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Containment Overpressure Protection Capability Weakness under Severe Accidents at Wolsong

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1. Introduction

At Wolsong, an uncontrolled overpressurization of the containment will likely occur during unmitigated severe accident conditions [1][2]. For this circumstance, a scoping analysis of containment airlock seal failure is made through this paper. The purpose of this task is to compile and review the personnel airlocks and to scope potential engineering solutions to their improvements in order to decrease their failure possibilities.

Containment envelope in Wolsong nuclear power plants is made up of the following three systems.

- Reactor building
- Airlocks
- Containment isolation system

Among these, it is recently reviewed that the airlock seals can be the weakest link in the ability of the containment to mitigate an overpressure transient. These are pneumatic seals on mechanical doors and their air inflation and failure pressures are both lower than the containment ultimate air pressures predicted in licensing based LOCA scenarios. With severe accident scenarios potentially resulting in even higher pressures, failure of these seals needs to be delayed to significantly higher pressures, if possible.

Two airlocks are provided for reactor building access, an equipment airlock and an auxiliary personnel airlock.

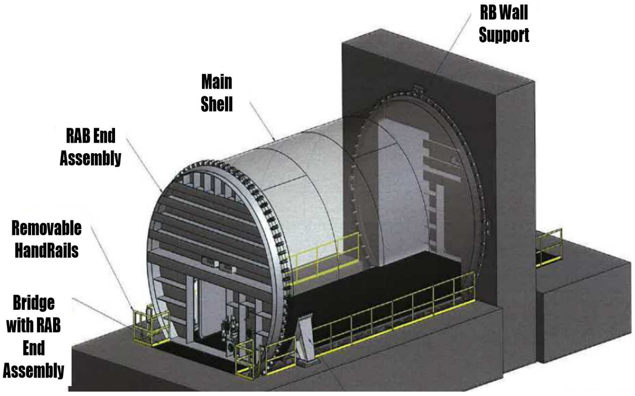

Fig. 1 Typical PHWR Airlock configuration (CANDU-6 Plant)

Normal entry to and exit from the reactor building for personnel and equipment is via the equipment airlock which leads to an access to laydown area in the service building (refer to Fig. 1). Personnel traffic, small maintenance and service supplies are via a small door installed within the main door of the equipment airlock. Major pieces of equipment are transferred through the larger main doors. As shown in Fig. 2, the equipment airlock door is 3.9m wide and 4.2m high while the personnel airlock door is 0.9m wide and 2.1m high. The auxiliary (emergency) personnel airlock is located in the reactor building basement and is primarily intended for the emergency entrance and exit of personnel. Its lower elevation is above the reactor building design water level resulting from a LOCA. Both airlocks are enclosed in the service building, which is tornado qualified.

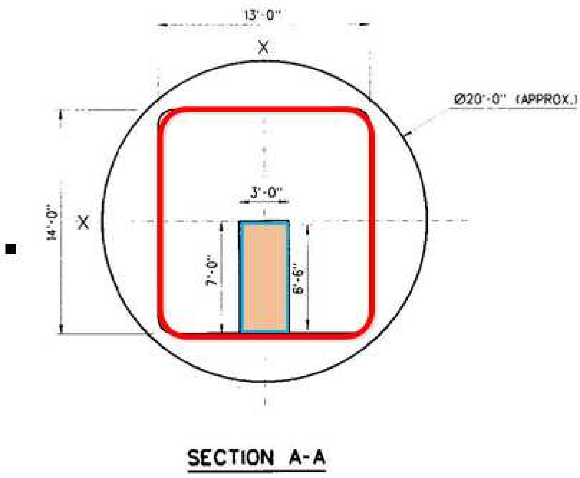

Fig. 2 CANDU-6 Equipment Airlock Door Sizes

2. Review of CANDU-6 Airlock Behavior under Severe Accidents

According to a review of CANDU-6 airlock design [3], containment access consists of two airlocks, the equipment airlock and auxiliary personnel airlock, and one spent fuel transfer containment door. The airlocks and spent fuel transfer containment door are designed such that access into the reactor building is possible without breaching the integrity of the containment. The airlocks are cylindrical steel structures with door assemblies at each end, one at the reactor building (RB) side and one at the service building (SB) side. For the equipment airlock, the door assembly consists of an equipment door with a personnel door mounted within it. The personnel airlock has a personnel door at each end.

The spent fuel transfer containment door has the same size as the personnel doors of the airlocks.

The airlocks have elastomeric double seals, qualified to LOCA condition, on each door. Door closure can be monitored continuously and the performance of seals can be tested to assure that a fully capable barrier exists at all times. During a severe accident, the seals on the RB side may be subject to degradation due to the extreme harsh environment. The seals on the SB are expected to provide the sealing capability at first even after the seals on the RB side start to be degraded, thus maintaining the containment integrity. But after some time when the space between the two sides would also become a harsh environment, the seals on the SB are expected to lose the sealing capability.

During a severe accident, the containment may be flooded with dousing light water and heavy water released from heat transport system and moderator. The bottom of the airlock is at 2.1 m from the RB basement floor. An anti-flooding dam is installed to extend the flood protection level to 2.3 m elevation from the basement floor (protects the airlock seal from exposure to water up to that level). When external source of water is supplied to the calandria vault, the basement water level will rise. If submergence of the airlock will have adverse consequences, then the supply stop of external water should be considered by emergency staffs.

