# Analysis of a Postulated Main Steam Line Break Accident using Multi-Physics Simulation

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*Korean Nuclear Society Autumn Meeting, Gyeongju, Korea, October 26-27, 2023*

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# 01. Introduction

- MSLB scenario is selected - A large SLB inside the containment at full-power operation + LOOP concurrent + single failure and a stuck CEA (SLBFPLOOP)
- APR-1400 is the modelled plant
- First step is one way coupling of RELAP5/SCDAPSIM/MOD 3.4 with a point kinetics model to simulate core neutronics
- Followed by two way coupling of RELAP5/SCDAPSIM/MOD 3.4 with 3DKIN for core neutronics response
- Then a comparison of results for the two models

# 01. Accident Description

The largest possible size of SLB is the double-ended rupture of a steam line upstream of the MSIV

The excessive energy removal results in a decrease in temperature and pressure in the RCS and SG

The cooldown causes an increase in core reactivity due to the negative moderator and Doppler reactivity coefficients

MSLB has potential for post-trip RTP (cases inside containment)

# 02. Methodology

**Thermal-hydraulic (TH) model using RELAP5/SCDAPSIM/MOD3.4 with a point kinetics model to simulate core neutronics**

- Steady state validation
- Transient response modelling

**RELAP5/SCDAPSIM/MOD 3.4 is used to simulate the thermal-hydraulic response and coupled with 3DKIN for core neutronics response**

- Steady state validation
- Transient response modelling

# 03. Point Kinetics Model

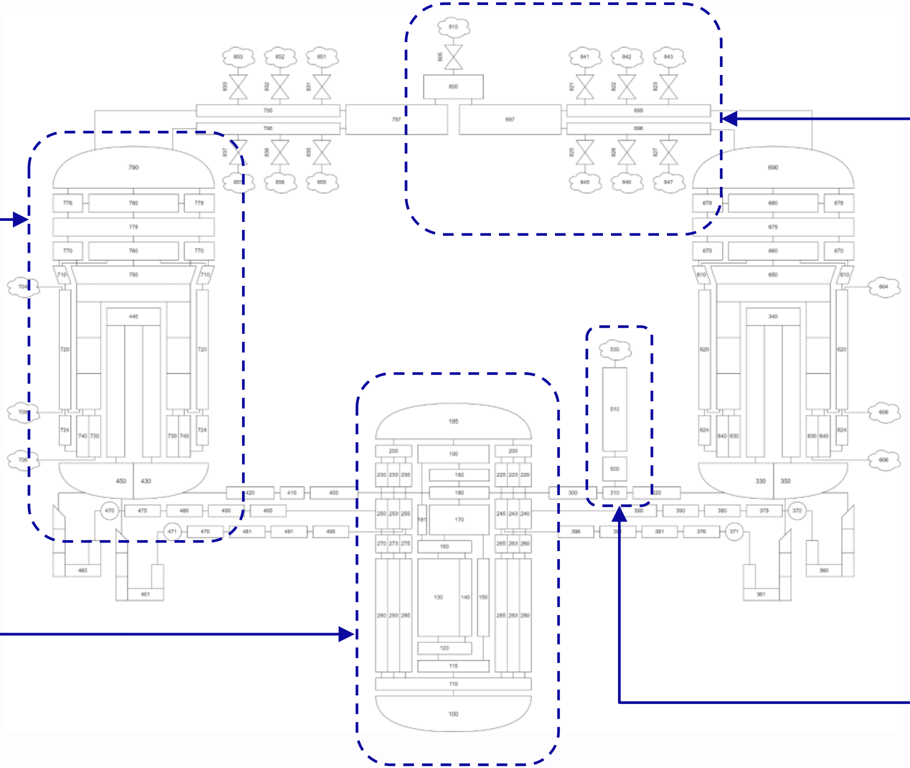
## APR-1400 Nodalization

### Steam Generators (SGs)

- Two SGs - each connected to the RPV via one hot leg and two cold leg
- Heat generated on the primary side is transferred to the SGs via the u-tubes
- The u-tube section is modeled with equivalent heat transfer and pressure drop conditions
- Secondary water is provided by the Main Feedwater System (MFWS) as boundary condition
- Steam generated in the SGs is directed via the main steam line to the turbine modeled as a boundary condition
- Other important components of the SGs are: evaporator, separator, dryer, dome

### Reactor Pressure Vessel (RPV)

- The core is represented using an average and a hot channel, surrounded by an annular core shroud together with the core bypass
- The core connects to an upper plenum and a lower plenum
- Two hot legs lead the coolant from the RPV to the SGs u-tubes, four cold legs connect the RCPs to the downcomer
- The downcomer is modeled using annulus six components



