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Simulation of Crash Cooling during SBO Transient in CANDU-6 Plants

KINS is a Cornerstone for a Safe Korea

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Contents

Introduction

Background

- This paper is the extension of one presented at KNS 2020 spring meeting;
  - Simulation of SBO in CANDU-6 using MARS-KS Code (Paper #: 20S-342), 2020 KNS Spring Meeting, Jeju (On-line)

- Crash cooling, one of the operator's measures to mitigate accidents
  - by mechanically fixing the main steam safety valves (MSSVs) in an open state according to the emergency operating procedure.
  - Positive effect of delaying the deterioration of heat removal from the shell side of steam generators (SGs) by abruptly reducing the SGs' pressure, but also
  - Negative effect of depleting the SG inventory more quickly.

Introduction

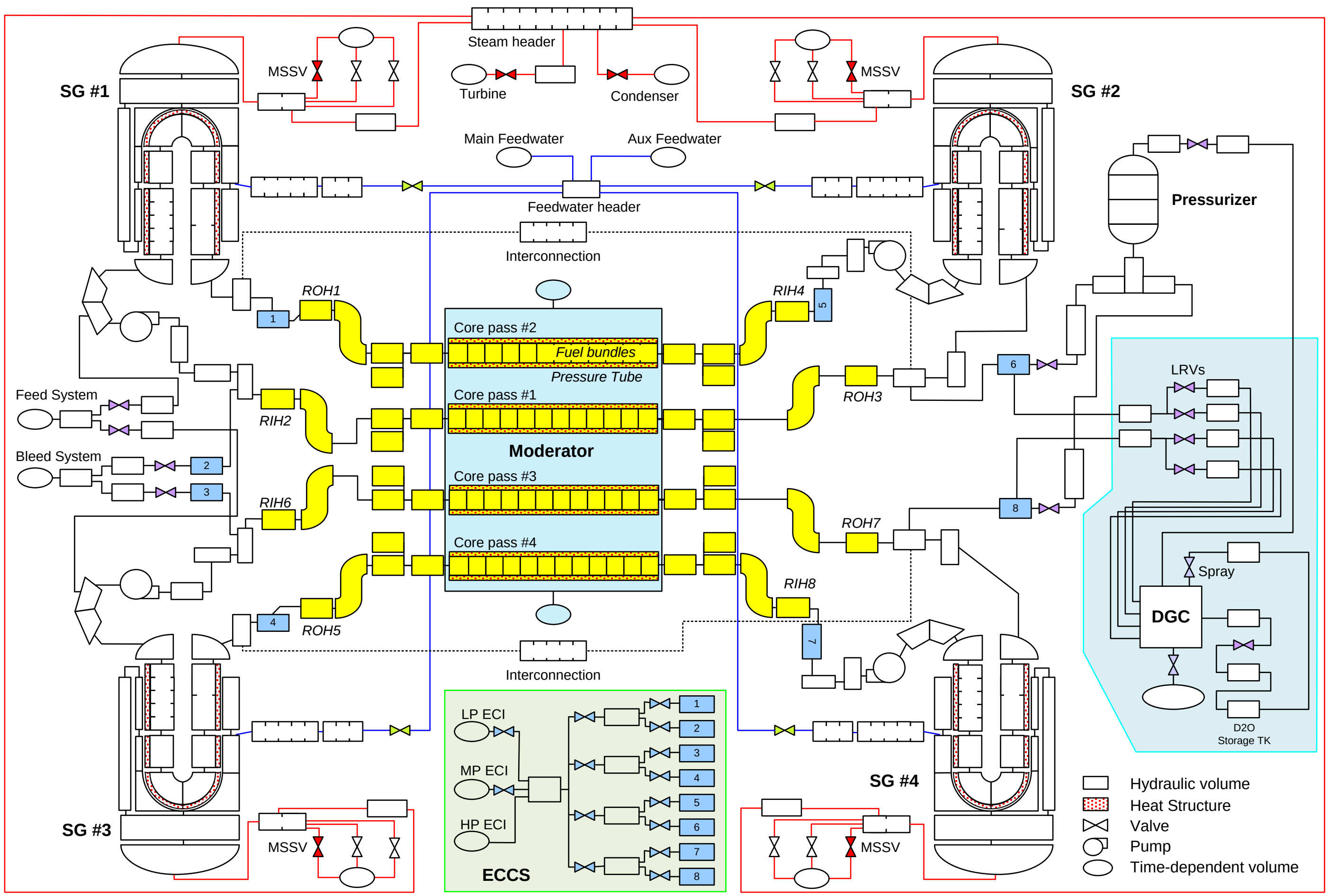
Objectives

- This study aims to investigate the effect of the crash cooling on the system behavior in the same transient condition of CANDU-6 plants.

- For this purpose,
  - the complete loss of AC power or station blackout (SBO) has been selected as a target accident scenario and,
  - previous input model has been modified so as to simulate the crash cooling with the regulatory audit code (MARS-KS).

Code Modelling

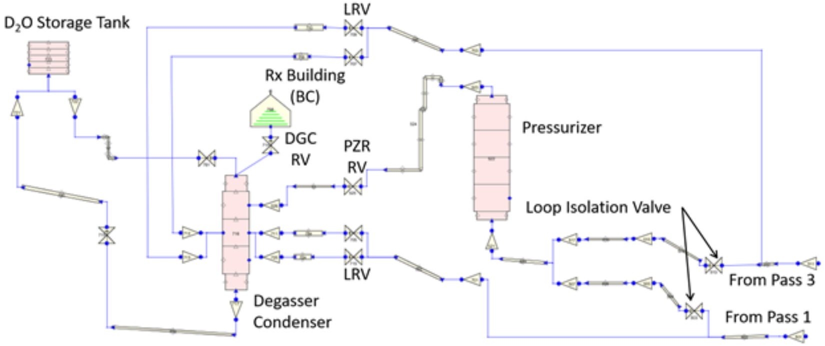
Nodalization for Event Simulation



Code Modelling

Nodalization for Event Simulation

- Primary Heat Transport System



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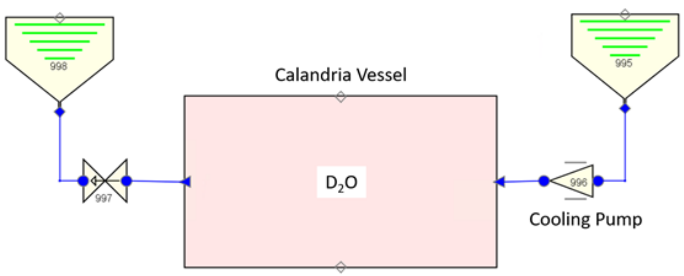
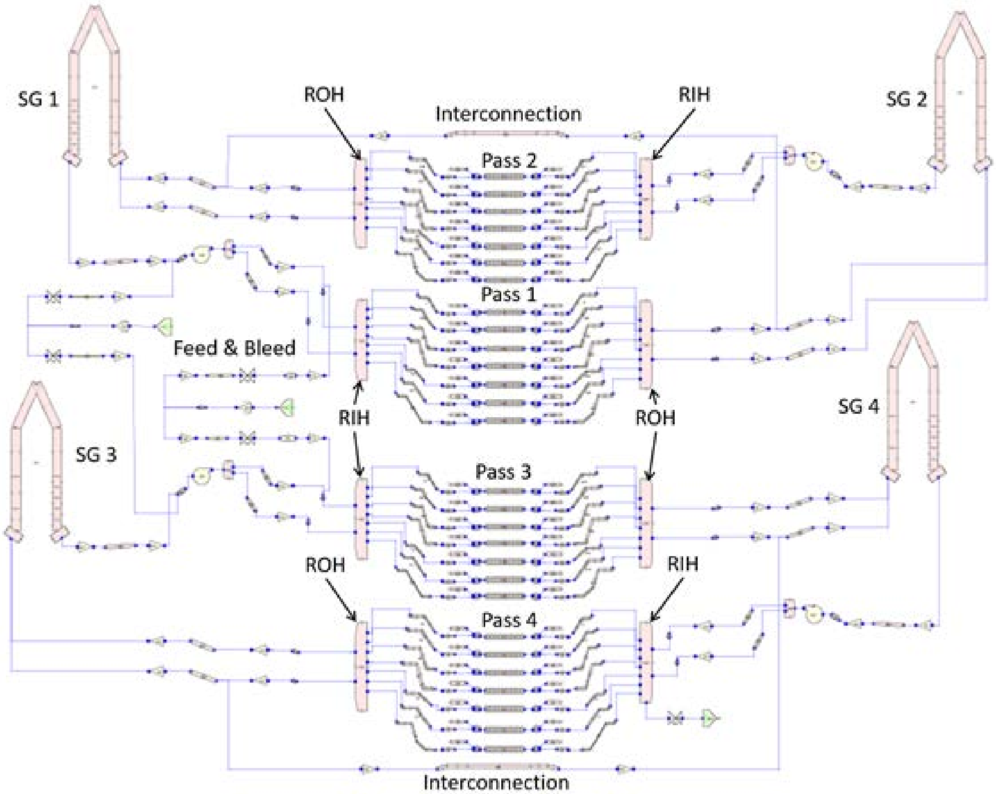


