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

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Introduction

- MAAP (Modular Accident Analysis Program) is an integrated computer code designed for Severe Accident Analysis in nuclear plants. MAAP developed by Fauske & Associates Inc. (FAI), used by 40+ international PWR / BWR utilities.
- MAAP is owned by EPRI
- MAAP4-CANDU, based on MAAP4-PWR / BWR, developed by FAI / OPG / AECL
- MAAP4-CANDU used for for assessing severe core damage accident progression and severe accident management in CANDU plants.
- The main distinguishing features of MAAP4-CANDU are models of the horizontal CANDU-type fuel channels and CANDU-specific systems such as calandria vessel, PHTS, containment systems: dousing spray, local air coolers, etc.
- MAAP4-CANDU contains CANDU core module developed by Ontario Power Generation (OPG) / AECL.

Introduction (cont'd)

- **Objective:**
  - The comparison is between results obtained with two independent CANDU 6 models using computer codes MAAP4-CANDU v4.0.5A and CATHENA Mod 3.5 Rev0
  - 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.
  - To compare the timing of channel dry-out between MAAP4-CANDU and a qualified deterministic thermalhydraulic code like CATHENA.
  - To 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.

Background

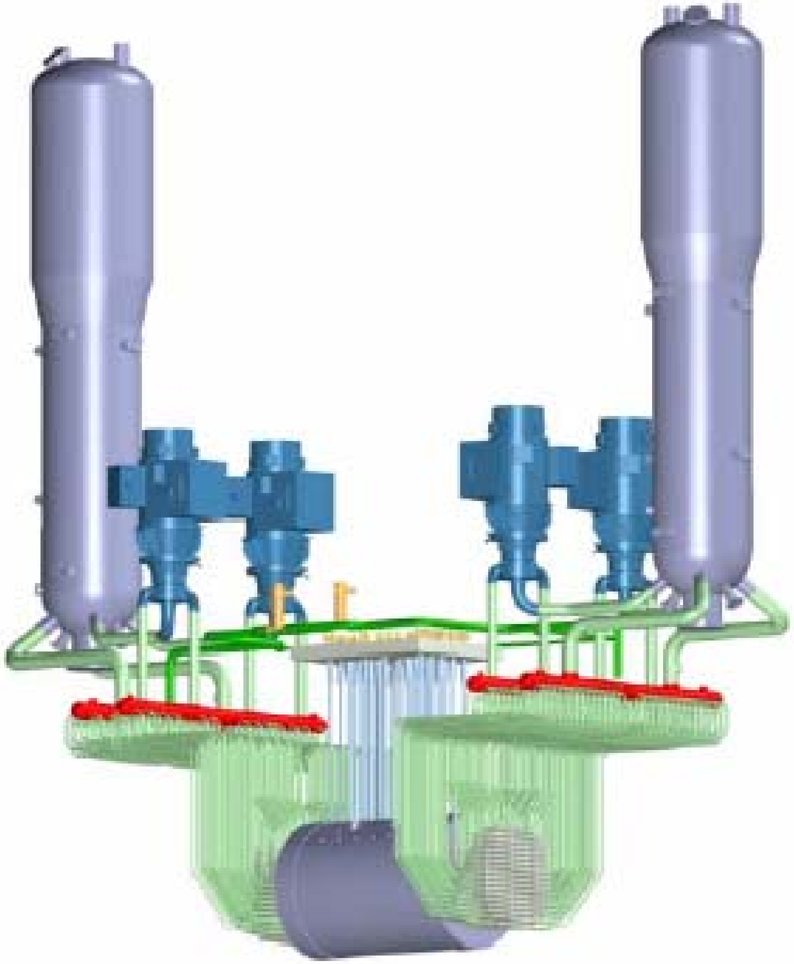
- MAAP4-CANDU models the PHTS with a coarse nodalization and simple models, such as a common pressure for the entire PHTS loop, the same thermodynamic conditions for each coolant phase, and an absence of momentum equation.
- CATHENA is a sophisticated two-fluid code, with thermodynamic conditions calculated for each phase at each PHTS node.
- 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 provides confidence in the use of MAAP4-CANDU for the thermalhydraulic phenomena involved in a LLOCA blow-down.

Background: MAAP4-CANDU Capabilities

Physical Processes Modeled in M4C

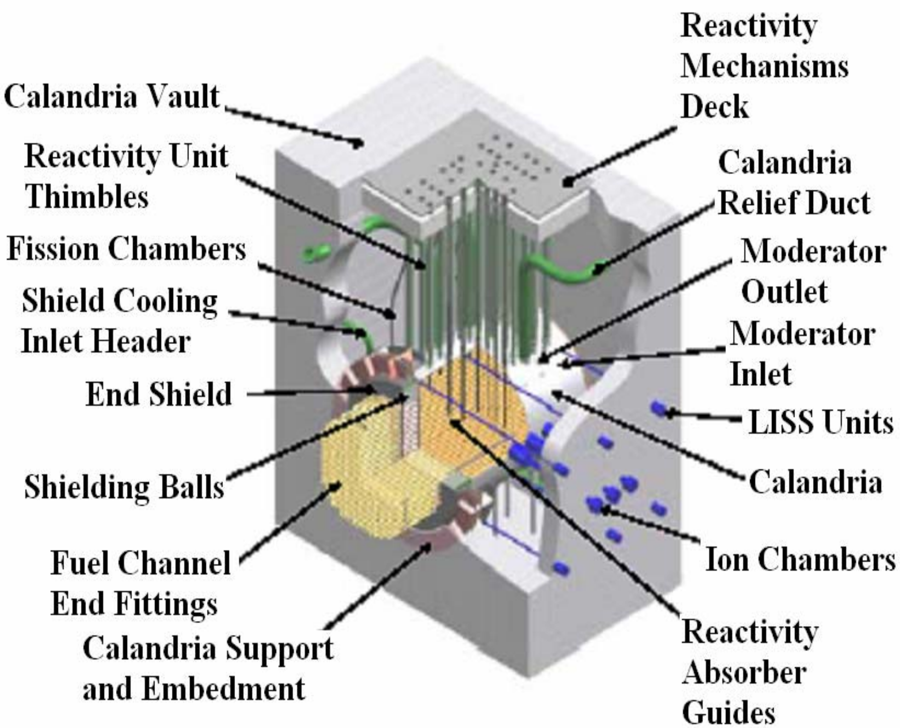
- Thermalhydraulic processes in: primary system, calandria vessel, reactor vault, end-shield, containment
- Core heat-up, melting and disassembly
- Zr oxidation by steam and hydrogen generation
- Material creep and possible rupture of pressure and calandria tubes, calandria vessel and shield tank walls, ignition of combustible gases, energetic corium-coolant interactions
- Molten corium-concrete interaction
- Fission product release, transport and deposition