### Main Steam System (MSS)

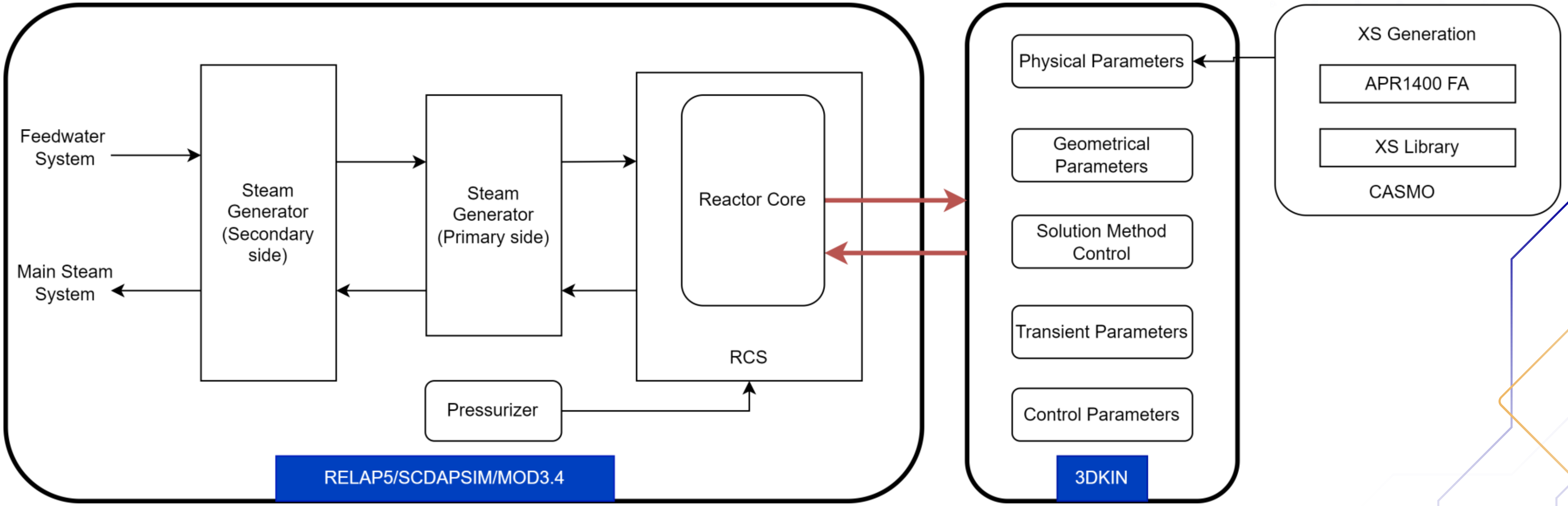
- The Main Steam System (MSS) has four main steam lines leading from the two SGs to a common header, and then to the turbine through an isolation valve.
- Each line is connected to a set of Main Steam Safety Valves (MSSVs) to protect the system against over-pressurization.

### Pressurizer (PZR)

- Maintains operational pressure in the primary system loop.
- In steady-state, the pressurizer pressure is imposed by a boundary condition. In transient, the pressure is determined by the system conditions and Pilot-Operated Safety Relief Valves (POSRVs) operation.