Moderator System



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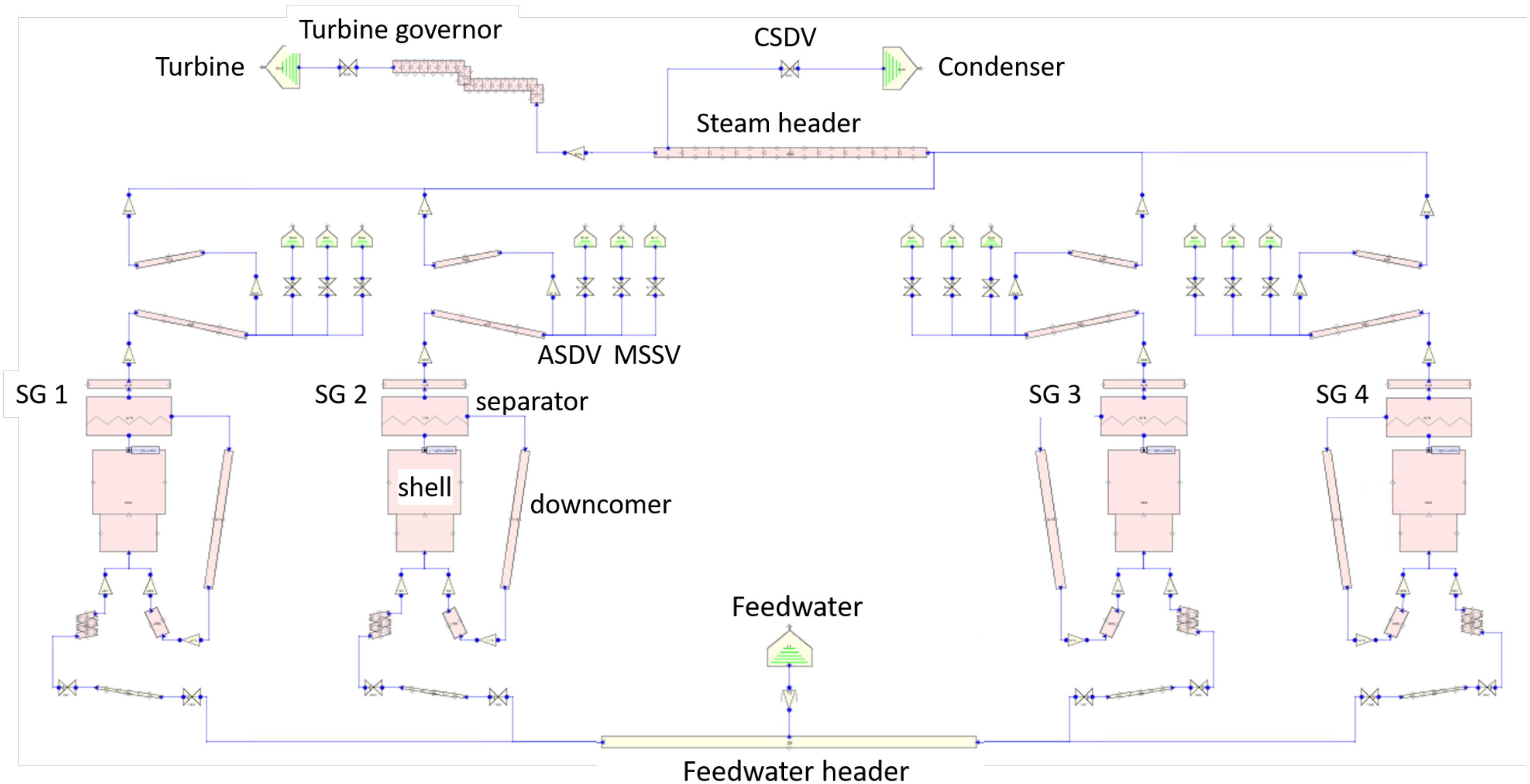
Code Modelling

