Influence of Coolant Phase Separation on Event Timing During a Severe Core Damage Accident in a Generic CANDU 6 Plant

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ABSTRACT

The Modular Accident Analysis Program for CANDU®* (MAAP4-CANDU) was developed to assess the consequences of a severe core damage progression in a CANDU nuclear power station. The results from MAAP4-CANDU analyses support Level 2 PSA activities being performed for CANDU stations.

During the early stages of a severe core damage accident in a CANDU plant, the primary heat transport system (PHTS) coolant is likely to be a two-phase homogeneous mixture. Because of the PHTS depressurization after a postulated initial event such as a large break, combined with a loss of coolant circulation and loss of any coolant makeup, the PHTS coolant void continuously forms. Eventually, the steam and liquid phases of the PHTS coolant will separate. Once phase separation occurs, the upper fuel channels in the reactor core could void. Fuel in the voided fuel channels would heat up from the decay heat and low cooling capacity of the PHTS coolant.

The onset of phase separation is an important parameter for severe core damage accident progression in a CANDU reactor, because it affects the overall timing of events, such as fuel heat-up initiation, debris formation inside the fuel channel, and fuel channel failure. MAAP4-CANDU has a simple thermalhydraulic model of the PHTS, and the PHTS coolant phases separate when the coolant void fraction exceeds a user-defined value (VFSEP).

This paper reports the results of a scoping study, conducted to investigate the influence of the input parameter VFSEP on the dryout (void) time of the upper level fuel channels in a generic CANDU 6 reactor core, during a postulated Large Loss-of Coolant Accident with complete loss of emergency core cooling (LLOCA+LOECC). A code-to-code comparison was performed to evaluate the values of the parameter VFSEP appropriate for a given LLOCA case. CATHENA (a detailed thermalhydraulic code used for design basis accident analyses of a CANDU plant) was used for the code-to-code comparison with MAAP4-CANDU. Code version MAAP-CANDU v4.0.5A and generic CANDU 6 plant data were used.

Results of the scoping analyses demonstrate that the input parameter for phase separation onset in the PHTS is important for predicting the timing of events of accident progression.

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1. INTRODUCTION

1.1 Objectives

The objective of this study is to compare simulation results for the initial primary heat transport system blow-down, during a large loss of coolant accident with complete loss of emergency core cooling (LLOCA+LOECC), as postulated for a CANDU 6 power plant. The comparison is between results obtained with two independent CANDU 6 models using computer codes MAAP4-CANDU v4.0.5A [1] and CATHENA Mod 3.5 Rev0 [2].

The timing of events is important for severe core damage accident analysis. Unlike CATHENA, the MAAP4-CANDU code does not calculate fuel heat up until the first channel is dry. A fuel channel is presently defined to be “dry” when the channel coolant inventory is less than 1 kg. Thus the timing of the severe core damage portions of the accident, as predicted by MAAP4-CANDU, depends upon the first channel dry-out. It is therefore important to compare the timing of channel dry-out between MAAP4-CANDU and a qualified deterministic thermalhydraulic code like CATHENA.

The results of this study also provide guidance to the MAAP4-CANDU user, for appropriate ways to modify the code inputs for simulating a severe core damage accident beginning with a LOCA+LOECC.

1.2 Background

MAAP is an integrated system analysis code for assessing severe core damage accident progression and severe accident management in nuclear power plants. The MAAP code was initially developed for pressurized and boiling light water reactor designs, by Fauske and Associates Incorporated (FAI). The MAAP code is owned by the Electric Power Research Institute (EPRI).

MAAP was extended to include the Ontario Power Generation (OPG) multi-unit CANDU power stations and the AECL single-unit CANDU stations. This was achieved with the addition of the MAAP4-CANDU Channel System modules by OPG, to model the horizontal fuel channel system and the calandria vessel of the CANDU reactor. Additional changes were made to MAAP4-CANDU, so that later code versions can model other CANDU designs, including the Advanced CANDU Reactor (ACR).

MAAP4-CANDU is a consequence analysis tool to assist the probabilistic safety assessment of CANDU reactors during severe accidents; the code is not designed for analysing design-basis accidents. It can simulate the early stages of an accident, however, that are normally simulated with design basis accident (DBA) codes (e.g., CATHENA). This ability allows MAAP4-CANDU to simulate the integrated response of the entire reactor and containment during the early stages of an accident, in preparation for simulating later severe accident events (e.g., core disassembly, calandria vessel failure) that are beyond the scope of the design basis accident codes. A comparison between results from DBA codes and MAAP4-CANDU, for the early stages of a particular severe accident, enables the MAAP4-CANDU user to assess the impact of the uncertainties of input parameters on calculations for the severe core damage phase of the accident.

MAAP4-CANDU models the PHTS with a coarse nodalization (Figure 1) and simple models, such as a common pressure for the entire PHTS loop, the same thermodynamic conditions for each coolant phase, and an absence of momentum equation calculations. CATHENA is a sophisticated two-fluid code, with thermodynamic conditions calculated for each phase at each PHTS node. The CATHENA model of a CANDU 6 contained significantly more core nodes and system components (Figure 2) than the MAAP4-CANDU model.

CATHENA MOD 3.5 Rev 0 was validated against critical and other sizes of inlet header breaks in the RD-14 thermalhydraulic loop, among many other phenomena and integral tests. A code-to-code comparison between MAAP4-CANDU and CATHENA thus provides confidence in the use of MAAP4-CANDU for the thermalhydraulic phenomena involved in a LLOCA blow-down.

MAAP4-CANDU v4.0.5A was used in this study, and MAAP4-CANDU refers to this version unless otherwise noted.

2. ANALYSIS CASE: LARGE LOSS OF COOLANT ACCIDENT WITH LOSS OF EMERGENCY CORE COOLING

MAAP4-CANDU and CATHENA simulation results were compared for the initial PHTS blow-down period during a large LOCA with a complete loss of the ECC system, in a CANDU 6. Losing the core coolant would cause channel heat up, due to the fuel decay heat and additional heat from the steam-zirconium reaction. This could lead to the loss of core structural integrity if the moderator heat sink is also lost. Such an accident could therefore be a precursor to a severe core damage accident.

The specific LLOCA+LOECC transient assessed in this analysis was a 35% break in the reactor inlet header (RIH) of one pass of one loop of a CANDU 6 reactor. By definition, a 100% RIH break is the complete guillotine failure of the header; such a break is double-sided, fed from each section of the header. Therefore, the 35% break size for this study is 35% of twice the cross-sectional area of the RIH, or 0.07455 m^2. This break had been previously analyzed, using CATHENA Mod 3.5 Rev0.

The CATHENA model had the following conditions and generated the resulting event sequence:

- reactor initially at 103% full power, which created a partial void at the outlet sections of some fuel channels, outlet feeders, reactor outlet headers (ROH) and the hot legs of steam generators.
- Class III and IV power available continuously.
- Moderator and shield cooling available.
- RIH break occurred at 0.00 s. Reactor (i.e., fission process) tripped at 0.43 s.
- LOCA signal occurred at 8.6 s, based on low pressure in the RIH - loop isolation occurs as the motorized isolation valves shut between 8.6 and 29 s.
- crash cooling (i.e., steam generator secondary side venting to atmosphere) began at 38.7 s.
- turbine steam valve closed at 40 s.
- primary coolant pumps tripped at 176 s.

Effort was made to match the MAAP4-CANDU PHTS component volumes with those of the CATHENA model. In addition, artificial containment junctions were necessary so that the PHTS reactor inlet header break would vent to atmospheric conditions, like in the CATHENA simulation. The reactor inlet header is located in the fuelling machine room. In order to match CATHENA conditions and thus prevent local containment pressurization, the junction between the lower half of the steam generator room and the fuelling machine room was artificially enlarged to 100 m^2. In addition, an artificial containment junction, with an area of 10,000 m^2, was created between the lower half of the steam generator room and the external environment. Therefore, the flow of steam and water from the PHTS would discharge to atmospheric conditions like in the CATHENA simulation.