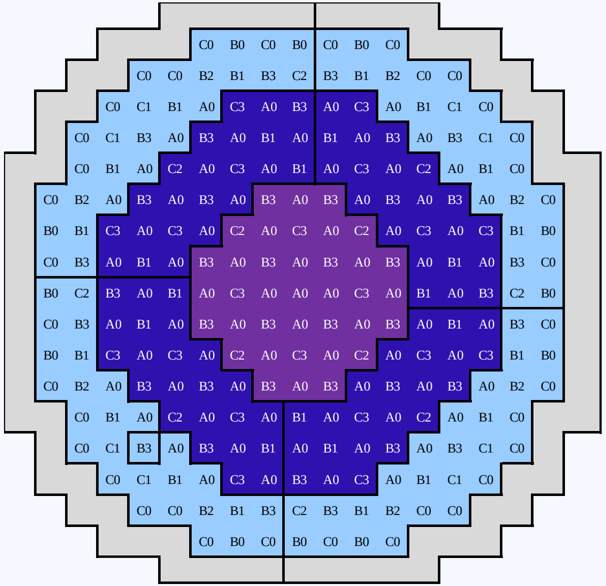
# 04. Nodal Kinetics Model

**Code Coupling**

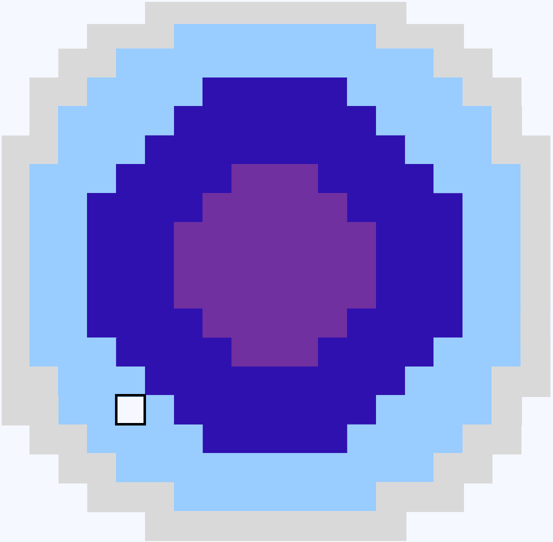


# 04. Nodal Kinetics Model

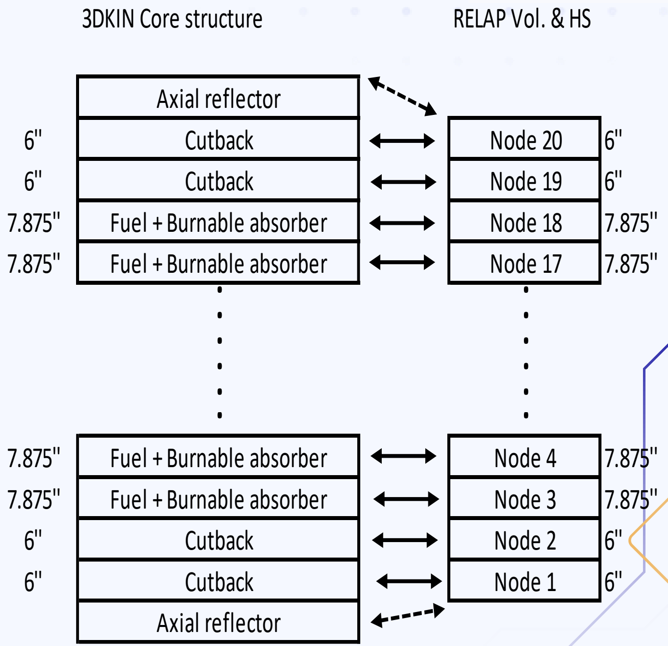
## Core Mapping – 3DKIN




**Core Structure**



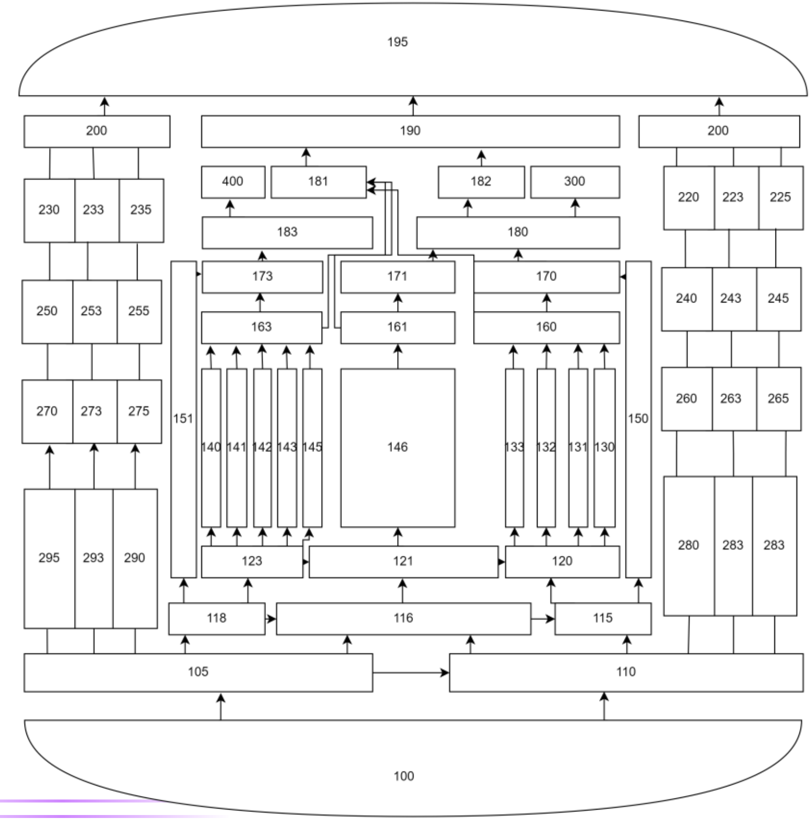
**Radial Map**

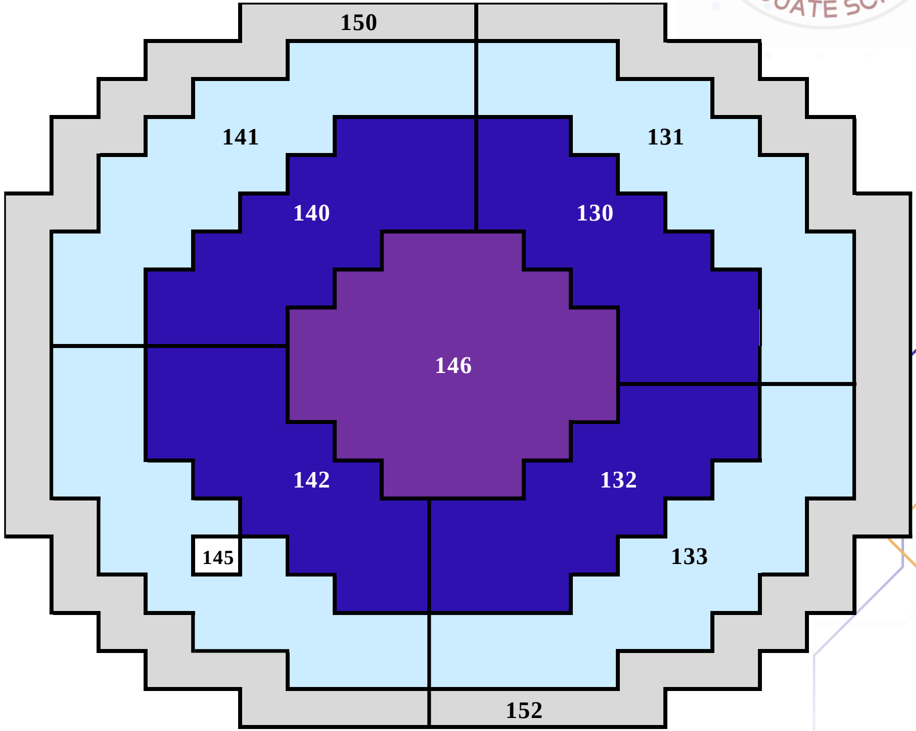



**Axial Map**

# 04. Nodal Kinetics Model

**Core Nodalization - RELAP**



# 04. Nodal Kinetics Model

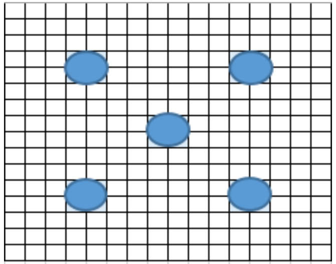
**Loading Pattern and Fuel assembly Data**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | C0 | B0 | C0 | B0 |
| | | | C0 | C0 | B2 | B1 | B3 | C2 |
| | | C0 | C1 | B1 | A0 | C3 | A0 | B3 |
| | C0 | C1 | B3 | A0 | B3 | A0 | B1 | A0 |
| | C0 | B1 | A0 | C2 | A0 | C3 | A0 | B1 |