CANDU Plant Primary System Layout (ACR-700)



	CANDU 6	ACR-700
RCS Loops	2	1
RCS Pumps	4	4
Steam Generators	4	2
React. Inlet Headers	4	2
React. Outlet Headers	4	2
Fuel Channels	380	292

CANDU Reactor Assembly



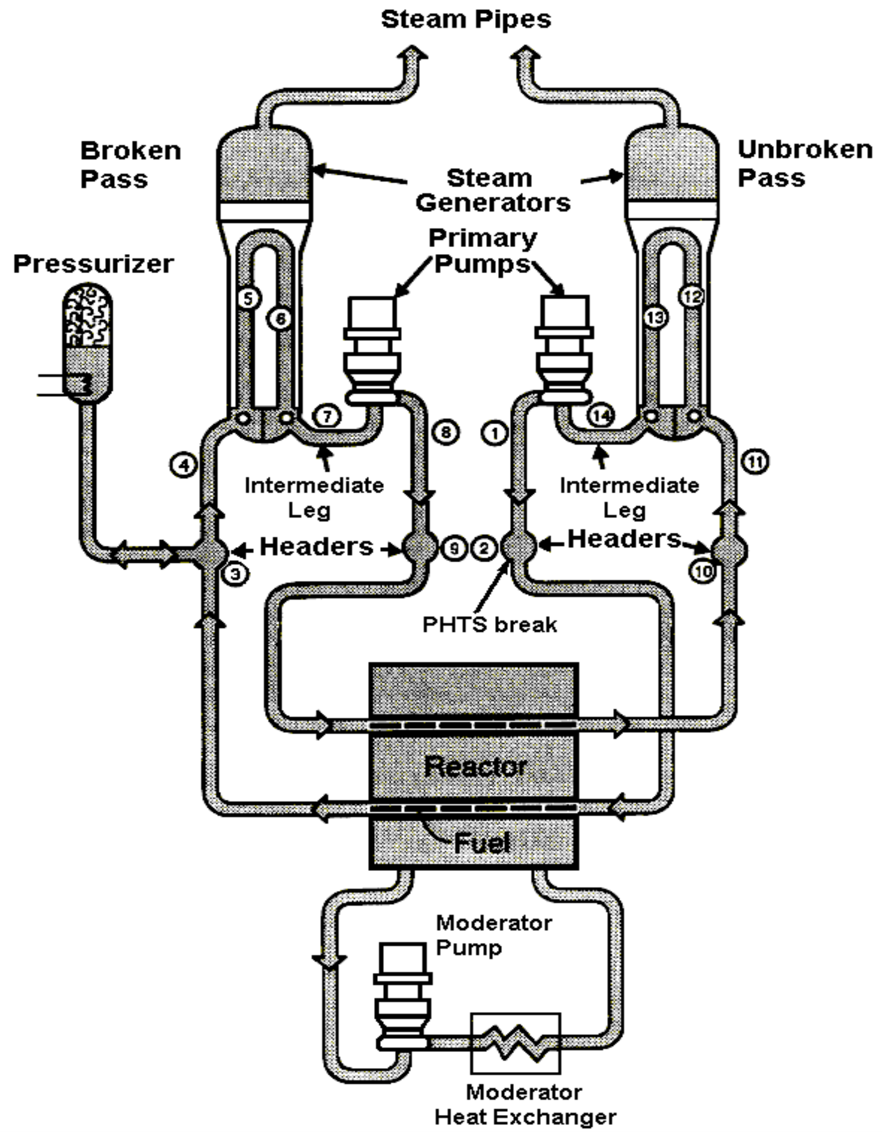
- **CANDU 6: 380 fuel channels**
  Water Inventory:
  D_2O in RCS: ~95 Mg
  H_2O in RV: ~465 Mg
  D_2O in CV: ~227 Mg
  Dous. Tank: ~2500 Mg