The Henry-Fauske two-phase critical flow break discharge model was used in the CATHENA simulation. In the CATHENA run, the PHTS coolant was discharged through the break, in the reactor inlet header, into a containment compartment with atmospheric conditions. The flow discharge coefficient was 0.61. The break flow rate calculated by MAAP4-CANDU is also based on the Henry-Fauske two-phase critical flow model, and the flow discharge coefficient (FCDBRK) was set equal to 0.61 in all the simulations of this study. The flow discharge model is the same for heavy or light water, using the appropriate fluid properties.

In all the MAAP4-CANDU simulations, a fuel channel was considered dry when the remaining coolant mass was less than 1 kg. This represents a void of 93 to 95% for saturated water, depending upon the pressure. Only after a fuel channel is dry does MAAP4-CANDU start to calculate any changes in that fuel channel (e.g., temperatures, heat flows, zirconium oxidation) [1].

The CATHENA LOCA+LOECC simulation was performed with heavy water properties, but MAAP4-CANDU only has light water properties available, as discussed in Section 3.

3. ANALYSIS RESULTS

A series of MAAP4-CANDU simulations were performed, to assess the ability of the code to model the blow-down of a large LOCA + LOECC in a CANDU 6, when compared with results previously predicted with CATHENA.

A total of eight MAAP4-CANDU simulations were performed with different input factors, to identify the most suitable input values for this large LOCA+LOECC scenario. An additional six simulations were run to provide data points on the effect of input parameter VFSEP, as discussed in Section 3.2. The key input values and results of these simulations are summarized in Table 1. Because of the limited space, only results for the most representative runs are discussed in current paper.

The CATHENA CANDU 6 model calculates different pressures and temperatures throughout the PHTS. At initial conditions, the pump outlet pressure was 11.38 MPa (all pressures are absolute values) at the primary pump discharge, 11.35 MPa at the reactor inlet header, 10.02 MPa at the outlet header, and 9.58 MPa at the primary pump suction. MAAP4-CANDU has only one primary system pressure, because almost no PHTS flow calculations are performed; the exceptions are the break flow and the channel steam flow rate during the later core heat up stage of the simulation. Typically, MAAP4-CANDU simulations are run with the initial pressure equal to the average of the reactor inlet and outlet header pressures. Thus, in all but one of the following simulations, the initial primary pressure was set to 10.69 MPa.

The CATHENA LOCA+LOECC simulation was performed with heavy water properties, but MAAP4-CANDU only used light water properties. To simplify the comparison between the simulations, the heavy water fluid masses predicted with CATHENA were divided by 1.103 to give the equivalent masses of light water. The value of 1.103 is the density ratio of liquid heavy water to liquid light water at typical CANDU operating conditions.

Comparing the light water masses calculated by MAAP4-CANDU, with the “light-water equivalent masses” of heavy water from the CATHENA simulation, is simplistic. It was, nonetheless, sufficient for the present comparison of the effect of blow-down on the PHTS. All CATHENA fluid masses in this report are “light-water equivalent masses” of heavy water.

3.1 Run 3 Results

For the Run 3 MAAP4-CANDU simulation, the initial PHTS loop coolant mass was equal to that of the CATHENA simulation (i.e., the heavy water + heavy steam mass divided by 1.103). An initial total PHTS void (α_0) of 6.80% was necessary in MAAP4-CANDU so the initial PHTS loop fluid masses would match between the two codes. Run 3 results are shown in Figures 3 to 8. The figures show that even with the model simplifications and coarse nodalization, MAAP4-CANDU output demonstrated the expected trends of loop depressurization and break mass flow.

The void fraction (VFSEP), at which phase separation occurs in the PHTS, was 50% in Run 3. This is the value used in all MAAP4-CANDU simulations to date. When the total loop void reached 50%, the individual volumes (nodes) in the MAAP4-CANDU PHTS model were no longer filled with a homogeneous mixture, but separated into vapour and liquid phases depending on the node elevation. This affected the break flow rate because, after phase separation, MAAP4-CANDU calculated the break flow based on the phase present at the break rather than on a homogeneous mixture. If the water level was below the bottom of the break, the break flow would be gas only; if the water level was above the break, the break flow was water only. If the water level was between the bottom and top of the break, a local homogeneous two-phase flow was calculated until the water level decreased below the bottom of the break.

The total PHTS loop fluid masses were initially the same as those of the CATHENA simulations, because the initial void fraction was adjusted to make them match (Figure 7). For the first 100 s, the fluid inventories of the intact PHTS loop were similar between the MAAP4-CANDU and CATHENA simulations, but the MAAP4-CANDU broken loop inventory remained higher than that of the CATHENA simulation.

The intact loop void fraction rapidly dropped to zero, and went slightly subzero due to the coding in MAAP4-CANDU (Figure 8). When the intact loop filled with liquid, the code set the intact loop pressure to that of the pressurizer, and the void fraction remained zero until 24 s when the loop began to void again. After the loops were isolated at 45 s, the intact loop void fraction from MAAP4-CANDU remained close to that in the CATHENA simulation. The MAAP4-CANDU broken loop void fraction was between 20 and 30% lower than that from CATHENA, during the first 100 s.

The first channel to dry out in the broken loop did not do so until 4481 s in the MAAP4-CANDU simulation. The CATHENA simulation showed complete voiding by 40 s, for the channel pass connected to the broken inlet header, and 100 s for the other pass in the broken loop.

It is important for MAAP4-CANDU to predict channel dry-out close to the expected time (i.e., as predicted by CATHENA) because first channel dry-out determines the time when MAAP4-CANDU begins to calculate channel heat up and subsequent severe core damage events. Predicting a longer time to first channel dry-out is non-conservative, because it may incorrectly lengthen the time available for operator intervention and not capture the timing of subsequent core degradation.

The difference in timing for the first channel to dry out in the broken loop was largely due to CATHENA simulating an initial high mass flow of subcooled water through the RIH break, since CATHENA can model many PHTS nodes with different thermodynamic conditions in each node. MAAP4-CANDU, on the other hand, calculates only a single pressure and equilibrium thermodynamic conditions for the entire PHTS. This meant the initial RIH break mass flow calculated by MAAP4-CANDU was substantially lower than that calculated by CATHENA, because the break flow was lower-density two-phase flow from the beginning of the simulation.

The user-input parameter VFSEP was useful to adjust the time to first channel dry-out, during MAAP4-CANDU simulations. This parameter is the PHTS loop void fraction at phase separation. When the average PHTS loop void fraction increases above VFSEP, the PHTS fluid separates into liquid and vapour phases. Until phase separation, the PHTS coolant flowing through the break is modelled as a uniform-density homogeneous fluid; after phase separation, the collapsed liquid level may be below the break elevation. Given the latter condition upon phase separation, as occurred in the MAAP4-CANDU simulations performed for this paper, the break flow changed from a high-density homogeneous two-phase flow to a low-density single-phase vapour flow.

Increasing the value of VFSEP prolongs the time that the PHTS fluid remains two-phase; thus the break flow remains two-phase and at a higher mass flow than would occur with single-phase steam. Prior to this study, a value of VFSEP=0.50 was used during MAAP4-CANDU simulations, including Run 3. During a large LOCA, a high value of VFSEP is physically acceptable because the PHTS fluid would be well mixed by the highly turbulent flow.

3.2 Effect Of Void Fraction, At Which The Phases Separate

To investigate the effect of the input parameter VFSEP on the first fuel channel dry-out time and the PHTS response, an additional MAAP4-CANDU simulation was conducted (Run 7). For Run 7, all the input data were the same as in Run 3 except VFSEP, which was set to 0.99 instead of 0.5 in Run 3.