| C0 | B2 | A0 | B3 | A0 | B3 | A0 | B3 | A0 |
| B0 | B1 | C3 | A0 | C3 | A0 | C2 | A0 | C3 |
| C0 | B3 | A0 | B1 | A0 | B3 | A0 | B3 | A0 |
| B0 | C2 | B3 | A0 | B1 | A0 | C3 | A0 | A0 |

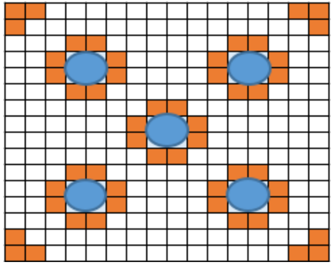
| FA Type | No. of Fuel Assemblies | Fuel Rod Enrichment (w/o) | No. of Rods per Assembly | No. of $Gd_2O_3$ Rods per Assembly | $Gd_2O_3$ Enrichment (w/o) |
|---|---|---|---|---|---|
| A0 | 77 | 1.71 | 236 | - | - |
| B0 | 12 | 3.14 | 236 | - | - |
| B1 | 28 | 3.14/2.64 | 172/52 | 12 | 8 |
| B2 | 8 | 3.14/2.64 | 124/100 | 12 | 8 |
| B3 | 40 | 3.14/2.64 | 168/52 | 16 | 8 |
| C0 | 36 | 3.64/3.14 | 184/52 | - | - |
| C1 | 8 | 3.64/3.14 | 172/52 | 12 | 8 |
| C2 | 12 | 3.64/3.14 | 168/52 | 16 | 8 |
| C3 | 20 | 3.64/3.14 | 120/100 | 16 | 8 |

