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Instability in Liquid Zone Control System of CANDU Reactor

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1. Introduction

When reactivity insertion occurs such as replacement of nuclear fuel in CANDU reactors, local power and water level in the liquid control zone system in the outer top of reactor surge, oscillate at a certain frequency for a certain period of time and drop unstably. As the reactor becomes unstable in the aforementioned manner, it cannot be controlled as intended, safety, economic viability and in turn, reliability of such a reactor are also adversely impacted. The instability described in the above is observed in most of CANDU reactors in service around the world, yet, its root cause and viable solution are not identified.

2. Liquid Zone Control System

2.1 LZCS Functions

Liquid Zone Control System is one of the reactivity control mechanism of CANDU reactor intended to regulate excessive power tilt following replacement of nuclear fuel. The power tilt is regulated by controlling the inventory of light water which is used to absorb neutron in reactor compartment. If LZCS functions as intended, the power tilt falls as water level rises and the other way around.

2.2 LZCS Configuration & works

The compartments are filled with helium in the top and light water in the bottom and the helium and the light water circulate continuously within the system. Helium is filled on the top of light water to allow for pressure measurement and maintain pressure within compartment as light water flows in and out. A certain volume of helium flows in from the bottom of each compartment and out through the top.

3. Instability Phenomenon

The most typical instability in the LZCS of CANDU reactor is found when water level within compartment surges over 80%, then cycles for a certain period of time (1-5days) or drops as indicated. The power tilt pattern is also similar to that of water level as opposed to the normal control. Instability is found mostly in the upper outer zone of Calandria as shown in Fig. 1 and, notably, in Zone #1, 6, 8, 13. In other words, when fuel is replaced in the channels corresponding to the upper outer zones, power output and water level of applicable zone behave abnormally.

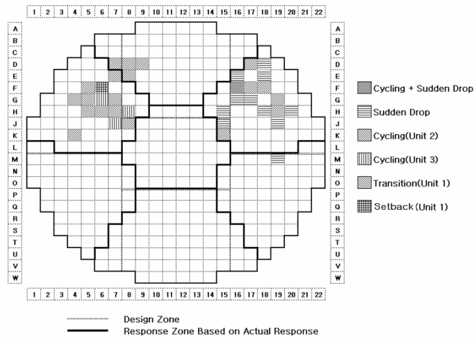

Fig 1. Instability-affected zones in Wolsong plant and fuel channels replaced prior to the instability event

4. LZCS Structure

4.1 Compartment

Fig 2(a) shows length of compartment, location of tube support plate and 80% water level. Fig 2(b) shows the compartment cross section rotated 90° and paths of helium and light water flowing in and out of each compartment.

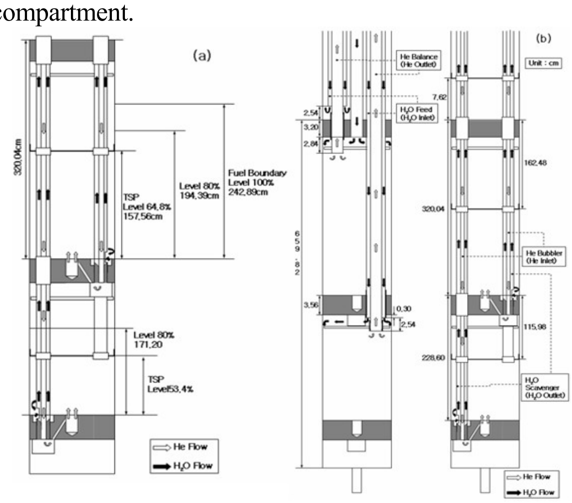

Fig 2. Detailed view of compartment in upper outer zone. (a) Dimensions of the compartment, (b) Flow paths of water and helium

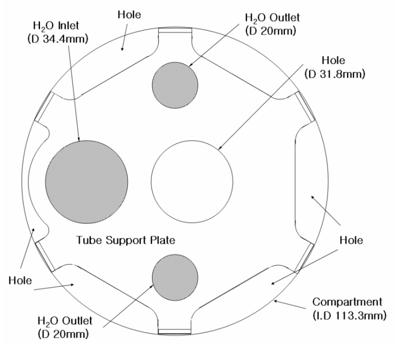

Fig 3. The drawing of TSP in compartment of upper outer zone

4.2 Tube Support Plate (TSP)

TSP installed in the compartments of the upper and outer zones (#1, 6, 8 13). As piping arrangement differs for compartments, the tube support plate in each compartment is also designed to be different. (Fig 3.)