Figures 9 to 14 show results for Run 7. One of the major findings from Run 7 is that when VFSEP=0.99 in MAAP4-CANDU, the predicted total fluid masses in the intact and broken PHTS loops are much closer to the CATHENA predictions (Figures 13 and 14). The PHTS pressure and break discharge flow rate from MAAP4-CANDU Run 7 also remained in reasonable agreement with the CATHENA results.

A VFSEP value of 0.99 decreased the time to first channel dry-out, as calculated with MAAP4-CANDU Run 7, to 91 s. The CATHENA simulation predicted a first channel dry-out of 40 s. Within the scope of a severe accident, lasting many thousands of seconds, this discrepancy is small.

An additional six MAAP4-CANDU simulations, beyond the original eight, were run to provide more data on effect of the input parameter VFSEP on the first fuel channel dry-out time and overall PHTS response (See Table 1, “Supplemental”).

The times to first channel dry-out are listed in Table 1, and illustrate the effect of changing VFSEP. A better illustration is shown in Figure 15, which shows the first channel dry-out time as a function of VFSEP. This figure is specific for a 35% reactor inlet header break with an initial PHTS pressure of 10.69 MPa and an initial loop void of 6.80%, for the MAAP4-CANDU runs.

For large breaks, such as the one described in this paper, it is justifiable to have high values of VFSEP because of the highly turbulent nature of the blow-down and because the primary pumps continued to run. With about 60,000 kg of water and steam venting out of the PHTS in 40 to 60 seconds, there would likely be no phase separation in most of the core. When the water inventory got very low, the remaining steam flow would drag along the water as a mist, particularly in the fuel channels where any remaining water would vigorously boil.

It is important to note that VFSEP is only used for the PHTS coolant, so any changes in its value do not affect other calculations except by the resulting PHTS behaviour.

4. SUMMARY

This study demonstrates that MAAP4-CANDU performs in a similar fashion to the rigorous models and detailed nodalization of the CATHENA code. This occurred in spite of MAAP4-CANDU having simple models (e.g., a common pressure for the entire PHTS loop, the same thermodynamic conditions for each coolant phase), the absence of momentum equation calculations, and using coarse PHTS nodalization. Also, MAAP4-CANDU uses light water properties, which posed some difficulties in comparing the results to the CATHENA simulation, which used heavy water.

The MAAP4-CANDU PHTS loop coolant inventory decreased with time, the PHTS pressure decreased in both loops, loop void fractions increased, and the break flow decreased. The timings of events and rates of change were different from the CATHENA simulations, but the general trends were observable with the very first MAAP4-CANDU run. Additional simulations were made to improve the correspondence between the MAAP4-CANDU and CATHENA results.

The PHTS loop void fraction at phase separation (VFSEP) is a very important input parameter for changing the break flow rate and hence the time until sufficient water had blown and boiled out of the PHTS to cause the first fuel channel to dry out.

In order for MAAP4-CANDU to simulate severe accidents, it is important for it to be able to simulate reactor and containment conditions during the precursor (i.e., pre-core damage) stages of the accident sequence. As noted above, it is particularly important to establish the correct channel dry-out time. This paper shows that by comparing the MAAP4-CANDU output with validated deterministic design basis accident codes, MAAP4-CANDU models can be adjusted to simulate the appropriate conditions at the time beyond which the design basis codes cannot simulate (e.g., core disassembly). This study showed that, for a large LOCA+LOECC scenario, MAAP4-CANDU input parameters could be effectively adjusted to calculate the broken PHTS loop fluid mass similar to CATHENA, and to generate channel dry-out at a similar time to that calculated by CATHENA.

REFERENCES

1. Fauske and Associates Inc. and OPG Inc., "MAAP4-CANDU - Modular Accident Analysis Program for CANDU Power Plant", Volumes 1-3, April 1998.
2. CATHENA: A Thermalhydraulic Code for CANDU Analysis. B.N. Hanna. Nuclear Engineering and Design 180 (1998), p. 113-131.

NOMENCLATURE

P_0 Initial PHTS pressure {MPa absolute}. Also known as PPS0 in the MAAP4-CANDU input parameter file.

α_0 Initial total PHTS void fraction. Also known as VFPS0 in the MAAP4-CANDU input parameter file.

α_{sep} Total PHTS void fraction at phase separation. Also known as VFSEP in the MAAP4-CANDU input parameter file.

Table 1
Input Variables Changed for the MAAP4-CANDU Simulations, and Resulting Time to First Channel Dry Out

MAAP4-CANDU Simulation	Initial Loop Void Fraction VFPS0 (%)	Initial Loop Pressure PPS0 (MPa)	Void Fraction at Phase Separation VFSEP (%)	Time When First Channel Dries Out (s)
1 (Base Case, same initial void as CATHENA run)	14.30	10.69	50	4431
2 (Initial 0% void)	0.00	10.69	50	4684
3 (Initial loop fluid mass same as CATHENA)	6.80	10.69	50	4481
4 (Initial loop fluid mass same as CATHENA, lower MAAP4-CANDU initial PHTS pressure)	9.47	9.58	50	4538
5 (Initial loop fluid mass same as CATHENA, VFSEP=95%)	6.80	10.69	95	768
6 (Initial 0% void, VFSEP=95%)	0.00	10.69	95	814
7 (Initial loop fluid mass same as CATHENA, VFSEP=99%)	6.80	10.69	99	91
8 (Initial loop fluid mass same as CATHENA, VFSEP=95%, initial pressurizer level decreased)	6.80	10.69	95	764
Supplemental**	6.80	10.69	25 60 70 80 85 90	4871 4150 3723 2949 2412 1795
CATHENA Simulation	14.30	9.58 to 11.38, depending upon location in loop	Not Applicable	40 s (broken pass) 100 s (intact pass) ***

* Initial pressurizer water level decreased from standard 13.5 to 9.66 m to reduce initial inventory
** Six more simulations performed, with identical inputs to Runs 3, 5 and 7, except with different VFSEP values. Simulations not described in detail in paper, and only used to add further data for Figure 15.
*** MAAP4-CANDU does not differentiate between different passes in the same PHTS loop.