# 04. Nodal Kinetics Model

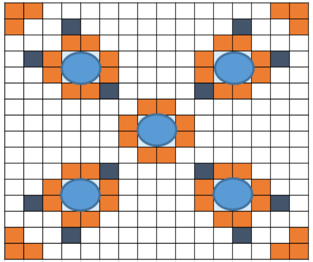
**First Cycle FA Configurations**



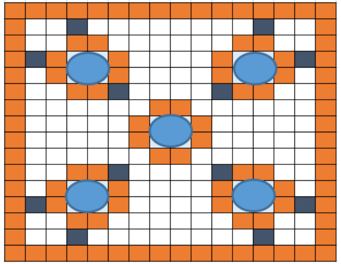
A0, B0



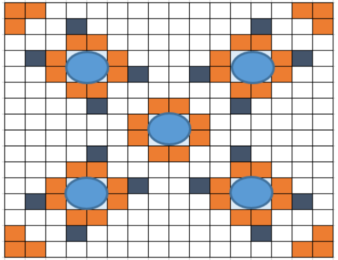
C0



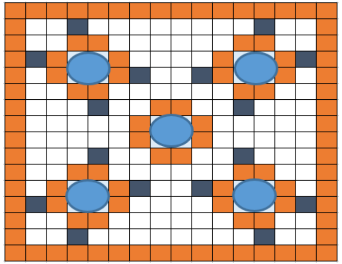
B1, C1



B2



B3, C2



C3

Water hole | Normal enriched fuel pin | Low enriched fuel pin | $Gd_2O_3$ rods

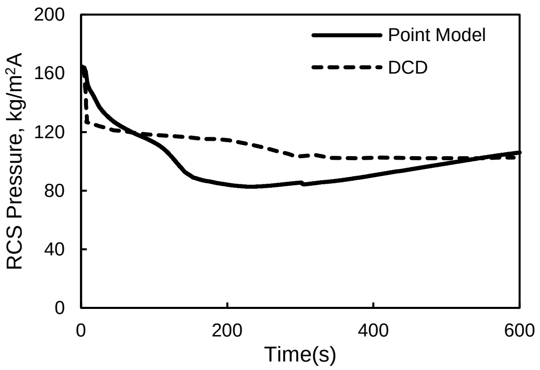
# 05. Results

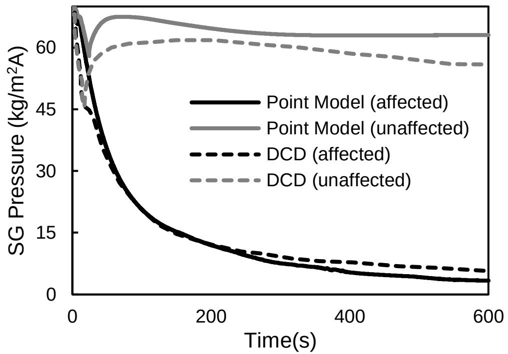
**Point Kinetics Model – Steady State**

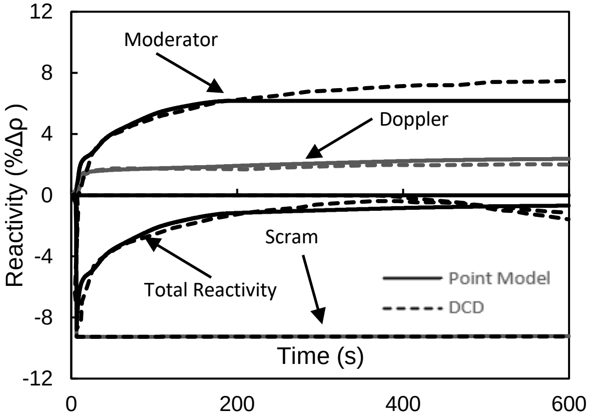
| Parameter | DCD | Model |
|---|---|---|
| Initial Power level (MWt) | 4062 | 4062 |
| Initial core inlet coolant temperature, °C | 295 | 290 |
| Initial core mass flow rate kg/s | 19344.44 | 19318 |
| Initial pressurizer pressure, kg/cm2A | 163.46 | 163.13 |
| Initial pressurizer water volume, m3 | 39.91 | 39.94 |
| Axial Shape Index | 0.3 | 0.3 |
| CEA worth for trip %Δρ | -9.3 | -9.3 |
| Moderator coefficient | most negative | most negative |
| Doppler coefficient | most negative | most negative |
| Initial steam generator liquid inventory per SG, kg | 124113 | 124595 |
| Two safety injection pumps | Inoperable | Inoperable |
| Core burn up | End of cycle | End of cycle |