Nodalization for Event Simulation

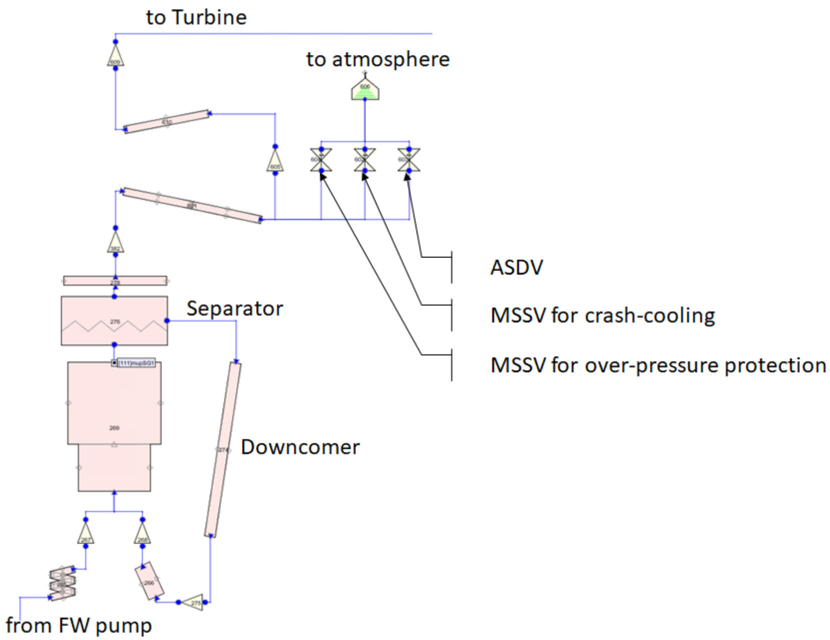
- Secondary Heat Transport System



Code Modelling

Modelling of MSSVs

- MSSVs (4 per SG) has two functions
  - Overpressure protection for the main steam system
  - Rapid cooling through SGs
- MSSVs modelled separately in this study,
  - 8 / 16 MSSVs for overpressure protection
  - 7 / 16 MSSVs for crash cooling
- Because the available number of MSSVs was different depending on the function,
  - two valves with different flow areas were modelled to avoid operating at the same time.