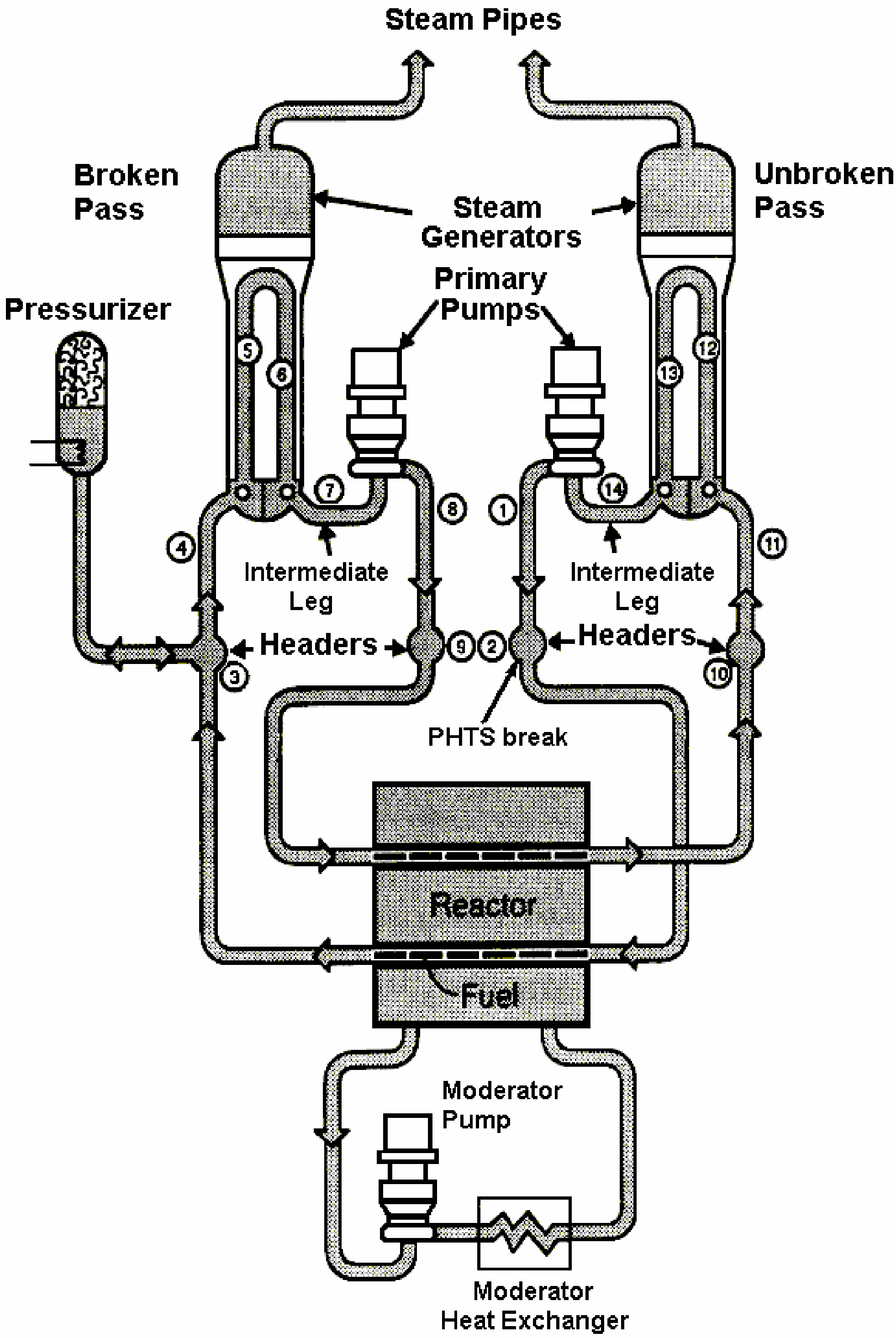

Figure 1 MAAP4-CANDU Primary Heat Transport System Model. Node numbers correspond to MAAP4-CANDU PHTS volumes.

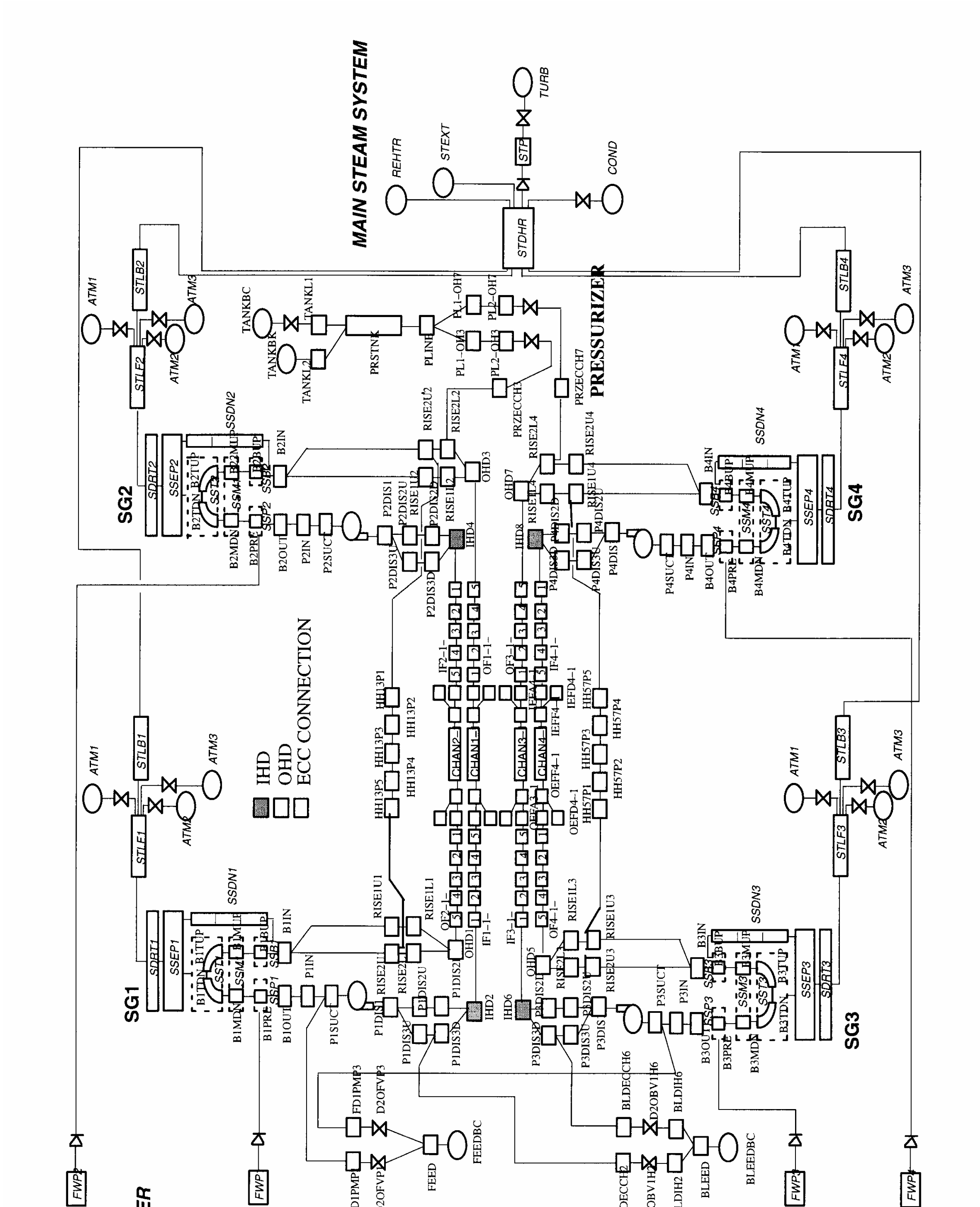

Figure 2 CATHENA Primary Heat Transport System Model.

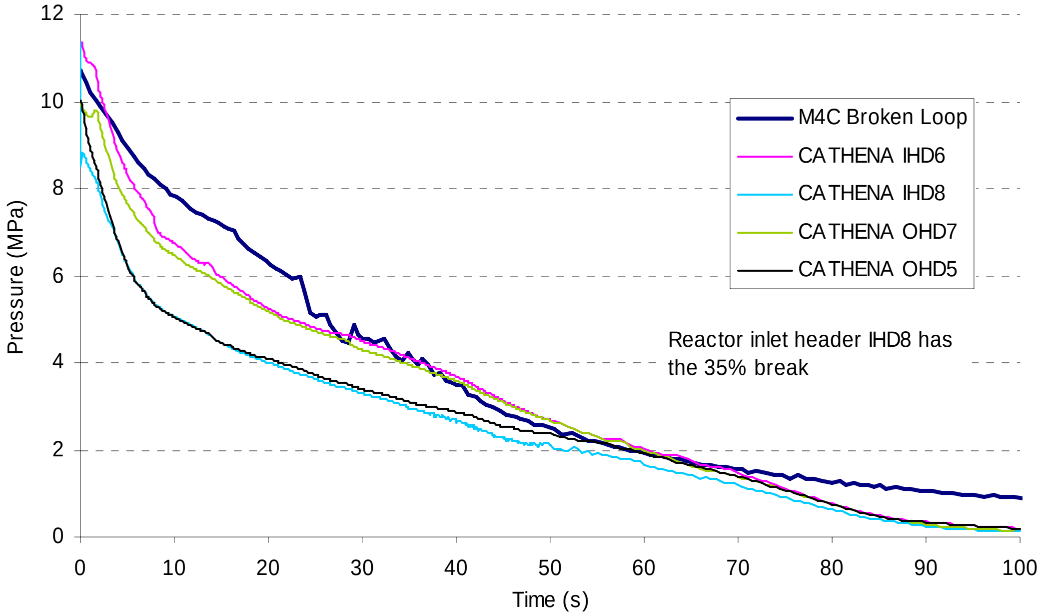

Figure 3 **Broken Loop Pressure During a 35% RIH Break Comparing CATHENA Mod-3.5(Rev0) with MAAP4-CANDU v4.0.5A.**
MAAP4-CANDU Run 3: P_0=10.69 MPa, α_0=6.80%, α_{sep}=50%.