# 05. Results

## Point Kinetics Model – Transient Response

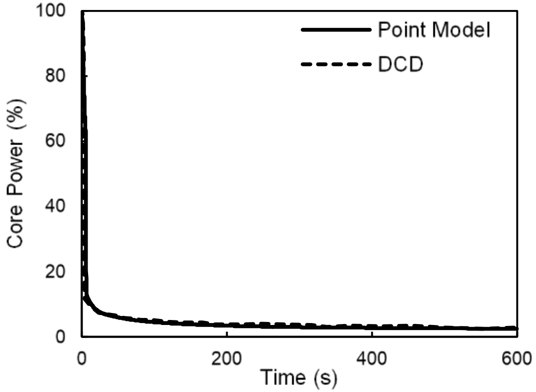


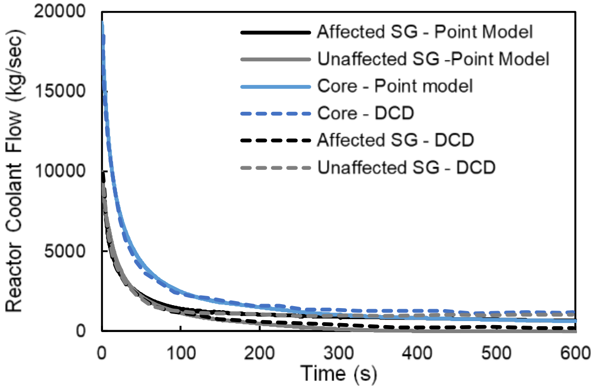



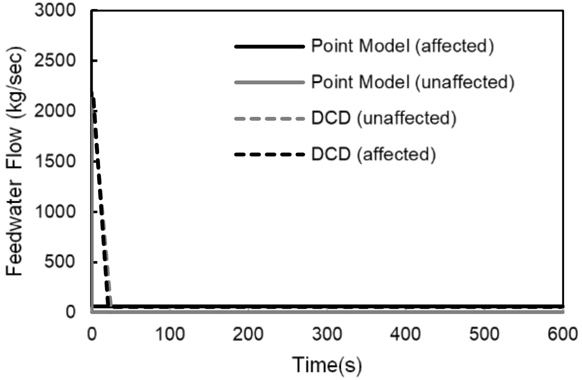



# 05. Results

## Point Kinetics Model – Transient Response



# 05. Results

## Nodal Kinetics Model – Steady State

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.80 | 1.02 | 1.16 | 1.12 | 1.16 | 1.02 | 0.80 | | | | | |
| | | | 0.82 | 1.14 | 1.07 | 1.13 | 1.10 | 1.18 | 1.10 | 1.13 | 1.07 | 1.15 | 0.82 | | | |
| | | 0.85 | 1.12 | 1.16 | 0.98 | 1.15 | 0.98 | 1.06 | 0.98 | 1.15 | 0.98 | 1.16 | 1.12 | 0.85 | | |
| | 0.82 | 1.12 | 1.04 | 0.95 | 1.03 | 0.94 | 1.12 | 0.95 | 1.12 | 0.94 | 1.04 | 0.95 | 1.04 | 1.12 | 0.82 | |
| | 1.14 | 1.16 | 0.95 | 1.11 | 0.89 | 1.05 | 0.90 | 1.06 | 0.90 | 1.06 | 0.90 | 1.11 | 0.95 | 1.16 | 1.15 | |
| 0.80 | 1.07 | 0.98 | 1.03 | 0.89 | 0.95 | 0.85 | 0.94 | 0.85 | 0.94 | 0.85 | 0.96 | 0.90 | 1.04 | 0.98 | 1.07 | 0.80 |
| 1.02 | 1.13 | 1.15 | 0.94 | 1.05 | 0.85 | 1.00 | 0.81 | 0.96 | 0.81 | 1.00 | 0.85 | 1.06 | 0.94 | 1.15 | 1.13 | 1.02 |
| 1.16 | 1.10 | 0.98 | 1.12 | 0.90 | 0.94 | 0.81 | 0.87 | 0.79 | 0.87 | 0.81 | 0.94 | 0.90 | 1.12 | 0.98 | 1.10 | 1.16 |
| 1.12 | 1.18 | 1.06 | 0.95 | 1.06 | 0.85 | 0.96 | 0.79 | 0.81 | 0.79 | 0.96 | 0.85 | 1.07 | 0.95 | 1.06 | 1.18 | 1.12 |
| 1.16 | 1.10 | 0.98 | 1.12 | 0.90 | 0.94 | 0.81 | 0.87 | 0.79 | 0.87 | 0.81 | 0.94 | 0.90 | 1.12 | 0.98 | 1.10 | 1.16 |
| 1.02 | 1.13 | 1.15 | 0.94 | 1.05 | 0.85 | 1.00 | 0.81 | 0.96 | 0.81 | 1.00 | 0.85 | 1.05 | 0.94 | 1.15 | 1.13 | 1.02 |
| 0.80 | 1.07 | 0.98 | 1.03 | 0.89 | 0.95 | 0.85 | 0.94 | 0.85 | 0.94 | 0.85 | 0.95 | 0.89 | 1.03 | 0.98 | 1.07 | 0.80 |
| | 1.15 | 1.16 | 0.95 | 1.11 | 0.89 | 1.05 | 0.90 | 1.06 | 0.90 | 1.05 | 0.89 | 1.11 | 0.95 | 1.16 | 1.14 | |
| | 0.82 | 1.12 | 1.04 | 0.95 | 1.03 | 0.94 | 1.12 | 0.95 | 1.12 | 0.94 | 1.03 | 0.95 | 1.04 | 1.12 | 0.82 | |
| | | 0.85 | 1.12 | 1.16 | 0.98 | 1.15 | 0.98 | 1.06 | 0.98 | 1.15 | 0.98 | 1.16 | 1.12 | 0.85 | | |
| | | | 0.82 | 1.15 | 1.07 | 1.13 | 1.10 | 1.18 | 1.10 | 1.13 | 1.07 | 1.14 | 0.82 | | | |
| | | | | | 0.80 | 1.02 | 1.16 | 1.12 | 1.16 | 1.02 | 0.80 | | | | | |