- **Severe Core Damage progression in CANDU is generally slow**

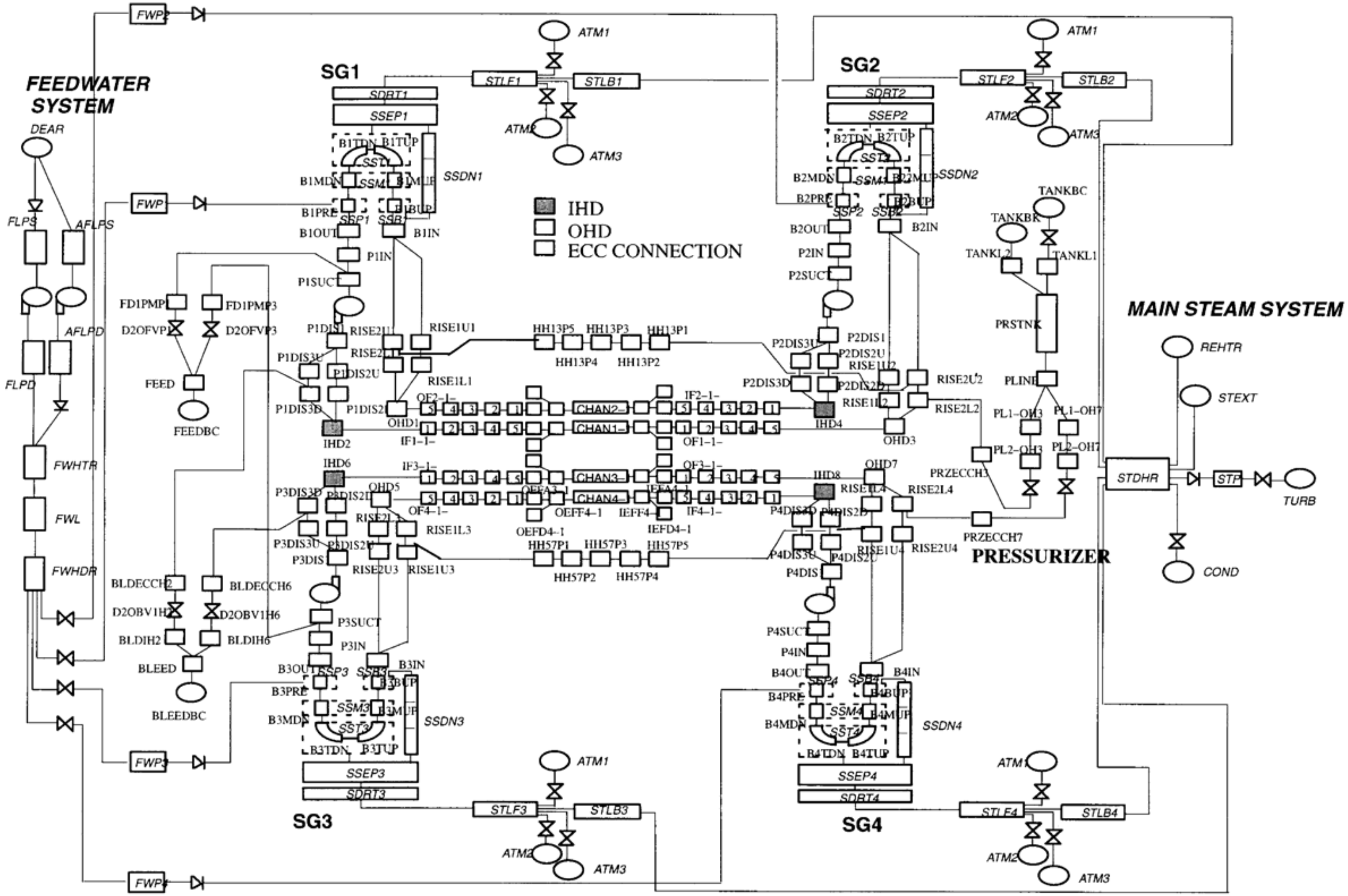
Nodalization of CANDU 6 Station

- PHTS
  - Two symmetric loops, each following "figure of 8"; 14 nodes in each loop: ROH, RIH, SG inlet piping, etc.
- Steam generator
  - Primary side modelled as 2 nodes ("hot" and "cold")
    Secondary side modelled as 1 node
- Core
  - 380 fuel channels arranged in 22 rows and 22 columns, represented by 6 vertical nodes, 18 characteristic channels per PHTS loop
  - 3 power groups of channels in each vertical core node
  - 12 fuel bundles represented by 12 axial nodes
  - 37 fuel elements, pressure and calandria tube modelled as 9 concentric rings
- Generalized Containment Model
  - Compartments represented by 13 nodes connected by 31 flow junctions
  - Containment walls modeled as 90 "heat sinks"

Nodalization of CANDU 6 PHTS-MAAP4-CANDU



Nodalization of CANDU 6 PHTS: CATHENA



Analysis Assumptions for LLOCA

- Large LOCA is initiated by a guillotine rupture of the reactor inlet header (RIH) in loop 1 followed by a double-sided blow-down of the PHTS coolant. Break area was assumed 35% of twice cross sectional area of RIH.
- Reactor shutdown immediately after accident initiation.
- Emergency Core Cooling System (ECCS): high pressure injection (HPI) and medium pressure injection (MPI), low pressure injection (LPI) are all unavailable.
- Shield and shutdown cooling unavailable.
- Moderator cooling system available.
- Main and auxiliary feedwater unavailable.
- Main turbine stop valves closed after accident initiation.
- Class IV power available.
- Crash cool-down system available.
- No operator interventions credited.

