolsong 2/3/4 modified design). Oversized valves with excess relief capacity, and pop open/close valve characteristics compound the problem. As a result, the fluid immediately upstream of the RV is accelerated very quickly and the pressure upstream of the RV decreases rapidly. If the pressure drop exceeds the blowdown, the RV will start to close. This may happen even though the degasser condenser is still above the relief set pressure. The same effect is expected for the reverse process. While the RV closes, the flow is being decelerated resulting in a rapid rise in the RV upstream pressure. The upstream pressure may then exceed the relief setpoint causing the RV to change direction and re-open. It is important to ensure that the RV/piping installation does not lead to valve chatter.

4.2.2 Degasser Condenser RVs

Various options have been considered to improve the performance of the degasser condenser RVs, such as refurbishing the existing RVs and replacement with new RVs with appropriate design features to ensure chatter-free operation. Finally, a RV with vibration damper and proportional characteristics is most suitable.

4.2.3 RV Testings

An exhaustive series of tests were performed to verify the performance of the RVs. All tests were conducted with water at room temperature. The test results confirmed that the RV meets the valve specification requirements. Throughout all the tests, no rapid cycling, oscillation, vibration nor chattering was recorded, heard or detected by direct visual observations of stem movement. The RV functioned as a proportional valve and the stem moved smoothly and proportionally in response to the system pressure(Ref.2). Figure 2 shows the typical result of a functional test.

4.2.4 Degasser Condenser RV Installation

The original piping arrangement for Wolsong 2/3/4 was similar to Wolsong 1 and it was designed based on considerations of thermal expansion of the degasser condenser and routing around the degasser condenser lateral supports.

As described in Section 4.2.1, the piping configuration is one of the most important parameters influencing the valve chatter behaviour. The longer the inlet line, the larger the expected pressure drop and inertia effect which increases the likelihood of valve chatter. The small pressure drop due to a large size of inlet line and small number of fittings will also reduce the likelihood of valve chatter.

For Wolsong 2/3/4, the degasser condenser RV inlet lines were modified. This configuration requires degasser condenser RV inlet length to be about 9 feet while maintaining the RV location for easy access. Dynamic analysis is also being performed to confirm the chatter-free operation of these RVs with the modified inlet piping configuration and to check piping support loads.

4.3 Changes to Reduce the Frequency of LRV Failure

Three different improvements have been considered to reduce the frequency of LRV failure, which are actuator improvemnent, LRV internals improvements, and LRV air lines improvement.

4.4 Operating Guidelines

Based on the assessment results of the station specific study, a number of operating guidelines upon a LRV failure were established for the Wolsong 2/3/4.

5. Safety Analysis

All trip coverage events were surveyed to assess the potential impact of recent LRV/RV design changes. The design changes pertinent to this assessment are automatic setback (section 4.1.1), automatic pressure setpoint reduction (section 4.1.2) and pressurizer level setpoint reduction (section 4.1.3). All three features to prevent the opening of the degasser condenser RV are initiated when the pressure in the degasser condenser reaches 3.9 MPa(g).

6. Conclusions

In recent years, several incidents of LRV failure occurred resulting in D_2O spill through the degasser condenser RVs. For Wolsong 2/3/4, long term improvements have also been incorporated into the design to further reduce the likelihood of a D_2O spill of such nature. Long term countermeasures to reduce the probability of overpressurization of the HT System to degasser condenser RV setpoint include automatic signals for reactor power setback, HT pressure setpoint reduction and pressurizer level setpoint reduction. All three signals are initiated on high degasser condenser pressure following a LRV failure. These changes have no impact on safety analysis as verified by assessment and re-analysis of trip coverage on selective events.

In the unlikely event that the degasser condenser RVs are challenged to perform their duties, it was also recommended to replace the current 4" x 6" pop open RVs with 2"x 3" size valves with vibration dampers and proportional characteristics to preclude potential for any damage due to chattering. The performance of the new valves has been verified by testing with cold water. The RV inlet lines have also been shortened to provide additional margin to chattering.

In order to reduce the frequency of failure of the LRVs that initiates the spill, recommendations to LRV diaphragm will be made which include frequent periodic replacement and adherence to the design and supplier's requirements. The stem diameter of the LRV has been increased. Complimentary to the design improvements, a station specific set of operating guidelines have been developed to provide corrective operator action if required and to ensure appropriate steps are taken to avoid another spill following repair and closure of the LRV.

Based on the study of a multi-discipline task team and generic studies, design improvements have been incorporated into the Wolsong 2/3/4 design as countermeasures to a spill that may result following a LRV failure. With these countermeasures in conjunction with good maintenance and periodic testing practice properly implemented and fully functional, a D_2O spill due to LRV failure will not occur.

References

1. *Joint CANDU Industry Generic Study of PHT Feed, Bleed and Relief System*, D. Jones, K. F. Hau, D. B. Burjorjee, N. Padhi. 2nd International CANDU Station Engineering / Technical Managers Workshop, 1995 Nov. 22-24.

