Proceedings of the Korean Nuclear Society Spring Meeting
Cheju, Korea, May 1996

A Preliminary Analysis of Large Loss-of-Coolant Induced by Emergency Core Coolant Pipe Break in CANDU-600 Nuclear Power Plant

Robert Aurelian Ion
Center of Technology and Engineering for Nuclear Projects, Bucharest, Romania

Yong Jin Cho, In Goo Kim, Kyun Tae Kim and Jong In Lee
Korea Institute of Nuclear Safety

Abstract

Large Loss-of-Coolant Accidents analyzed in Final Safety Analysis Reports are usually covered by Reactor Inlet Header, Reactor Outlet Header and Primary Pump Suction breaks as representative cases. In this study we analyze the total (guillotine) break of an Emergency Core Cooling System (ECCS) pipe located at the ECCS injection point into the Primary Heat Transport System (PHTS). It was expected that thermal-hydraulic behaviors in the PHT and ECC systems are different from those of a Reactor Inlet Header break, having an equivalent break size. The main purpose of this study is to get insights on the differences occurred between the two cases and to assess these differences from the phenomenon behavior point of view. It was also investigated whether the ECCS line break analysis results could be covered by header break analysis results. The study reveals that as the intact loop has almost the same behavior in both analyzed cases, broken loop behavior is different mostly regarding sheath temperature in the critical core pass and pressure decrease in the broken Reactor Inlet Header. Differences are also met in the ECCS behavior and in event sequences timings.

Introduction

Two calculations were performed, Reactor Inlet Header break and Emergency Core Coolant pipe break, and the results are given as a comparative study in this document.

In the case of a Large Break Loss-of-Coolant Accident (LBLOCA) induced by ECC pipe break, thermalhydraulic behaviors of PHT and ECC systems are expected to be different from the case of a Reactor Inlet Header (RIH) break having the same break area. This might be due to the reduced effectiveness of the emergency core coolant to refill the broken loop, specially the corresponding broken core pass. This study is performed to examine the overall behavior during the transient and to observe the differences which could occur between the results of the two cases analyzed. First case represents an analysis of a RIH break with the break area of 506.7 cm^2. The second case is the analysis of the ECCS pipe break located at the injection point in the same RIH analyzed in the first case. The ECCS pipe diameter is 25.4 cm, resulting in a flow area of 506.7 cm^2. This break represents the equivalent of 23.5% RIH break. The analyses are performed using the CATHENA MOD-3.5 computer code (Reference 1), which is a one-dimensional, two-fluid thermalhydraulic computer code designed for the analysis of two-phase flow and heat transfer in piping networks.

Problem Modeling

The RIH6 and the corresponding ECCS injection pipe into the PHTS loop were chosen for the two analyses. A simplified nodalization scheme used for the two analyses is shown in Figure 1. In this study, the two PHT loops are modeled identical, therefore an appropriate input having the same geometry, initial conditions and system models is used (see Reference 2). The initial conditions for both analyses are given in Table 1. The PHTS between headers is modeled by having four average channels, one for each core pass. Core pass 3 is designated to be the critical core pass. The 20% RIH power rundown curve, which was available at this stage (Reference 3), is used to model the reactor power rundown at the shutdown systems action.

Table 1 Initial Conditions used as input for CATHENA MOD-3.5, in RIH6 Break and ECCS Line Break Calculations

Parameter	Core Passes 1 & 3	Core Passes 2 & 4
Fuel Power for Avg. Channel [MW(th)]	527.875	527.875
RIH Pressure [MPa(a)]	11.36	11.36
RIH Temperature[°C] (*)	267.51	267.64
ROH Pressure [MPa(a)]	10.03	10.03
ROH Temperature[°C](*)	310.54	310.54
Pump Suction Pressure [MPa(a)]	9.58	9.58
Pump Discharge Pressure [MPa(a)]	11.38	11.38
ROH Void	0.368	0.371

(*) Average value of the four radial nodes of header model

Discussion of Results

After the break is initiated in both reactor inlet header break and ECCS line break cases, the pressure in RIH6 is decreasing rapidly (Figure 2), followed by the other headers. Reactor is tripped by Shutdown System 1 (SDS1) on low flow and low HTS pressure signals at 2.63 s for the RIH6 break, and at 4.84 seconds for the ECCS line break case.