Code Modelling

Modelling of MSSVs

	Function of MSSV	
	Over-pressure protection	Crash-cooling
Opening set-point	5.11~5.24MPa(a)	manual
# of available valves on simulation	8	7

Results and Discussion

Calculation Results of Normal Power Operation

- Steady state condition with 103% FP has been achieved by running for a long period to check for oscillations.
  - Major TH parameters predict the target values (FSAR) with stableness
  - Model parameters at the end of the calculation have been restored as the initial conditions for next transient calculations.

	MARS-KS ver.1.5	Target Value (FSAR)	diff., [%]	Criteria
Reactor power, [%]	103	103	0.00	
Pressure of RIH/ROH, [MPa(a)]	11.42/10.00	11.42/10.0	0.00/0.00	TV±0.103 MPa
Temperature of RIH/ROH, [K]	541.15/583.44	541.15/583.15	0.0/0.05	TV±2 K
Quality of ROH, [%]	4.9	4.9	0.0	
Level of Pressurizer, [m]	12.48	12.48	0.00	TV±0.25 m
Coolant Flowrate per pass, [kg/s]	1,903.10	1,903	0.01	TV±5%
Steam Flowrate to Turbine, [kg/s]	1,067.72	1,063	0.44	TV±5%
Steam Temp. of SGs, [K]	534.76	533.15	0.30	
Pressure of SGs, [MPa(a)]	4.82	4.7	2.55	TV±0.103 MPa

Results and Discussion

Calculation Results of Normal Power Operation

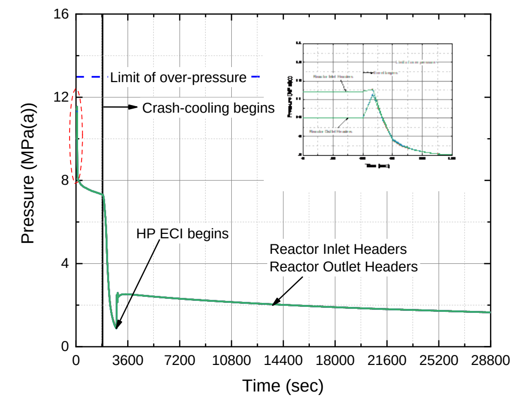
- Initial and operational conditions of major components

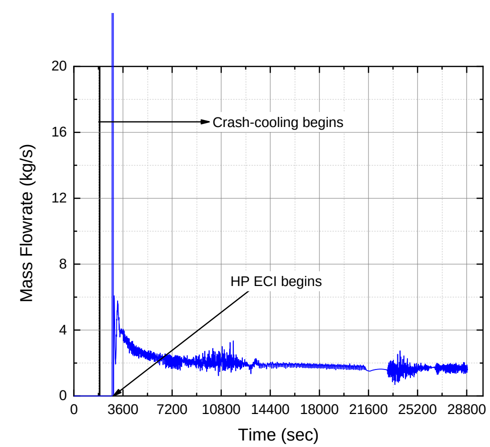
<table>
<tr><th></th><th>Steady</th><th>Transient</th><th colspan="2"></th><th>Steady</th><th>Transient</th></tr>
<tr><td>Reactor</td><td>103%</td><td>~ 2.2%</td><td colspan="2">Turbine Governor Valve or Emergency Stop Valve (ESV)</td><td>opened</td><td>closed</td></tr>
<tr><td>PHTS pumps, Moderator cooling circulation pump, Feedwater pump</td><td>operable</td><td>tripped</td><td rowspan="2">MSSV</td><td>over-pressure protection</td><td rowspan="2">operable</td><td>operable</td></tr>
<tr><td>Coolant Isolation Valve</td><td>opened</td><td>closed by LOCA signal</td><td>crash-cooling</td><td>manual open</td></tr>
<tr><td>PZR Relief Valve</td><td>closed</td><td>Fail-closed</td><td colspan="2">Valves for water injection from Dousing tank</td><td>Standby</td><td>operable</td></tr>
<tr><td>Liquid Relief Valve (LRV)</td><td>operable</td><td>Fail-open</td><td colspan="2">Valves for PHTS pump seal discharge</td><td>closed</td><td>Fail-open</td></tr>
<tr><td>DG Condenser Relief Valve</td><td>operable</td><td>operable</td><td colspan="2">Atmospheric Steam Discharge Valve (ASDV)</td><td>closed</td><td>closed</td></tr>
<tr><td>DG Condenser Spray</td><td>operable</td><td>Fail-closed</td><td colspan="2">Condenser Steam Discharge Valve (CSDV)</td><td>closed</td><td>closed</td></tr>
<tr><td>Main Feedwater Control Valve</td><td>operable</td><td>open</td><td colspan="2">Emergency Core Cooling System (ECCS)</td><td>Standby</td><td>operable (Accumulator)</td></tr>
</table>