**Model**

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.78 | 1.01 | 1.15 | 1.11 | 1.15 | 1.01 | 0.78 | | | | | |
| | | | 0.85 | 1.18 | 1.06 | 1.14 | 1.11 | 1.20 | 1.11 | 1.14 | 1.06 | 1.18 | 0.85 | | | |
| | | 0.88 | 1.16 | 1.20 | 0.98 | 1.16 | 0.97 | 1.07 | 0.97 | 1.16 | 0.98 | 1.20 | 1.16 | 0.88 | | |
| | 0.85 | 1.16 | 1.08 | 0.96 | 1.04 | 0.93 | 1.13 | 0.93 | 1.13 | 0.93 | 1.04 | 0.96 | 1.08 | 1.16 | 0.85 | |
| | 1.18 | 1.20 | 0.96 | 1.13 | 0.88 | 1.06 | 0.88 | 1.07 | 0.88 | 1.06 | 0.88 | 1.13 | 0.96 | 1.20 | 1.18 | |
| 0.78 | 1.06 | 0.98 | 1.04 | 0.88 | 0.96 | 0.83 | 0.92 | 0.81 | 0.92 | 0.83 | 0.96 | 0.88 | 1.04 | 0.98 | 1.06 | 0.78 |
| 1.01 | 1.14 | 1.16 | 0.93 | 1.06 | 0.83 | 0.98 | 0.78 | 0.93 | 0.78 | 0.98 | 0.83 | 1.06 | 0.93 | 1.16 | 1.14 | 1.01 |
| 1.15 | 1.11 | 0.97 | 1.13 | 0.88 | 0.92 | 0.78 | 0.84 | 0.75 | 0.84 | 0.78 | 0.92 | 0.88 | 1.13 | 0.97 | 1.11 | 1.15 |
| 1.11 | 1.20 | 1.07 | 0.93 | 1.07 | 0.81 | 0.93 | 0.75 | 0.77 | 0.75 | 0.93 | 0.81 | 1.07 | 0.93 | 1.07 | 1.20 | 1.11 |
| 1.15 | 1.11 | 0.97 | 1.13 | 0.88 | 0.92 | 0.78 | 0.84 | 0.75 | 0.84 | 0.78 | 0.92 | 0.88 | 1.13 | 0.97 | 1.11 | 1.15 |
| 1.01 | 1.14 | 1.16 | 0.93 | 1.06 | 0.83 | 0.98 | 0.78 | 0.93 | 0.78 | 0.98 | 0.83 | 1.06 | 0.93 | 1.16 | 1.14 | 1.01 |
| 0.78 | 1.06 | 0.98 | 1.04 | 0.88 | 0.96 | 0.83 | 0.92 | 0.81 | 0.92 | 0.83 | 0.96 | 0.88 | 1.04 | 0.98 | 1.06 | 0.78 |
| | 1.18 | 1.20 | 0.96 | 1.13 | 0.88 | 1.06 | 0.88 | 1.07 | 0.88 | 1.06 | 0.88 | 1.13 | 0.96 | 1.20 | 1.18 | |
| | 0.85 | 1.16 | 1.08 | 0.96 | 1.04 | 0.93 | 1.13 | 0.93 | 1.13 | 0.93 | 1.04 | 0.96 | 1.08 | 1.16 | 0.85 | |
| | | 0.88 | 1.16 | 1.20 | 0.98 | 1.16 | 0.97 | 1.07 | 0.97 | 1.16 | 0.98 | 1.20 | 1.16 | 0.88 | | |
| | | | 0.85 | 1.18 | 1.06 | 1.14 | 1.11 | 1.20 | 1.11 | 1.14 | 1.06 | 1.18 | 0.85 | | | |
| | | | | | 0.78 | 1.01 | 1.15 | 1.11 | 1.15 | 1.01 | 0.78 | | | | | |