Revisiting review of the ultimate pressure capacity of containment penetrations and airlocks for CANDU-6 stations identified that the RB airlock seals blow-by may occur at lower pressure than the concrete through wall cracking pressure [4]. However, severe accident mitigation measures, such as an emergency filtered containment venting, could limit the containment pressurization to prevent uncontrolled release of radioactivity to the environment.

3. Review of Airlock Failure Possibility

Each airlock is provided with hermetically sealed pressure doors and with an air valve for pressurization and depressurization. The operation of these doors, their seals and the air valves are sequence interlocked in order to maintain the integrity of containment at all times. All airlock operations relating to containment safety function are performed pneumatically and can be carried out either from within the airlock or from outside or inside the reactor building.

- The airlocks have two inflatable seals on each door. Door closure and seal inflation are monitored continuously (and alarmed in the MCR) to assure that a fully capable containment barrier exists at all times.
- Interlocks on airlocks and fuel ports prevent the opening of a containment barrier when the other containment barrier is not closed.
- These interlocks can be disabled during guaranteed shutdown conditions by use of a key obtained from the MCR. Procedural controls do not allow this key to be used except during shutdown.
- The main airlock personnel doors are tested (in effect) by their routine daily operation. The emergency airlock doors and main airlock equipment doors are operated on a monthly basis so as to provide a functional test. Functioning of the interlock is also confirmed at this time.

The two airlock door seals are 22 mm wide and 16 mm high. The clear opening created by a fully retracted seal between the door and the door frame is 10 to 13 mm. The seal pneumatic pressure of 276 kPa(g) defines their upper pressure retention capacity, although they are design rated at a lower pressure of 124 kPa(g).

Interlocking systems ensure that only one of 4 doors open at any given time. There are back-up air tanks and pressurized nitrogen bottles. The airlocks are designed to withstand a pressure of 124 kPa(g) and are tested to a pressure of 143 kPa(g). The airlocks are rated for a maximum temperature of 103.3°C. The maximum leakage is 1 liter/sec for a gage pressure of 124 kPa(g) for each of the two airlocks (personnel and equipment).

Early equipment airlock seal failure at about 276 kPa(g) at elevated containment temperatures results in excessive releases and doses for a number of accidents. This is especially of concern for accidents that result in early release of activity into the containment. This could include LOCA+LOECC, Large LOCA, steam line breaks inside the containment.

4. Feasibility of Airlock Enhancement

Releases into the atmosphere for severe accidents are affected significantly due to airlock seal failures at pressures well below those for improvements of airlock seals in pressure retention capacity at elevated temperatures which have been proposed by AECL, CANDU Energy and the manufacturers. To improve airlock reliability, as well as increased seal life span, the inflatable seals (of the personnel doors of the airlocks and of the containment door) is known to be changed from edge type to face type for the third Qinshan NPP.

Catastrophic failure is highly unlikely as the airlocks are largely structural components (i.e., concrete/welded metal) which are seismically qualified, and thus failure would be by small leak rather than large breakdown. However, failures have been experienced in the past (and are often attributed to seal failure or lack of procedural awareness/compliance). On the other hand, airlock seals and doors are redundant and failure of one would not result in significant consequences; in addition there are redundant airlocks that can be used while one is being repaired.

The airlocks are direct and critical part of the containment pressure boundary, and must be designed, built and tested in accordance with the requirements of CSA Standard CAN/CSA-N285.3 [5], which makes reference to Section III of the ASME Boiler and Pressure Vessel Code, Article NE-3000 for design and Article NE-7000 for overpressure protection. There are two types of seals on airlock doors. Edge type seals are used on all CANDU plants except the latest ones at Qinshan, China. The Qinshan plants use face type seals that have a higher reliability (60,000 cycles as opposed to the 6,000 cycles. To meet the Qinshan requirements, AECL has developed and qualified an improved inflatable door seal design for use in the face- or edge-sealing configuration. In the face-sealing configuration, the gap ranges from 0.6 mm to 5.5 mm, and the seal is qualified to operate to a maximum of 60,000 inflation-deflation cycles; in the edge-sealing configuration, the gap ranges from 5.5 mm to 13.7 mm, and the seal is qualified.

5. Summary

Sustained high temperature and pressure conditions may be detrimental to containment components such as airlock seals, electrical cables and penetrations, pneumatic hoses and concrete structures and to other safety-related equipment and instrumentation inside containment. In this sense, reducing containment temperature, pressure and humidity is beneficial in maintaining containment integrity and increasing the availability of safety-related equipment and/or instrumentation of potential use in mitigating the severe accidents. If the venting system is not used or is not available, and no other means of suppressing containment pressurization is available, then the containment may be breached by airlock seal blow-by under severe accidents. The timing of this depends on the scenario, but has the possibility to occur earlier than about 20 hours, according to Level 2 PSA calculations [6] using MAAP(1)-ISAAC code [7], for the extreme event where no mitigating systems are used. In general, the mitigating strategies are in the following order:

- Isolate the leak path to the environment (close isolation valves, dampers, airlock seals, crimp);
- Reduce the driving force using a containment heat sink (local air coolers and dousing serve multiple purposes – they not only remove heat, but also condense steam to reduce pressure, and remove fission products by plate out and wash out);
- Reduce the driving force by venting through a filtered, monitored release path (this is the lowest priority strategy because there is a temporary increase in release rate until the driving force for leakage is reduced).

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(1) MAAP is an Electric Power Institute (EPRI) software program that performs severe accident analysis for nuclear power plants including assessments of core damage and radiological transport. A valid license to MAAP4 and/or MAAP5 from EPRI is required.

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