Results and Discussion

Calculation Results of Transient Condition

- Pressure in PHTS
  - slightly increased immediately after the transient initiation, but rapidly decreased as the reactor tripped.
  - As the primary coolant of high temperature and high pressure leaked through the PHT pump sealing, the pressure gradually decreased.
  - Pressure began to decrease rapidly due to the increase in PHTS heat removal by the crash cooling.
  - At ~2,800 s, a HPSI signal occurred, and the pressure increased again as the emergency coolant of the accumulator was injected into the PHTS.
  - The PHTS, after reaching to the accumulator pressure, gradually decreased during the transient period.
  - The emergency coolant amount by HPSI for 8 hr, was estimated to be about 82.8 ton.





Results and Discussion

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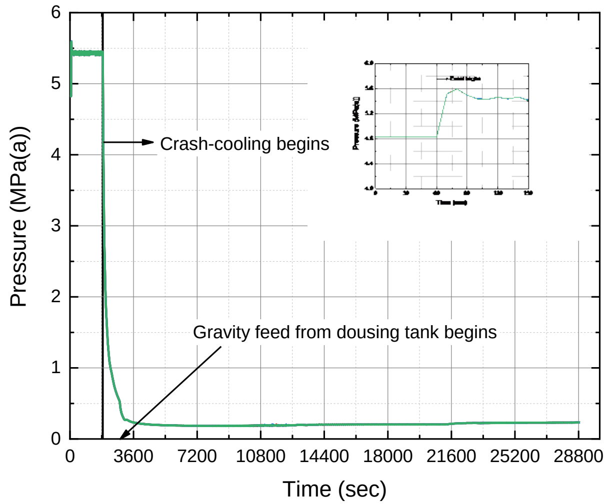
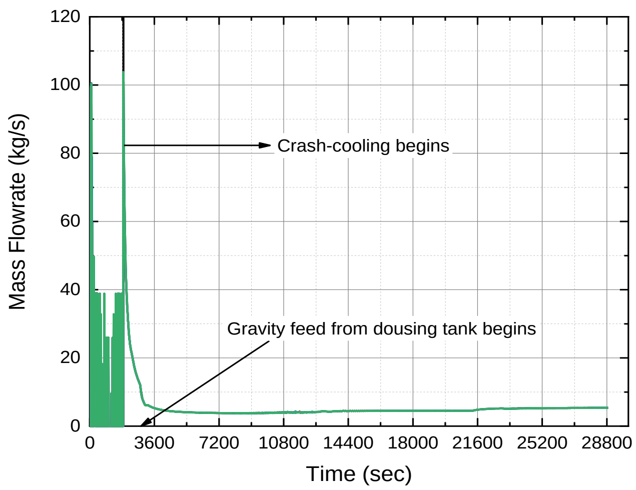
Calculation Results of Transient Condition

- Steam discharging flow through MSSVs
  - Before the crash cooling began, the MSSVs opened and closed repetitively to prevent SG overpressure.
  - After the manual opening of the MSSVs, the amount of discharge increased rapidly, after which the SG inventory and the pressure decreased, leading to decreasing in the amount of steam discharge.
  - The SG inventory was recovered by gravity water supply from the dousing tank, and the decay heat was removed through the SG u-tubes.
  - The water supply from the dousing tank was estimated to begin at ~2,850 s.