LOCA signal is initiated at almost the same time for the two cases (20 seconds) and D_2O isolation valves, High Pressure Injection valves and Dousing Tank isolation valve begin to open. At the same time the Loop Isolation signal is initiated and the pressurizer valves, feed and bleed valves begin to close. Twenty seconds after, the two loops are completely isolated and the pressure drop between the inlet and outlet headers in the intact loop experiences a much slower decrease than in the broken loop. Figure 3 presents the pressure drop between headers RIH2 and ROH3 in core pass 1 (see also Figure 1). Positive and proper magnitude of pressure differences guaranties the core flow sufficient to remove decay heat. The two average channels in the core passes of the intact loop are consequently well cooled by the HT coolant flow, a very low void fraction existing in these channels; Figure 4 gives the sheath maximum temperature in core pass 1. It can be stated that the behavior of the intact loop is approximately the same for the two cases analyzed.

The average channel upstream of the break (core pass 4) is well cooled during the transient (Figure 5) due to the pull of the break and pump head prior to ECC injection, and after that due to core pass refilling in the forward direction. However, the temperature peak shown in Figure 5, is given by the very low flow - lower (almost stagnant) in the ECCS line break case - in core pass 4, from approximately 70 to 90 seconds after break initiation.

The pressure decrease in Inlet Header 6 is lower in the ECCS line break case than in the RIH6 break case prior to the LOCA signal because of the effect of the break location in the early stage of the transient (Figure 2). Also the reversed flow in the average channel downstream of the break occurs about 10 seconds later in the ECCS line break case due to the same reason mentioned above (Figure 6). After LOCA signal, the pressure decrease becomes higher in the ECCS line break case.

That is because in this case the Rupture Disk 1 (RD1) breaks at about 22 seconds and the ECCS coolant is spilled out through the break in the reactor building instead of being injected into RIH6. As shown in Figure 7, the break discharge flow in the ECCS line break case is higher (excepting the very early stage of the transient - the first 6 seconds) than that of RIH6 break case. Break discharge consists of HT coolant coming from the RIH6 (core pass 3) and spilled out through one side of the guillotine break, coupled with HT coolant coming from the ROH5 (core pass 4) by the open D_2O isolation valves and ECC coolant which are spilled out through the other side of the guillotine break. Therefore the integrated break discharge mass is also higher in the ECCS line break case. At 200 seconds after the break initiation, almost 85% of the ECC coolant used is lost directly through the ECCS line break. In the case of RIH6 break, just HT coolant is lost until RD1 breaks -- much later than in the ECCS line break case -- and the ECCS flow is injected into RIH6.

As shown in Figure 8, the peak of the sheath maximum temperature is higher in core pass 3 average channel for the ECCS line break case than that for the RIH6 break case. Furthermore, in the ECCS line break case, the sheath experiences a temperature over 1000 °C for a longer period of time. The higher peak temperature experienced in the ECCS line break case might be due to the combined effects of various parameters. During the time when sheath is experiencing the peak temperature, a more gradual flow reduction can be observed in the ECCS line break case than in the RIH6 break case (Figure 6). The gradual flow reduction assumes flow rate values more close to a stagnation flow. The critical channel pressure and void fraction at the middle of the channel (at bundle 7) are also higher during the same period of time in the case of ECCS line break than in the RIH6 break case. In the refilling period, the sheath maximum temperature in the case of ECCS line break exceeds the temperature values given by the RIH6 break case.

For a better evaluation, the comparison between the two cases is given in Figure 9 for the sheath temperatures at the inlet, outlet and middle of the channel locations (at bundles 1, 12, and 7, respectively).