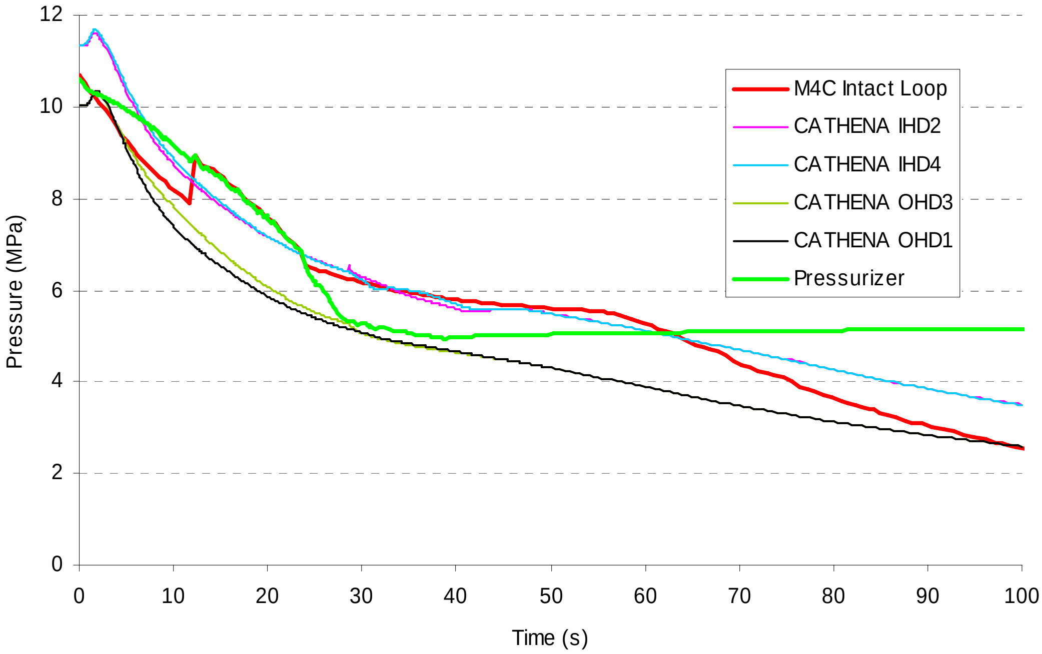

Figure 4 **Intact Loop and Pressurizer Pressure During a 35% RIH Break Comparing CATHENA Mod-3.5(Rev0) with MAAP4-CANDU v4.0.5A.**
MAAP4-CANDU Run 3: P_0=10.69 MPa, α_0=6.80%, α_{sep}=50%.

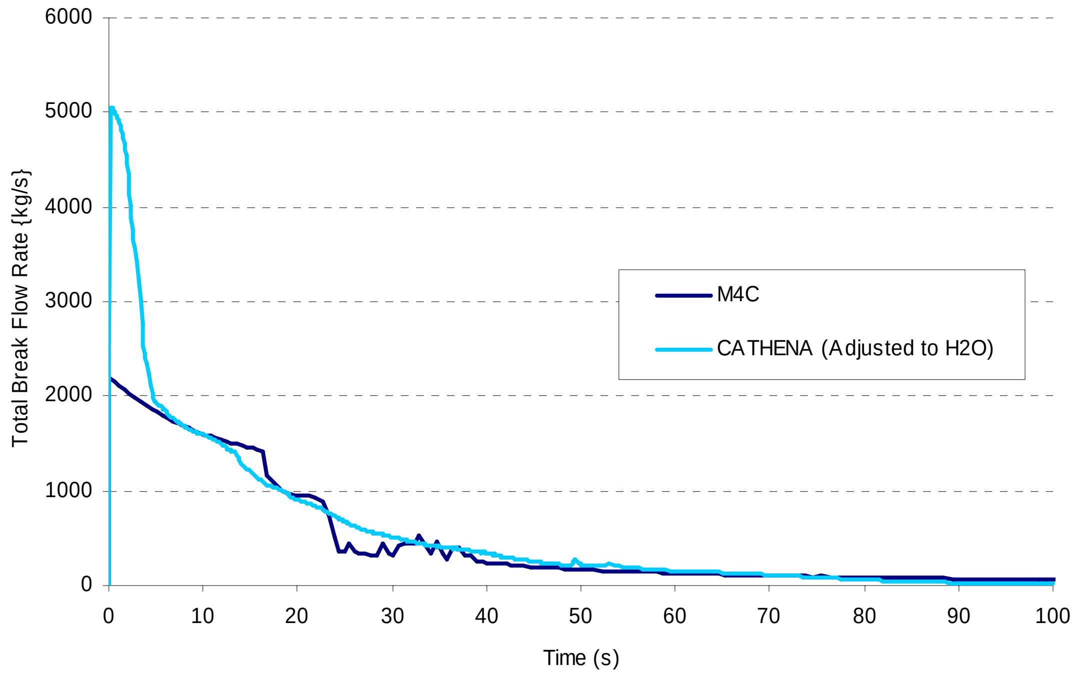

Figure 5 Total Break Flow Rate During a 35% RIH Break Comparing CATHENA Mod-3.5(Rev0) with MAAP4-CANDU v4.0.5A.
MAAP4-CANDU Run 3: P_0=10.69 MPa, α_0=6.80%, α_{sep}=50%.

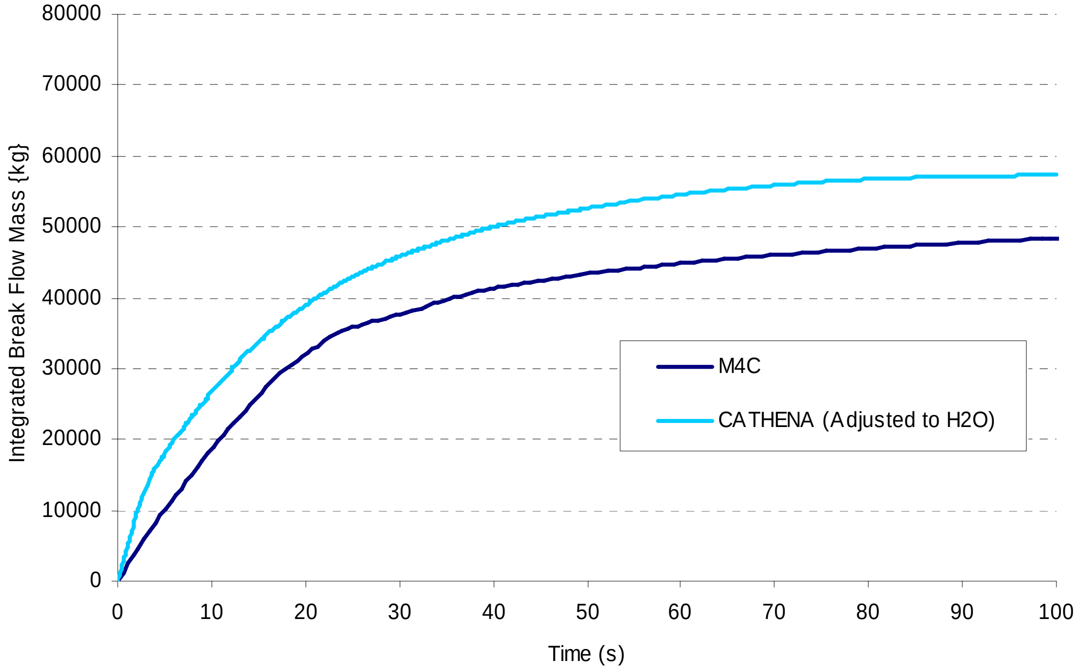

Figure 6 Integrated Break Flow During a 35% RIH Break Comparing CATHENA Mod-3.5(Rev0) with MAAP4-CANDU v4.0.5A.
MAAP4-CANDU Run 3: P_0=10.69 MPa, α_0=6.80%, α_{sep}=50%.