Results and Discussion

Sequence of Significant Events for Large LOCA (CATHENA run):

• ROH (loop1) two-sided break	0 s
• Reactor shutdown ………………...........………………	0.43 s
• PHTS loop isolation begins ……………........……………	8.6 s
• PHTS loop isolation completed ……………........………	29 s
• Crash cool-down begins …………………………........……	38.7 s
• Main turbine stop valves closed ………………….........	40.0 s
• PHTS pumps tripped ………………….…………….....	176 s

Results and Discussion (cont-d)

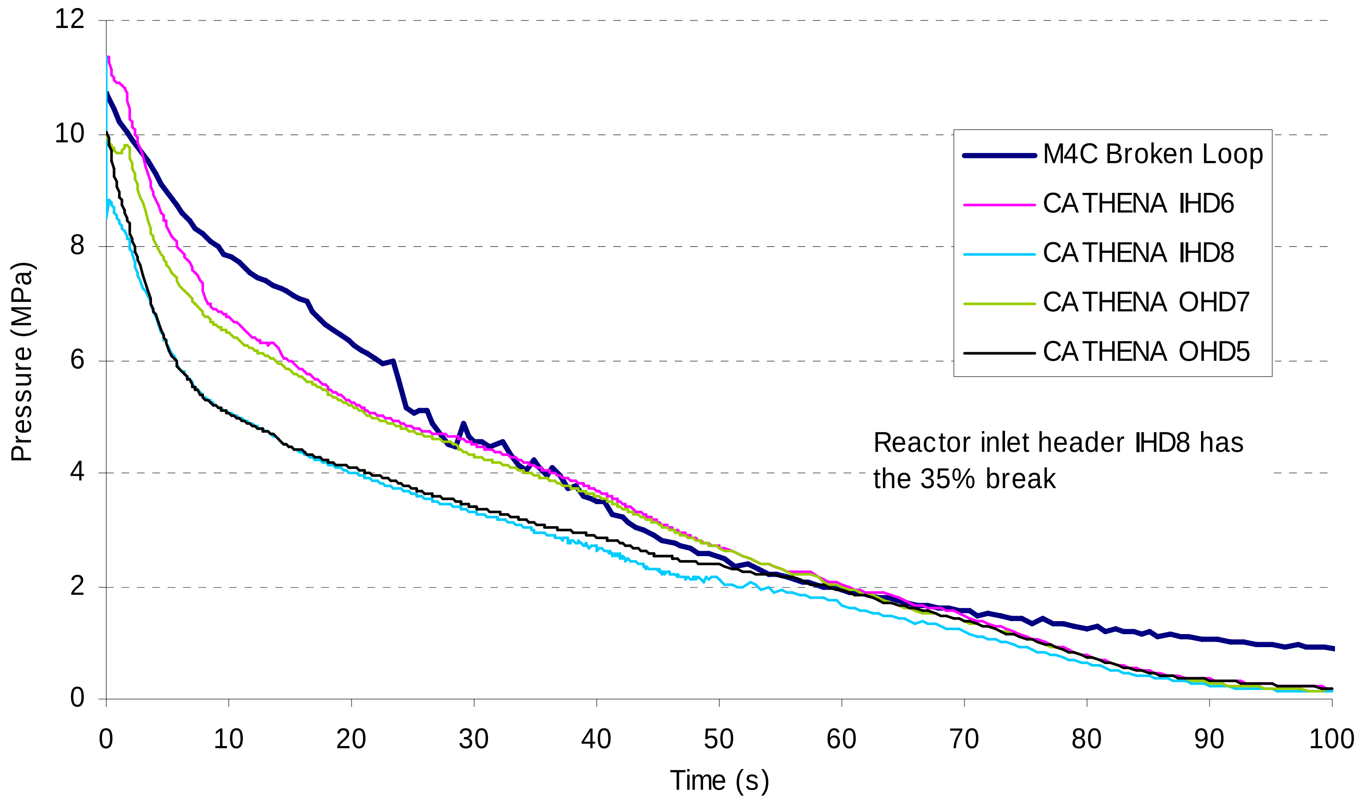
- Effort was made to match the MAAP4-CANDU PHTS component volumes with those of the CATHENA model;
- For the MAAP4-CANDU simulation, the initial PHTS loop coolant mass was equal to that of the CATHENA simulation (*i.e.*, the heavy water + heavy steam mass divided by 1.103).
- The value of 1.103 is the density ratio of liquid heavy water to liquid light water at typical CANDU operating conditions.
- Total of 15 runs performed using MAAP4-CANDU
- Major Initial Parameters changed for these runs:

  -Initial Loop Void Fraction VFPS0 (%);