After breaking of RD2 - at 73.95 seconds in the RIH6 break case and at 78.59 seconds in the ECCS line break case - emergency coolant is injected into all eight headers of the HTS. The ECC flows through the D_2O isolation valves into the headers of the broken loop are given in Figure 10. It should be noted that in the case of ECCS line break, the ECC flow through D_2O isolation valve is spilled out through the break and is not injected in the RIH6. The RD1 break initiation can be observed in Figure 10 by the increase in ECC flow towards RIH6 much earlier in the ECCS line break case than in the RIH6 break case. RD2 break initiation almost at the same time in both cases can be observed by the ECC flow increase towards RIH8 and ROH7.

The Medium Pressure ECC injection starts after High Pressure ECC water is depleted at 325.88 seconds in the RIH6 break case and at 301.01 seconds in the ECCS line break case. The flow in the critical pass (core pass 3) is mainly in the reverse direction and the flow in the core pass 4 upstream the break is mainly in the forward direction.

The overall sequence of events for both cases analyzed is given in Table 2. As it can be seen in this table, reactor trip is earlier in the RIH6 break case due to the location of the break signifying that the low HT pressure setpoint is reached earlier. The major difference consists in the RD1 break initiation. RD1 breaks much earlier -- shortly after LOCA signal -- because the pressure downstream the RD1 decrease more rapidly as the break is located in the ECCS line, resulting in reaching much earlier the pressure difference setpoint between upstream and downstream RD1 nodes.

Table 2 Sequence of Events for RIH6 break and ECCS line break

RIH6 Break	
Timing [s]	Event
0.0	Break initiation
2.63	Reactor trip on SDS1 signal
20.04	LOCA and Loop isolation signals
40.04	Pressurizer heaters turned off
43.60	Turbine trip
50.19	SG crash cooldown initiation
56.91	RD1 breaks
73.95	RD2 breaks
74.79	HT pump trip signal
325.88	MPECI starts
ECCS Line Break	
Timing [s]	Event
0.0	Break initiation
4.84	Reactor trip on SDS1 signal
20.78	LOCA and Loop isolation signals
22.82	RD1 breaks
38.16	Turbine trip
40.78	Pressurizer heaters turned off
50.81	SG crash cooldown initiation
69.63	HT pump trip signal
78.59	RD2 breaks
301.01	MPECI starts

Conclusions

The results from the analyses for RIH6 and ECCS line break cases were assessed.

Thermalhydraulic behavior of the intact loop is approximately the same for the two cases.

The most significant differences between thermalhydraulic behaviors of the broken loop are observed in the critical core pass. The sheath temperature at middle (bundle 7) of the critical core pass average channel has a higher peak in the ECCS line break case. Furthermore, this peak temperature of the bundle 7 sheath is even higher than in the 35% RIH break analysis results, which provides the highest sheath temperature resulting from the break survey analyses (Reference 4).

ECC flows into the headers of the broken loop are also different between the two cases.

Taking into account the results obtained from this study, it is highly recommended that a more comprehensive and detailed analysis be performed.

Acknowledgments

Robert Ion wishes to acknowledge International Atomic Energy Agency (IAEA) which has awarded and supported his fellowship, and also to acknowledge Korea Institute of Nuclear Safety (KINS) which has accepted him as an IAEA fellow. Last but not least, Robert Ion wishes to thank the KINS's Safety Analysis Group members who were providing him excellent support during his training program.