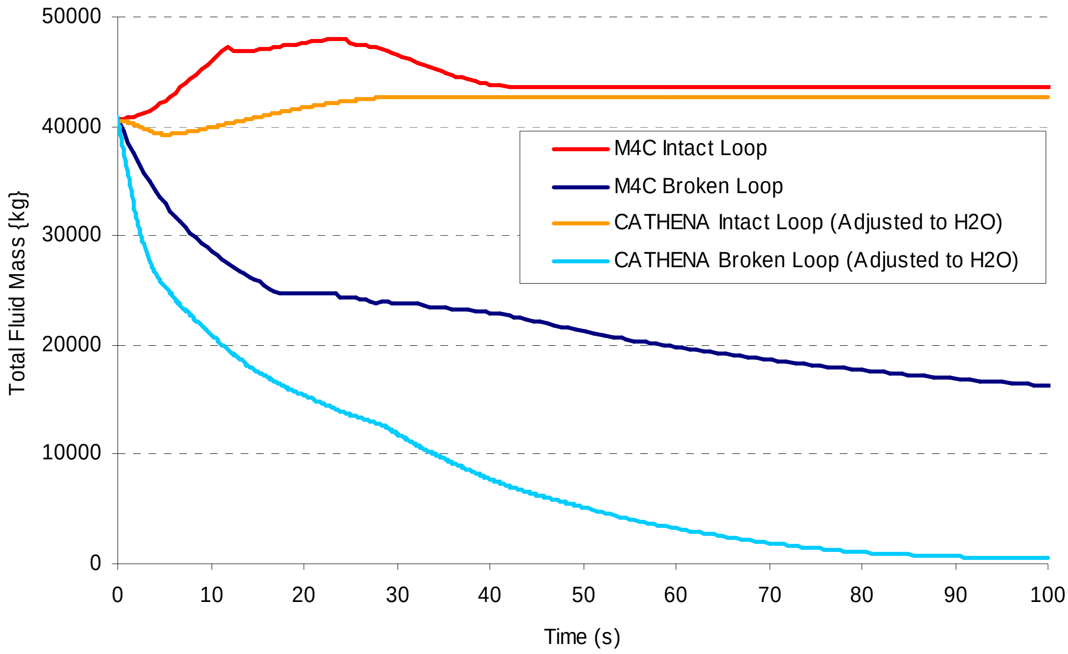

Figure 7 Loop Total Fluid Mass During a 35% RIH Break Comparing CATHENA Mod-3.5(Rev0) with MAAP4-CANDU v4.0.5A.
MAAP4-CANDU Run 3: P_0=10.69 MPa, α_0=6.80%, α_{sep}=50%.

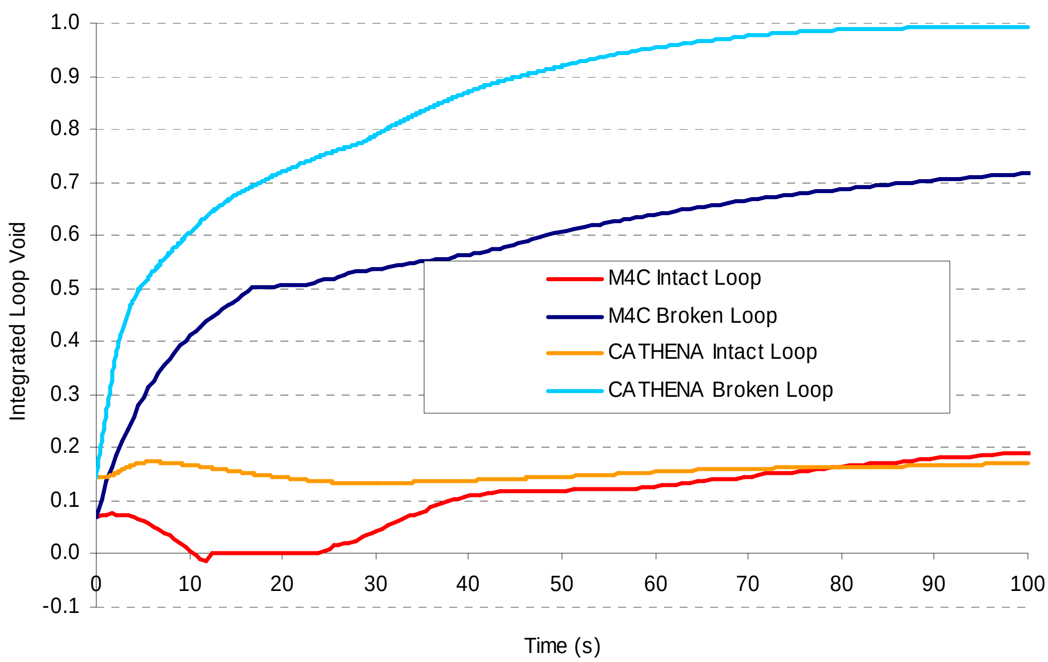

Figure 8 Integrated Loop Void Fractions During a 35% RIH Break Comparing CATHENA Mod-3.5(Rev0) with MAAP4-CANDU v4.0.5A.
MAAP4-CANDU Run 3: P_0=10.69 MPa, α_0=6.80%, α_{sep}=50%.

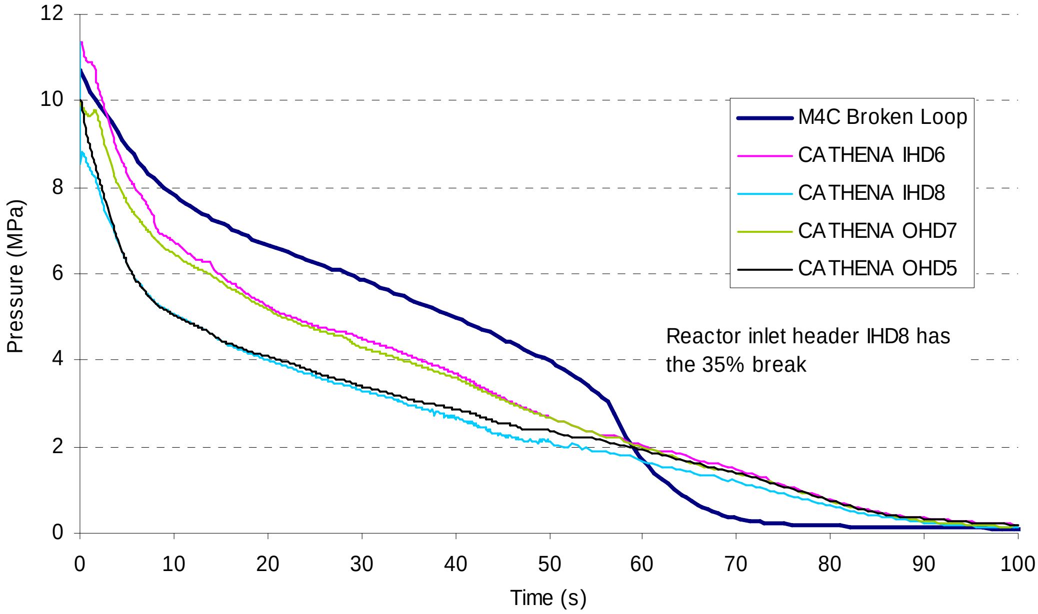

Figure 9 Broken Loop Pressure During a 35% RIH Break Comparing CATHENA Mod-3.5(Rev0) with MAAP4-CANDU v4.0.5A. MAAP4-CANDU Run 7: P_0=10.69 MPa, α_0=6.80%, α_{sep}=99%.