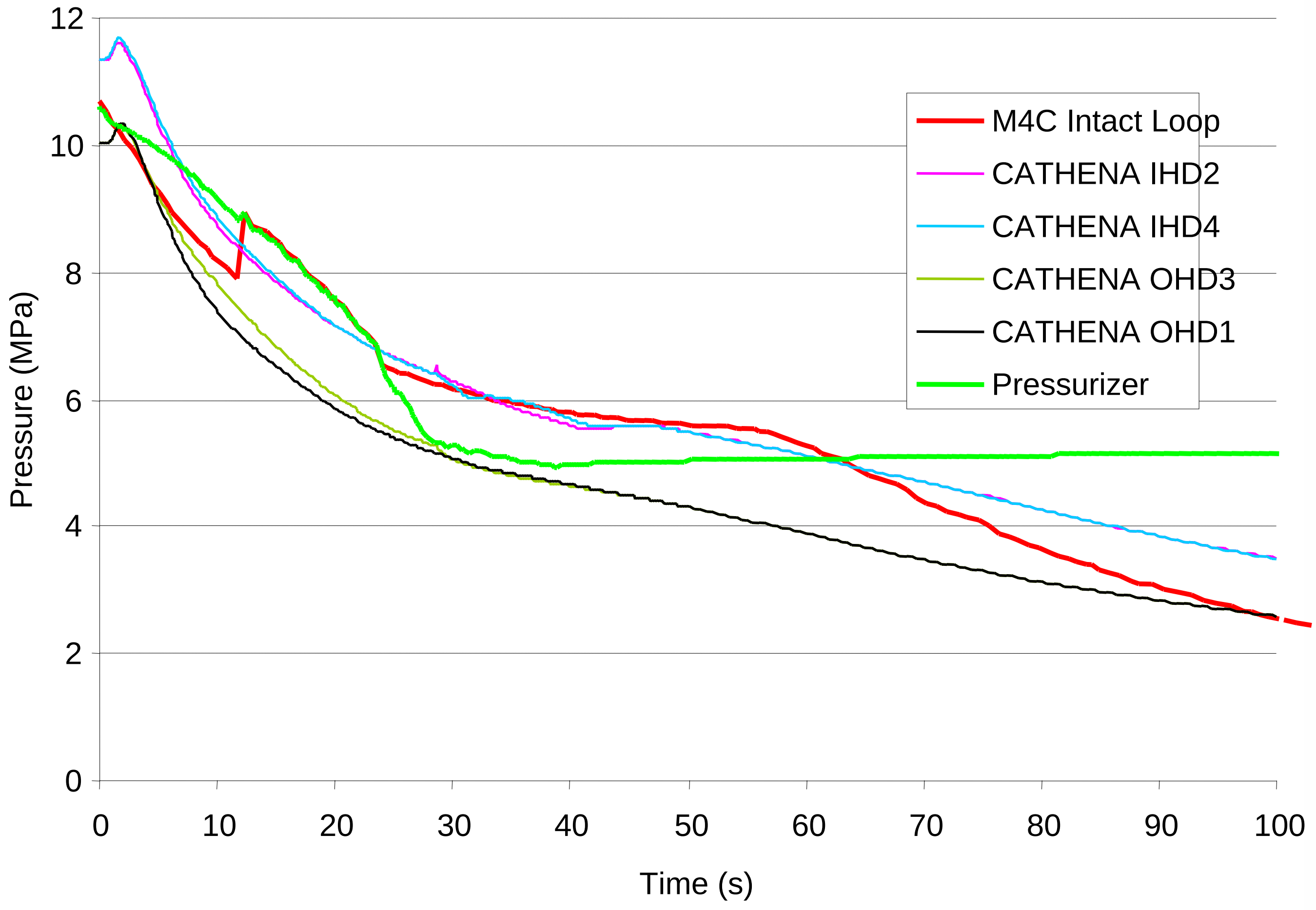
  -Initial Loop Pressure PPS0;

  -Void Fraction at Phase Separation VFSEP (%);
- Following Runs are discussed further:
- Base Case Run (α_{sep} =0.5)
- Run to study the Effect of Void Fraction, at which phases separate (α_{sep} =0.99).

Results and Discussion: PHTS Response (Broken Loop), α_{sep}=50%



Results and Discussion: PHTS Response (Intact Loop), α_{sep}=50%



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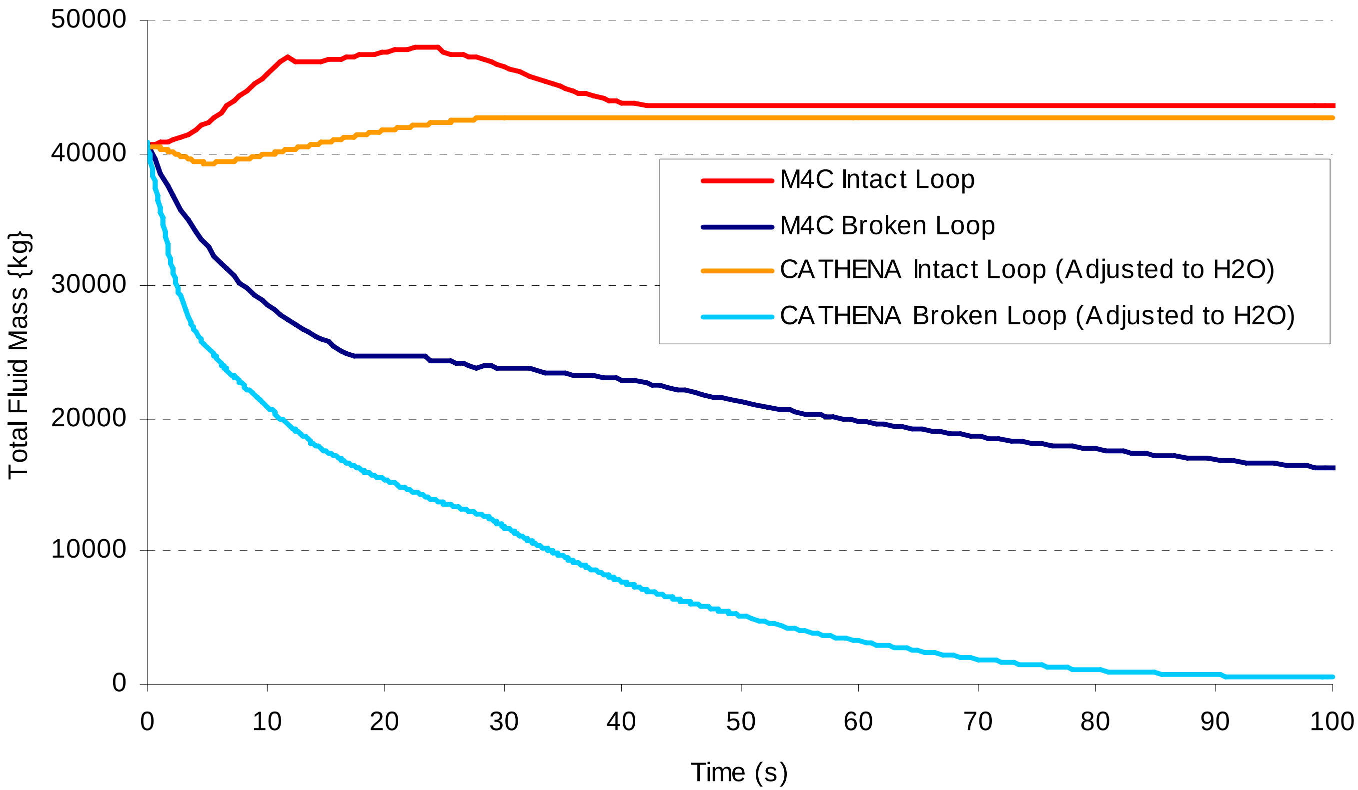