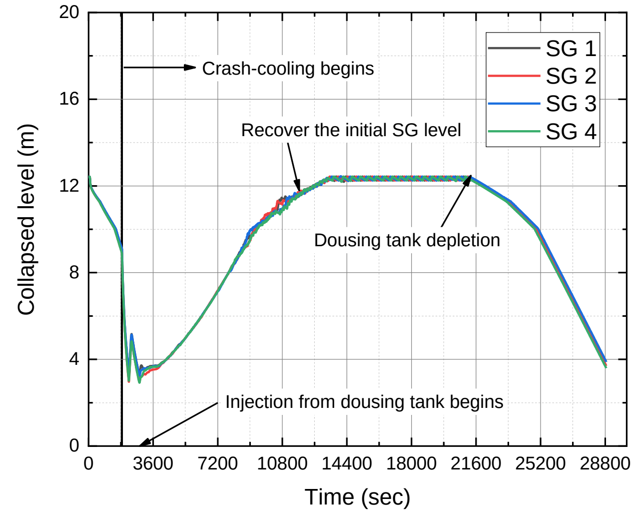




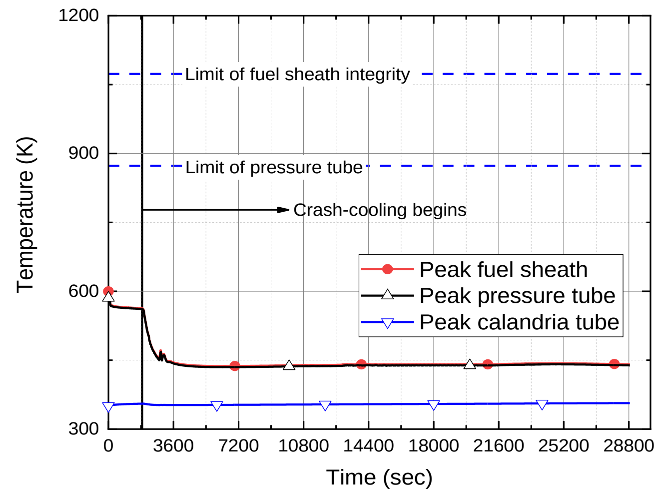
Results and Discussion

Calculation Results of Transient Condition

- Collapsed water level of SGs
  - As the cooling water from the dousing tank was supplied to the SG shell, and the water level of SGs was recovered with the level of the normal operating condition in ~11,480 s.
  - Cooling water in the dousing tank was depleted in ~21,310 s, and then the SG water level decreased again.