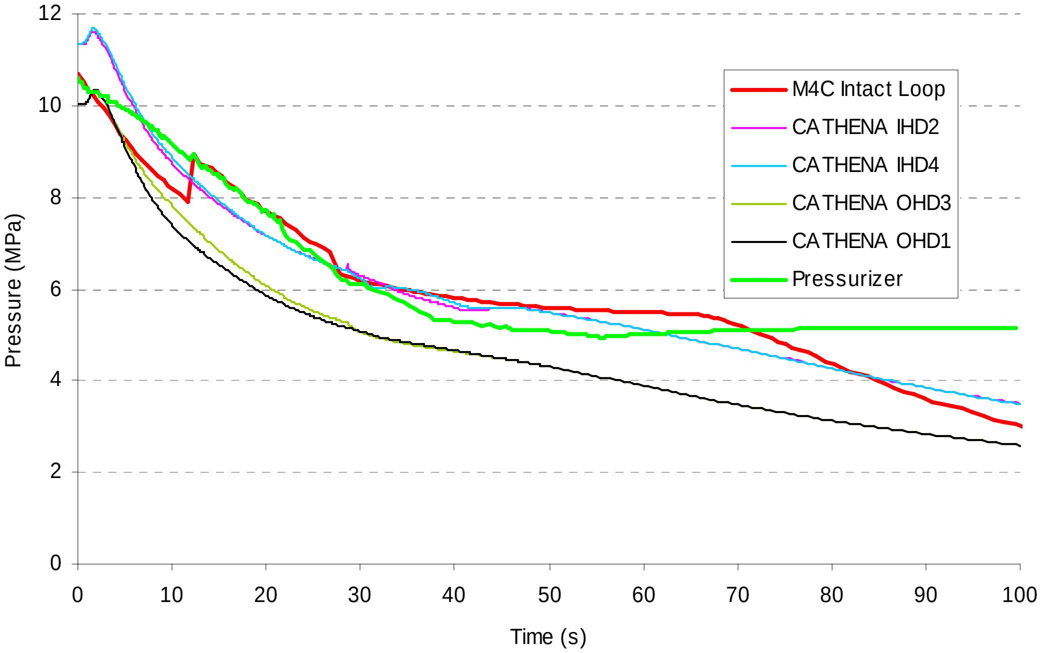

Figure 10 Intact Loop and Pressurizer Pressure During a 35% RIH Break Comparing CATHENA Mod-3.5(Rev0) with MAAP4-CANDU v4.0.5A. MAAP4-CANDU Run 7: P0=10.69 MPa, α0=6.80%, αsep=99%.

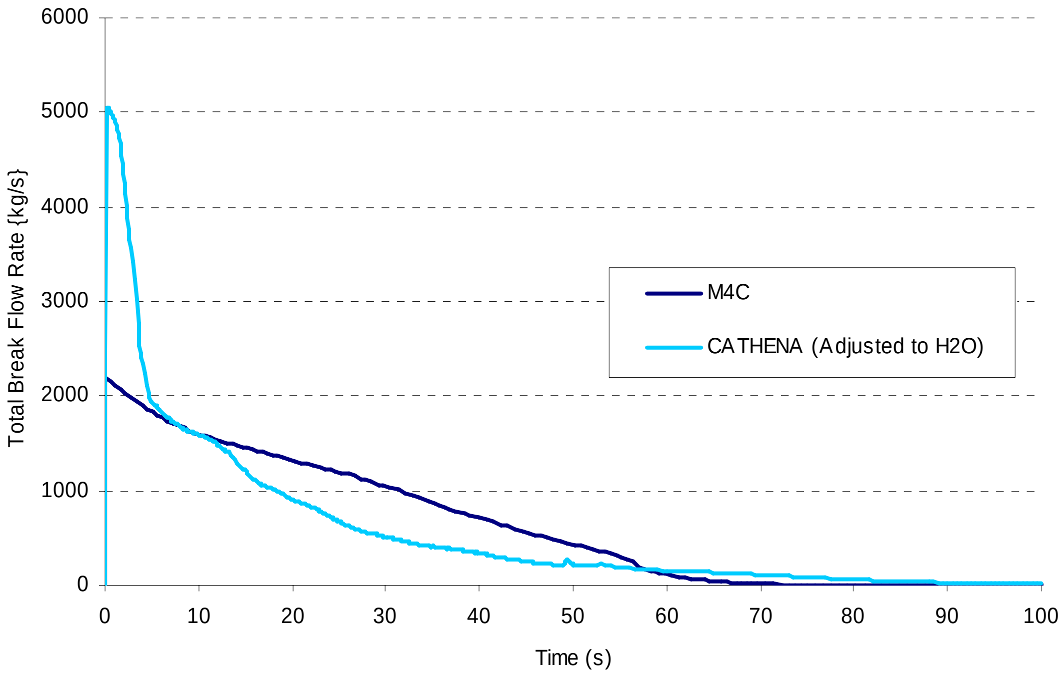

Figure 11 Total Break Flow Rate During a 35% RIH Break Comparing CATHENA Mod-3.5(Rev0) with MAAP4-CANDU v4.0.5A. MAAP4-CANDU Run 7: P0=10.69 MPa, α0=6.80%, αsep=99%.

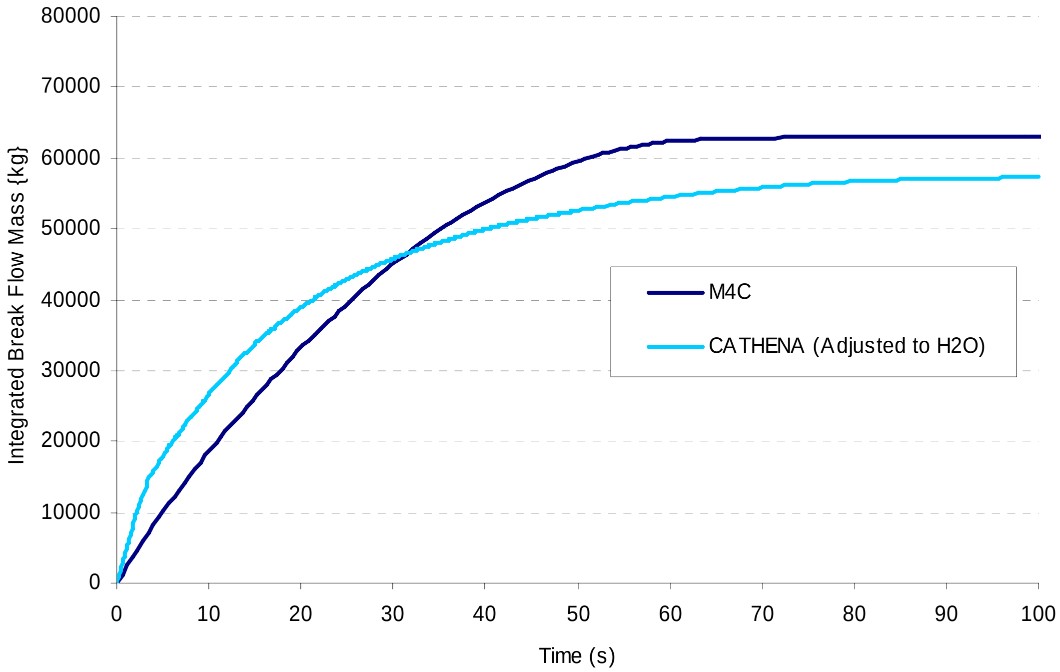

Figure 12 Integrated Break Flow During a 35% RIH Break Comparing CATHENA Mod-3.5(Rev0) with MAAP4-CANDU v4.0.5A. MAAP4-CANDU Run 7: P0=10.69 MPa, α0=6.80%, αsep=99%.