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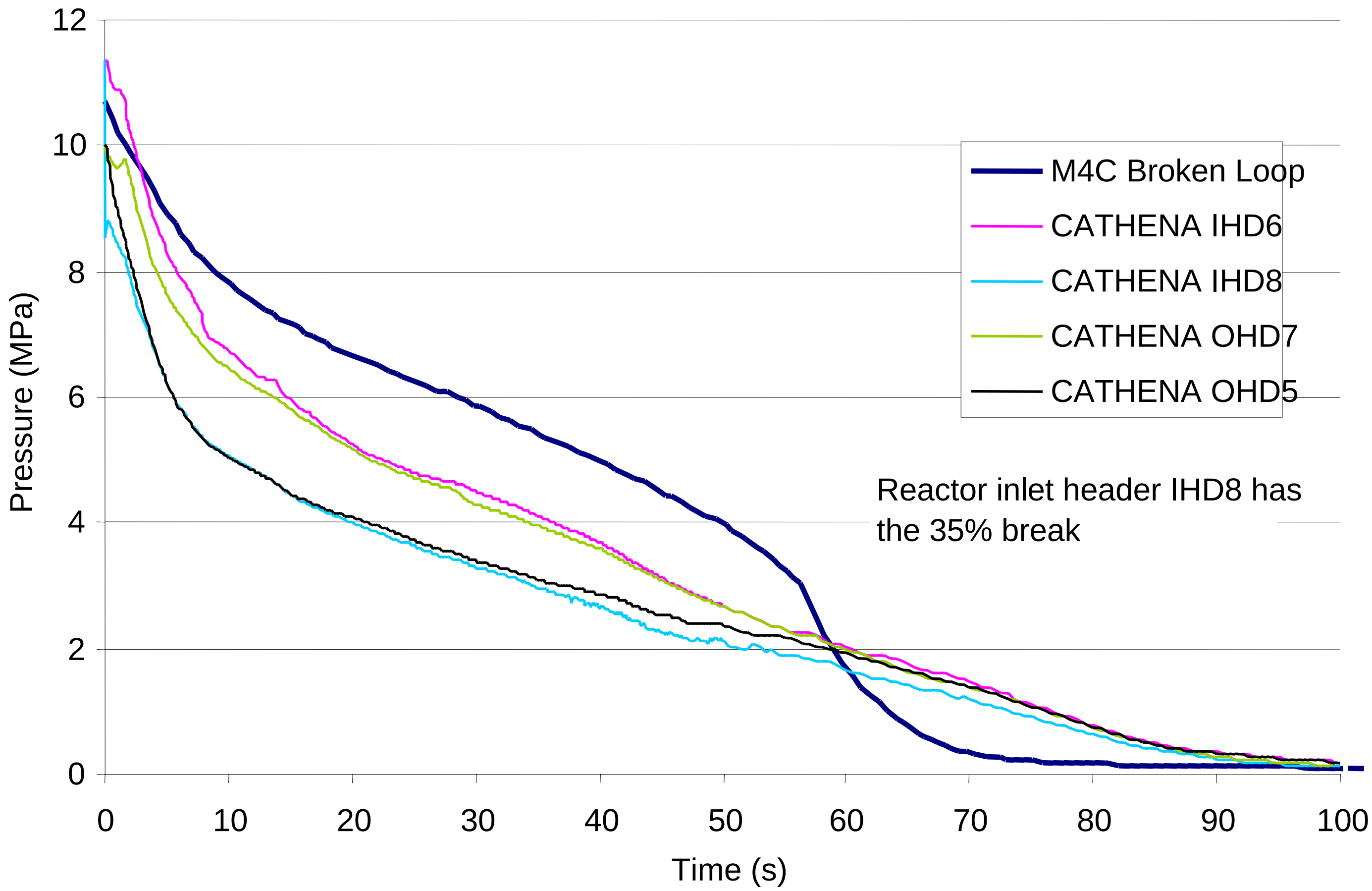