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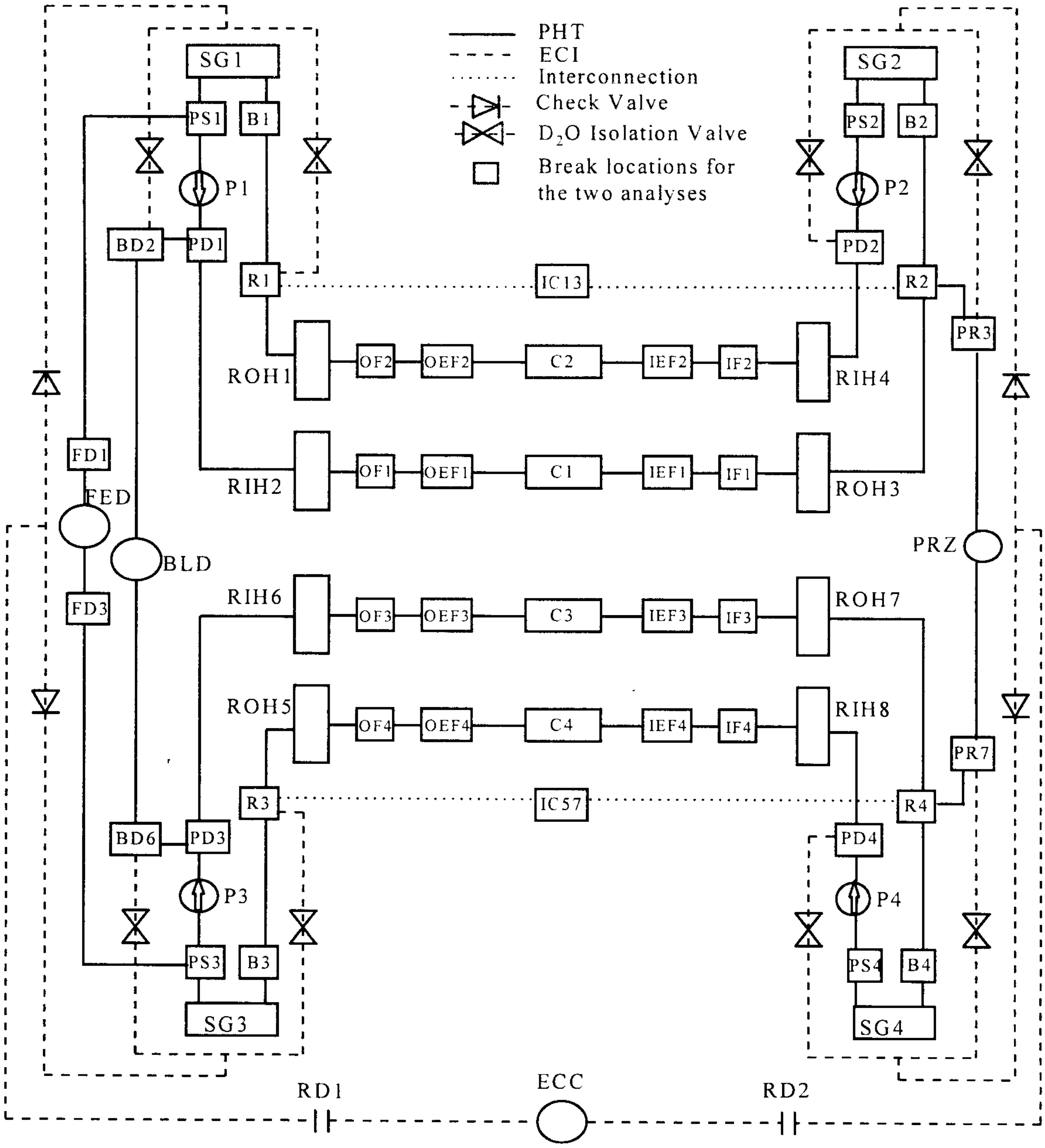