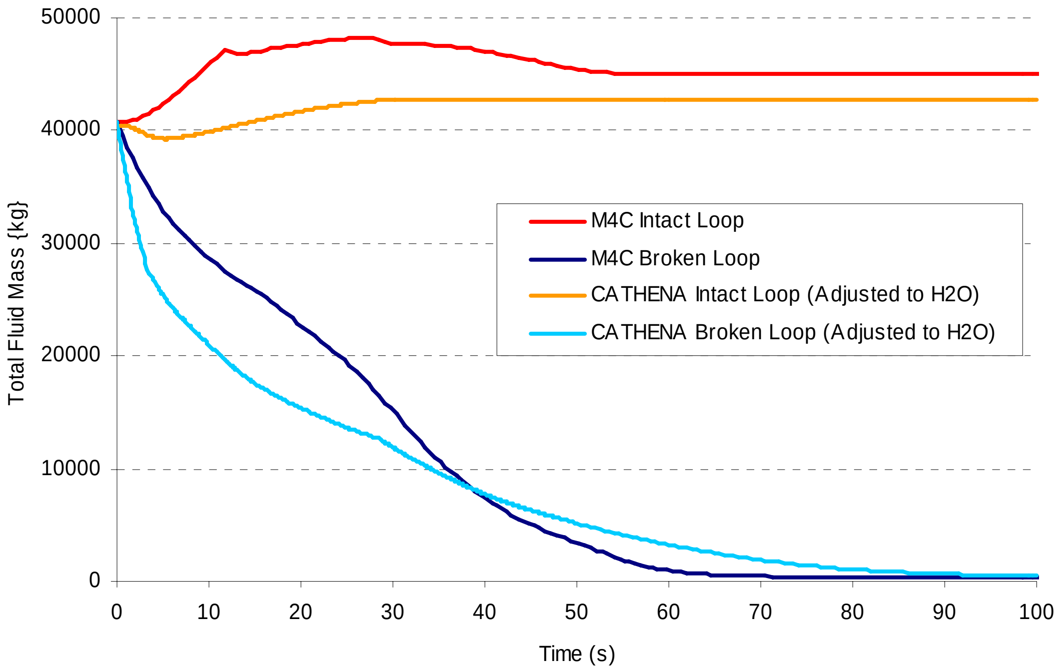

Figure 13 Loop Total Fluid Mass During a 35% RIH Break Comparing CATHENA Mod-3.5(Rev0) with MAAP4-CANDU v4.0.5A.
MAAP4-CANDU Run 7: P0=10.69 MPa, α0=6.80%, αsep=99%.

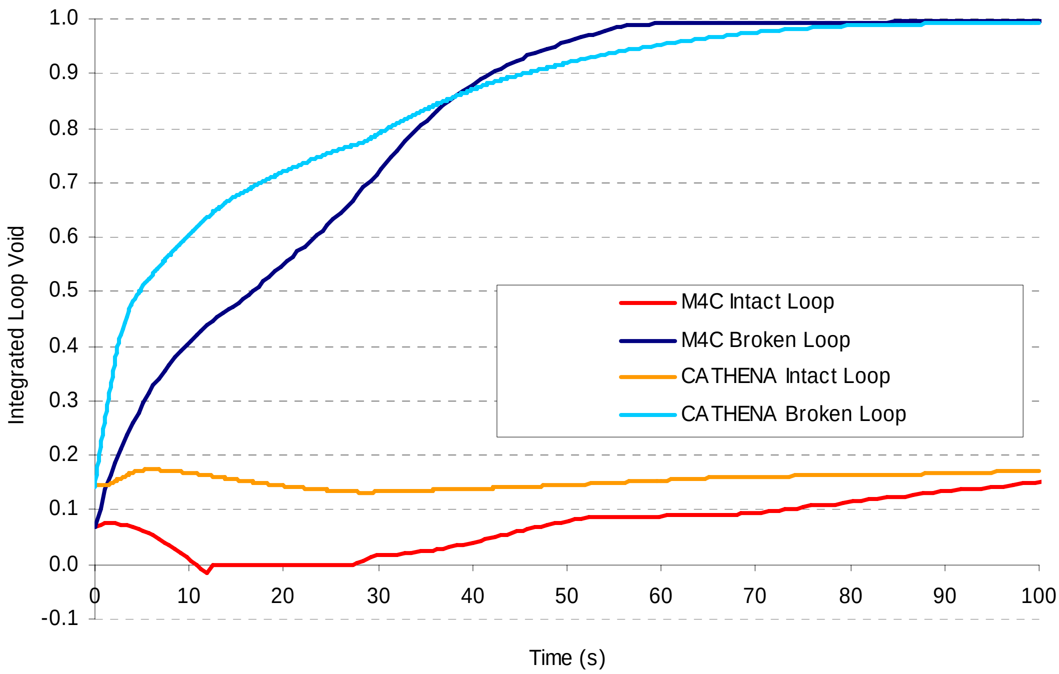

Figure 14 Integrated Loop Void Fractions During a 35% RIH Break Comparing CATHENA Mod-3.5(Rev0) with MAAP4-CANDU v4.0.5A.
MAAP4-CANDU Run 7: P0=10.69 MPa, α0=6.80%, αsep=99%.

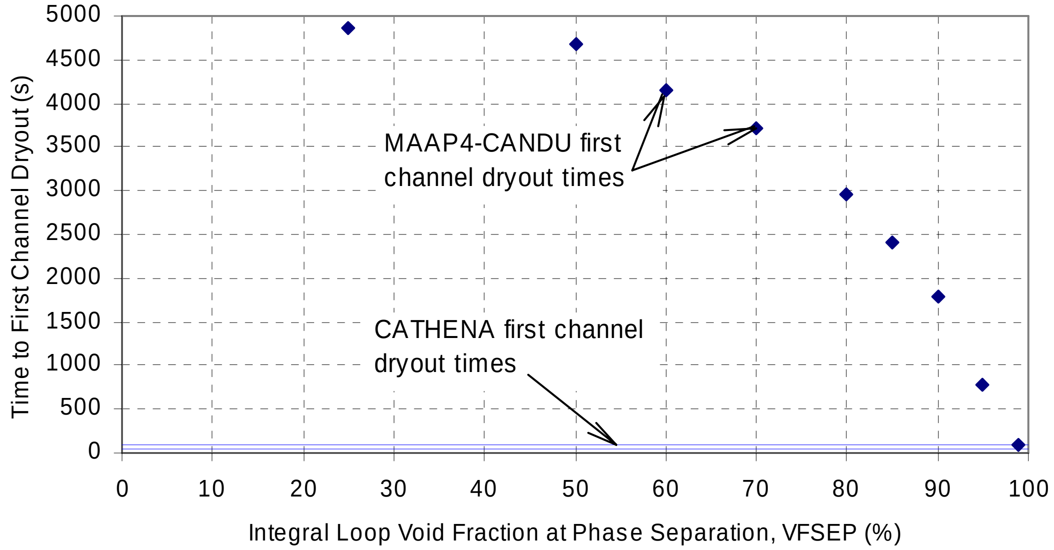

Figure 15 Time of First Channel Dryout Using MAAP4-CANDU, During a 35% RIH Break LOCA+LOECC in a CANDU 6, as a Function of Input Parameter VFSEP (α_{sep}). Initial Pressure of 10.69 MPa and Initial PHTS Loop Void Fraction of 6.80%.