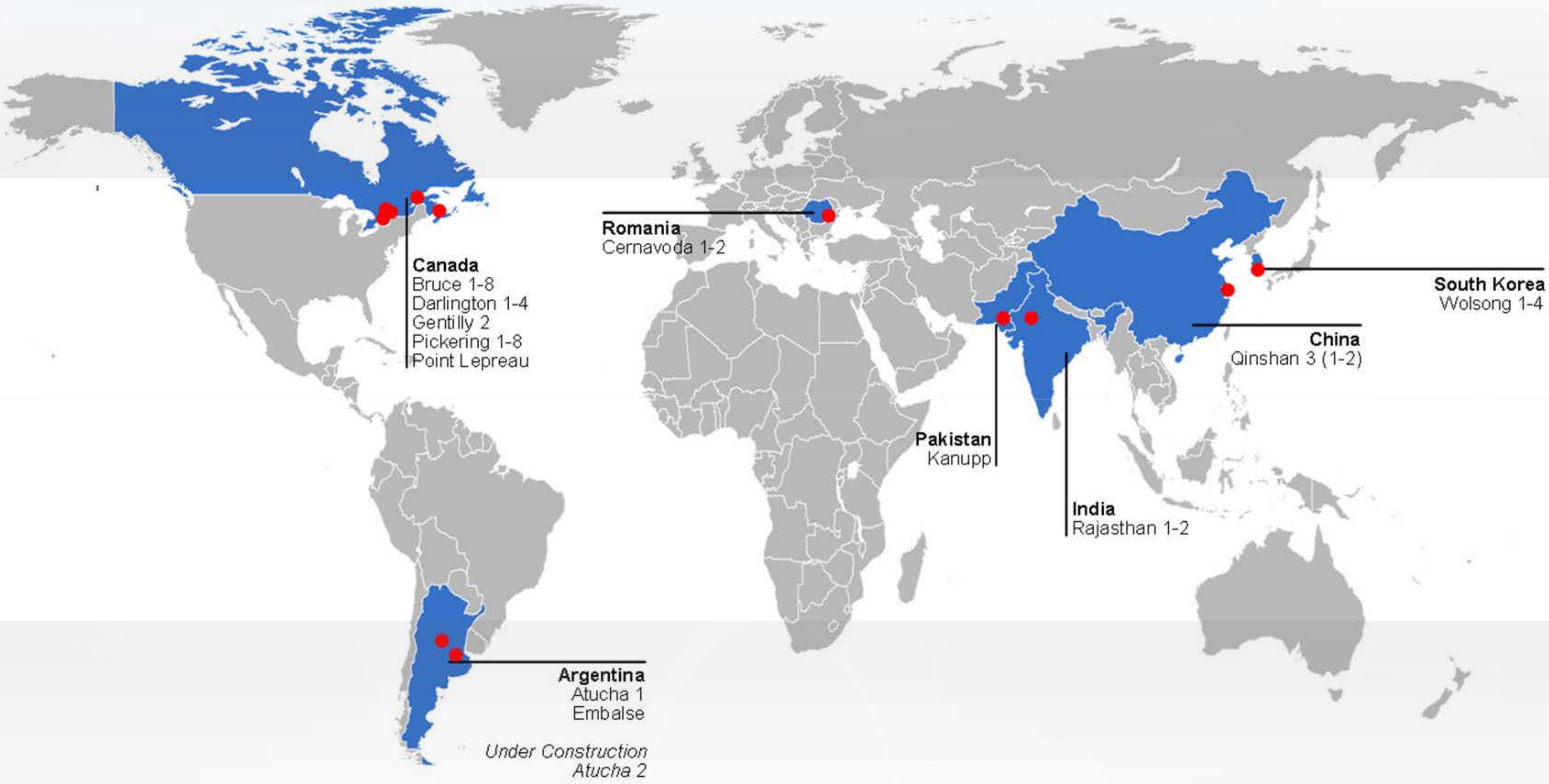


- Max. temp. of fuel sheath and PT
  - Due to the cooling water supplied from the dousing tank to the secondary-side shell, the SGs functioned as a heat sink
  - The fuel cladding and pressure tube were maintained below the failure criteria.



Conclusions

- The SBO in CANDU-6 plants was simulated using MARS-KS code under the transient condition with mitigation action of crash cooling.
  - the logic controllers of crash cooling using SGs, water injection from the dousing tank, and PHT pump seal leakage were applied to the input model.
- Through examining the system responses induced by crash cooling and water injection from the dousing tank, it was found that the calculation results by the modified model were reasonable in the present given conditions.
- Under the SBO condition with crash cooling, it was evaluated that the integrity of fuel and fuel channels was maintained by the combined effect of SG depressurization, water supply from the dousing tank, and high-pressure emergency coolant injection.
- Sensitivity analysis on the initiation time of crash cooling is on progress.



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Thanks for your kind attention

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