Figure 1 Nodalization of CANDU-600 Nuclear Power Plant

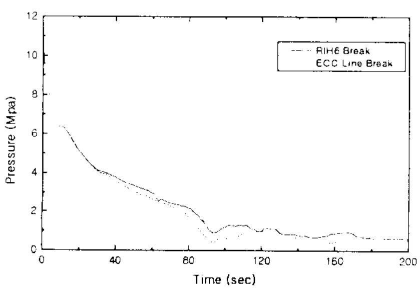

Figure 2 Pressure Transient in RIH6

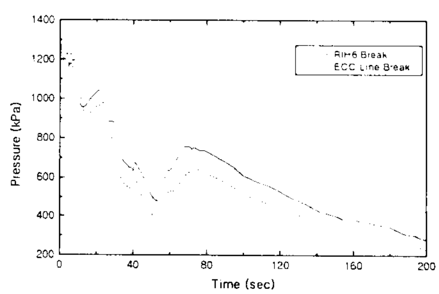

Figure 3 Pressure Differences Between RIH2 and ROH3

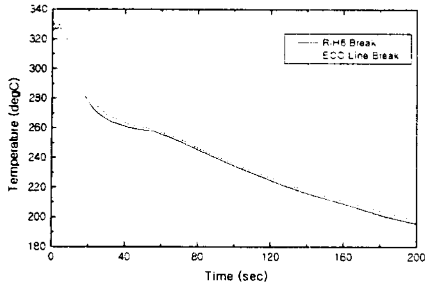

Figure 4 Sheath Maximum Temperature in Core Pass 1

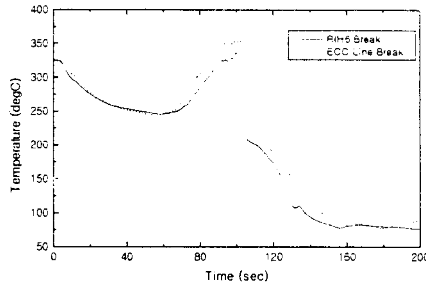

Figure 5 Sheath Maximum Temperature in Core Pass 4

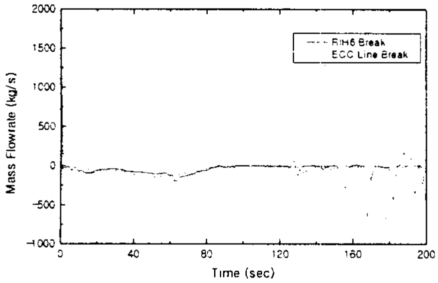

Figure 6 Flow Rate in Core Pass 3

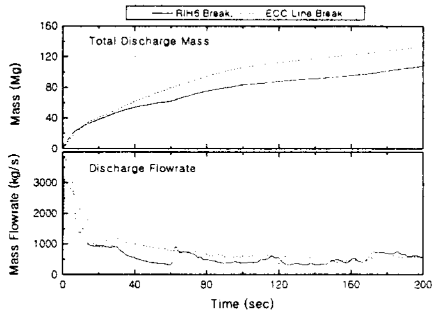

Figure 7 Break Discharge Rate and Mass

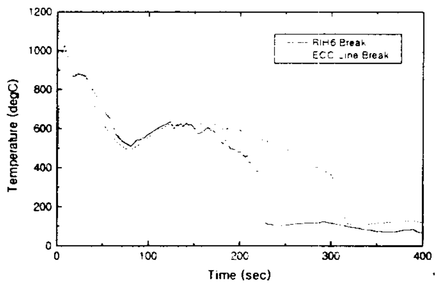

Figure 8 Sheath Maximum Temperatures in Core Pass 3

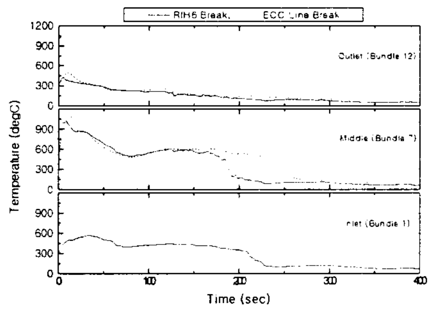

Figure 9 Sheath Temperatures of Selected Bundles

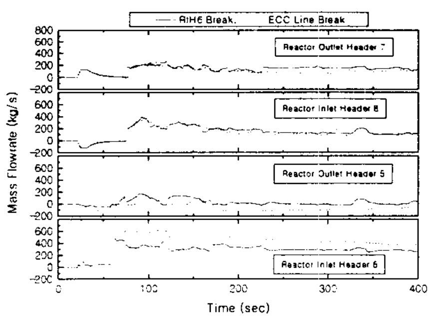

Figure 10 ECC Flow Rate into Headers