2. *Performance Qualification Testing of the Bopp & Reuther Degasser Condenser Relief Valves, 3332-RV11, -RV21, for Use in CANDU Nuclear Reactors*, AECL Technical Document, 86-30834-371-030, Rev.0, 1996.2

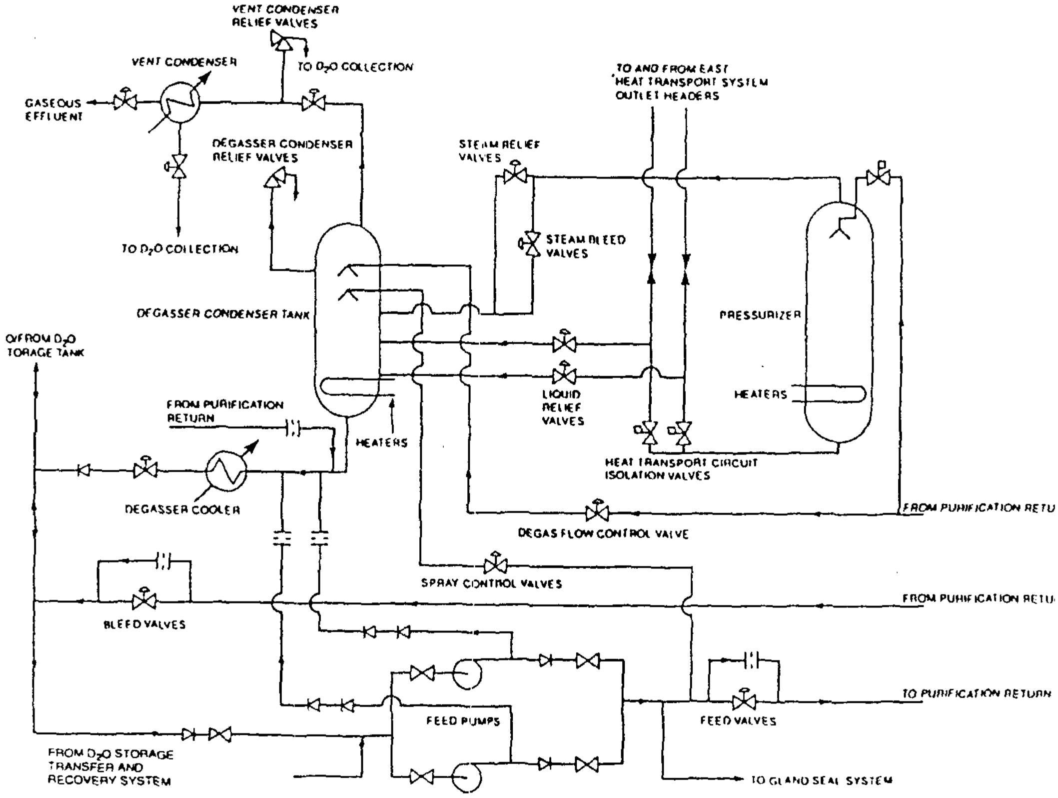

Fig. 1 Pressure and Inventory Control System for Wolsong 1

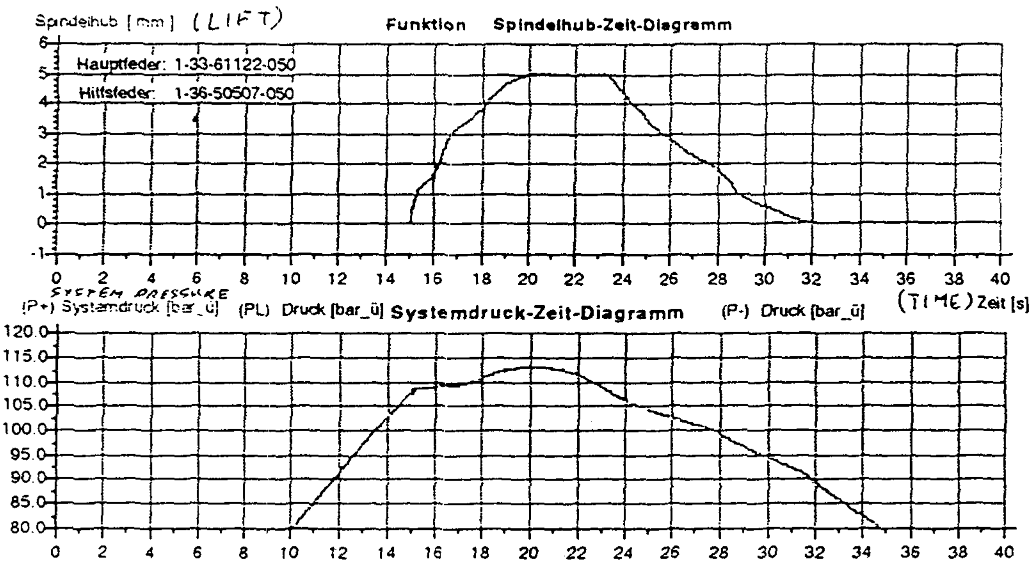

Fig.2 Cold Test Result of DCRV (Time vs. Lift, Time vs. System Pressure)