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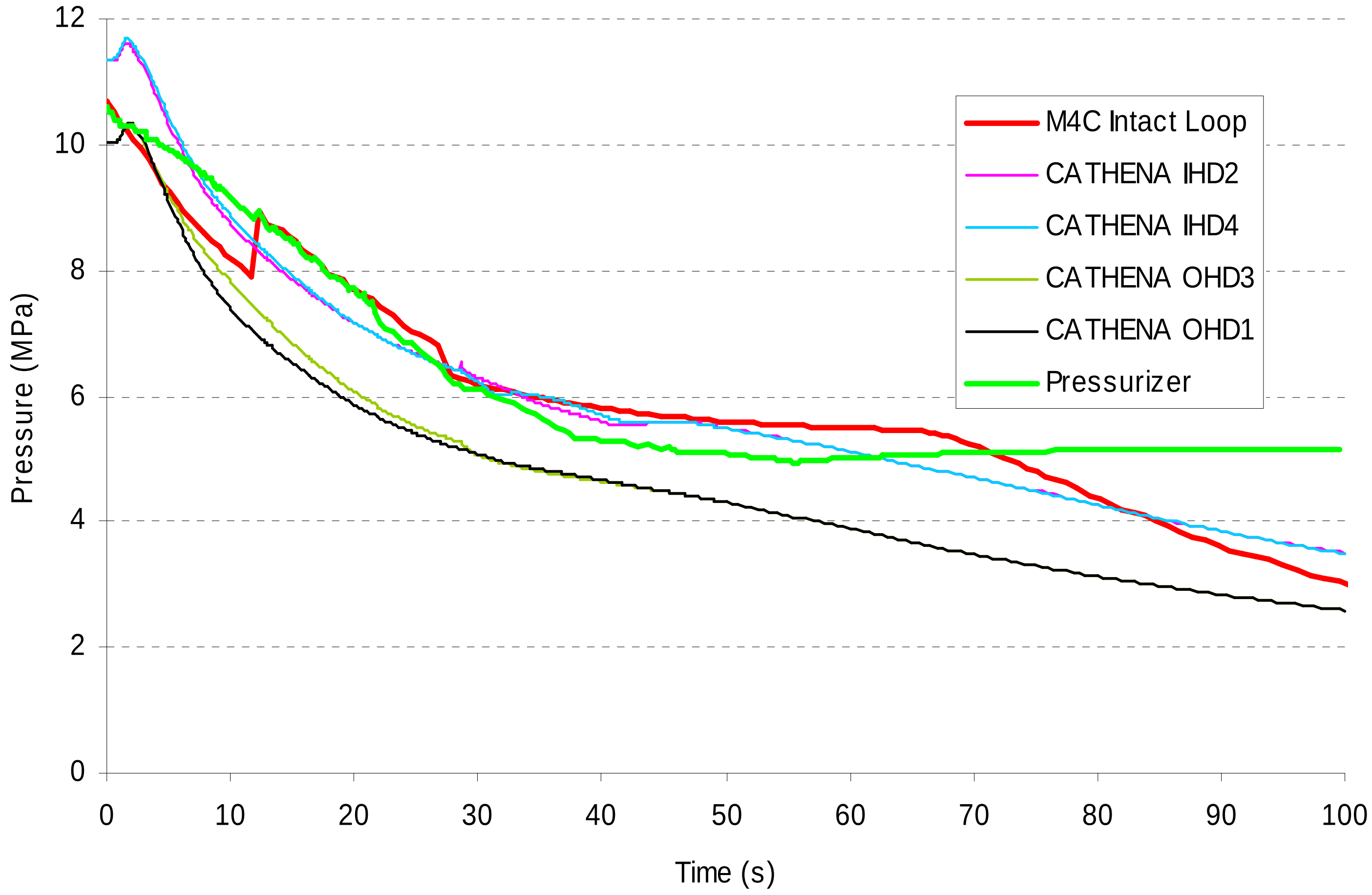
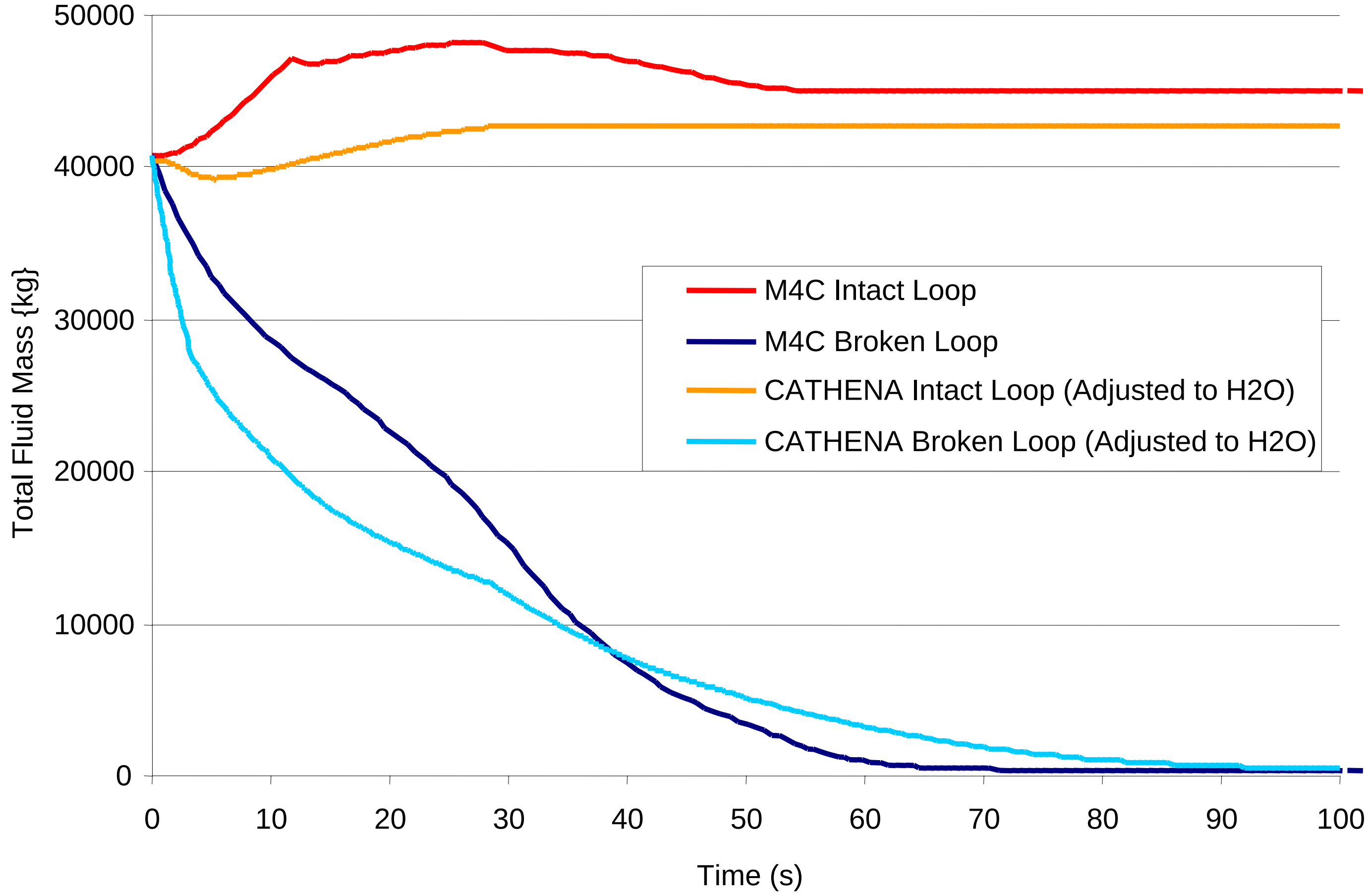
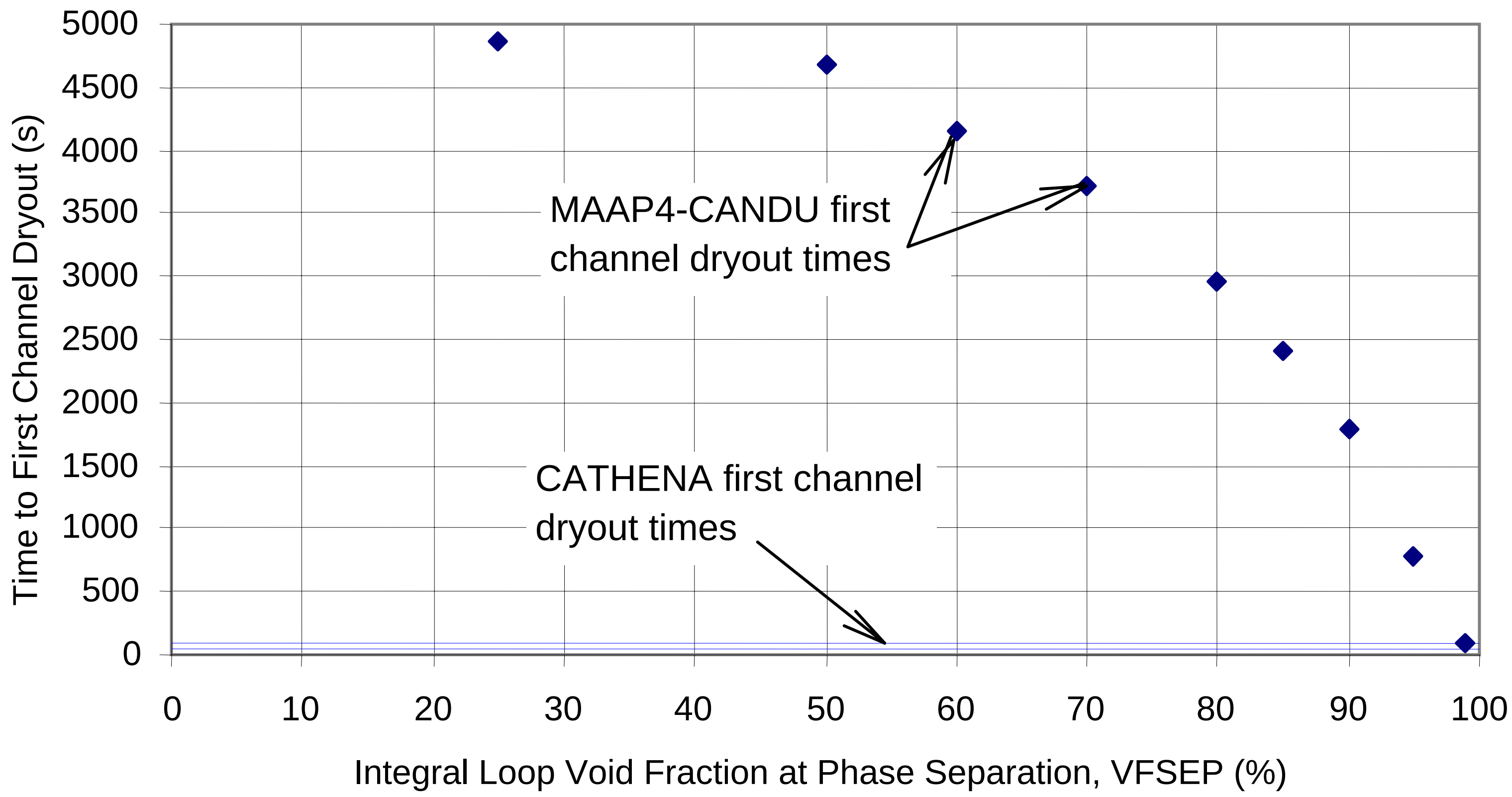


Results and Discussion: PHTS Response

α_{sep}=99%



Time of First Channel Dry-out as a Function of Input Parameter αsep



SUMMARY

- MAAP4-CANDU performs in a similar fashion to the rigorous models and detailed nodalization of the CATHENA code.
- MAAP4-CANDU uses light water properties, which posed some difficulties in comparing the results to the CATHENA simulation, which used heavy water.
- The PHTS loop void fraction at phase separation 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.
- 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.

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