5. Test and Results

To simulate instability phenomenon of LZCS, the test rig almost identical to actual compartment was fabricated. (Fig 4.)

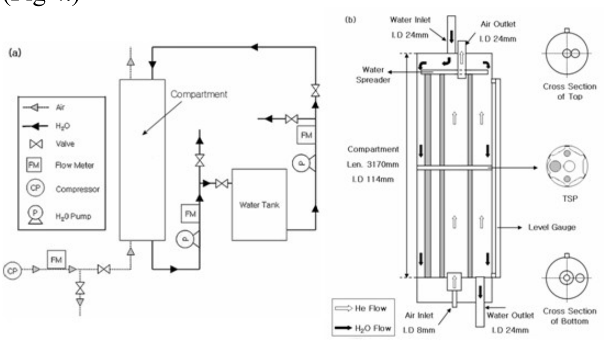

Fig 4. Schematic diagram of test rig. (a) Test loop, (b) Test compartment

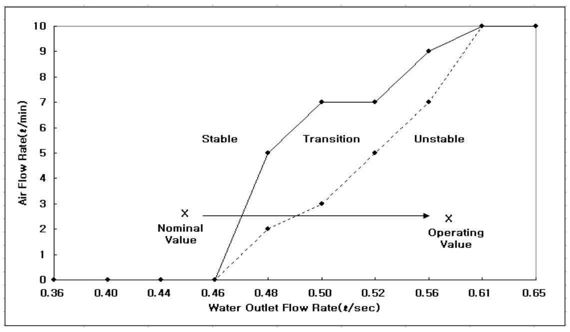

Fig 5. Abnormality pattern map

Abnormalities of light water and air were confirmed in the instability simulation test. Therefore, the test was repeated at different volumes of light water discharge and air influx and the range of volume of light water and air that caused abnormal flow within compartment was identified. (Fig 5. & Fig 6.) Volumetric flow rate defined in the technical specification of CANDU 6 is 0.45ℓ/sec for light water discharge and 150ℓ/hr for helium influx. The operating parameters in the technical specification are in stable range compared to the result of test. However, it was measured to be 140-160ℓ/hr in Wolsong Reactor 1 and 160-184ℓ/hr in Reactor 2. In addition, the volume flow rate may increase by about 40% by head pressure if light water level of compartment is 80% compared to 40%. Given various uncertainty in operating parameters, the volumetric flow rate of light water discharge volume and helium influx volume may fall in unstable range in actual operation.

6. Code Simulation

To find out the power increase due to the light water relocation in the compartment #1, the power reduction capability by the light water level change was simulated by the RFSP. In the calculation, a module named SIMULATE was used.

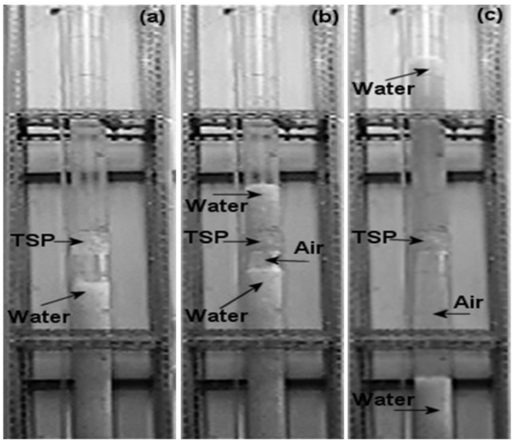

Fig 6. Snapshots of abnormal processes taken during test. (a) Normal, (b) The start of separation (abnormal), (c) The matured abnormality

7. Conclusion

The root cause of instability found in CANDU reactor, which is represented by sudden rise, cycling and drop of water level and power tilt of LZCS compartments, lies in the light water hold-up on the TSP intended to prevent flow-induced vibration of compartment penetrating pipes. Since the root cause of the instability is due to the hydrodynamic phenomena associated with two phase flow of light water and helium gas in the reduced flow area of TSP, the instability can be prevented when the hydrodynamic abnormality is subdued. Therefore, two solutions are suggested to prevent the instability.

First of all, as it is hard to renovate reactors already in operation, instability can be prevented by regulating the volume of light water discharge and the one of helium influx within stable range of the envelope in Fig. 5.

Secondly, flow path of light water and helium in TSP can be increased as suggested in Section 7 for reactors planned to be constructed.

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