**DCD**

# 05. Results

## Nodal Kinetics Model – Transient Response

t = 0.013 s

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.77 | 0.98 | 1.11 | 1.07 | 1.11 | 0.98 | 0.77 | | | | | |
| | | | 0.79 | 1.11 | 1.04 | 1.10 | 1.07 | 1.15 | 1.07 | 1.10 | 1.04 | 1.11 | 0.79 | | | |
| | | 0.82 | 1.09 | 1.14 | 0.97 | 1.14 | 0.97 | 1.06 | 0.97 | 1.14 | 0.97 | 1.14 | 1.09 | 0.82 | | |
| | 0.79 | 1.09 | 1.03 | 0.95 | 1.04 | 0.95 | 1.14 | 0.96 | 1.14 | 0.95 | 1.04 | 0.95 | 1.03 | 1.09 | 0.79 | |
| | 1.11 | 1.14 | 0.95 | 1.12 | 0.91 | 1.08 | 0.93 | 1.10 | 0.93 | 1.08 | 0.91 | 1.12 | 0.95 | 1.14 | 1.11 | |
| 0.77 | 1.04 | 0.97 | 1.04 | 0.91 | 0.98 | 0.88 | 0.98 | 0.89 | 0.98 | 0.88 | 0.99 | 0.91 | 1.04 | 0.97 | 1.04 | 0.77 |
| 0.98 | 1.10 | 1.14 | 0.95 | 1.08 | 0.88 | 1.05 | 0.86 | 1.01 | 0.86 | 1.05 | 0.88 | 1.08 | 0.95 | 1.14 | 1.10 | 0.98 |
| 1.11 | 1.07 | 0.97 | 1.14 | 0.93 | 0.98 | 0.86 | 0.93 | 0.84 | 0.93 | 0.86 | 0.98 | 0.93 | 1.14 | 0.97 | 1.07 | 1.11 |
| 1.07 | 1.15 | 1.06 | 0.96 | 1.10 | 0.89 | 1.01 | 0.84 | 0.87 | 0.84 | 1.01 | 0.89 | 1.10 | 0.96 | 1.06 | 1.15 | 1.07 |
| 1.11 | 1.07 | 0.97 | 1.14 | 0.93 | 0.98 | 0.86 | 0.93 | 0.84 | 0.93 | 0.86 | 0.98 | 0.93 | 1.14 | 0.97 | 1.07 | 1.11 |
| 0.98 | 1.10 | 1.14 | 0.95 | 1.08 | 0.88 | 1.05 | 0.86 | 1.01 | 0.86 | 1.05 | 0.88 | 1.08 | 0.95 | 1.14 | 1.10 | 0.98 |
| 0.77 | 1.04 | 0.97 | 1.04 | 0.91 | 0.98 | 0.88 | 0.98 | 0.89 | 0.98 | 0.88 | 0.98 | 0.91 | 1.04 | 0.97 | 1.04 | 0.77 |
| | 1.11 | 1.14 | 0.95 | 1.12 | 0.91 | 1.08 | 0.93 | 1.10 | 0.93 | 1.08 | 0.91 | 1.12 | 0.95 | 1.14 | 1.11 | |
| | 0.79 | 1.09 | 1.02 | 0.95 | 1.04 | 0.95 | 1.14 | 0.96 | 1.14 | 0.95 | 1.04 | 0.95 | 1.03 | 1.09 | 0.79 | |
| | | 0.82 | 1.09 | 1.14 | 0.97 | 1.14 | 0.97 | 1.06 | 0.97 | 1.14 | 0.97 | 1.14 | 1.09 | 0.82 | | |
| | | | 0.79 | 1.11 | 1.04 | 1.10 | 1.07 | 1.15 | 1.07 | 1.10 | 1.04 | 1.11 | 0.79 | | | |
| | | | | | 0.77 | 0.98 | 1.11 | 1.07 | 1.11 | 0.98 | 0.77 | | | | | |

t = 5.96 s

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.74 | 0.94 | 1.06 | 1.03 | 1.06 | 0.94 | 0.74 | | | | | |
| | | | 0.76 | 1.06 | 1.01 | 1.07 | 1.05 | 1.12 | 1.05 | 1.08 | 1.02 | 1.07 | 0.76 | | | |
| | | 0.79 | 1.05 | 1.11 | 0.96 | 1.13 | 0.97 | 1.05 | 0.98 | 1.13 | 0.97 | 1.12 | 1.06 | 0.79 | | |
| | 0.76 | 1.05 | 1.01 | 0.95 | 1.04 | 0.96 | 1.15 | 0.98 | 1.16 | 0.97 | 1.05 | 0.95 | 1.01 | 1.06 | 0.76 | |
| | 1.06 | 1.11 | 0.95 | 1.12 | 0.93 | 1.11 | 0.96 | 1.13 | 0.96 | 1.11 | 0.93 | 1.13 | 0.95 | 1.12 | 1.07 | |
| 0.74 | 1.01 | 0.96 | 1.04 | 0.93 | 1.01 | 0.91 | 1.02 | 0.93 | 1.02 | 0.92 | 1.02 | 0.93 | 1.05 | 0.97 | 1.02 | 0.74 |
| 0.94 | 1.07 | 1.13 | 0.96 | 1.11 | 0.91 | 1.10 | 0.90 | 1.06 | 0.90 | 1.10 | 0.92 | 1.11 | 0.97 | 1.14 | 1.08 | 0.94 |
| 1.06 | 1.05 | 0.97 | 1.15 | 0.95 | 1.02 | 0.90 | 0.98 | 0.90 | 0.98 | 0.90 | 1.02 | 0.96 | 1.16 | 0.98 | 1.05 | 1.06 |
| 1.03 | 1.12 | 1.05 | 0.98 | 1.13 | 0.93 | 1.06 | 0.89 | 0.93 | 0.90 | 1.06 | 0.93 | 1.13 | 0.98 | 1.06 | 1.13 | 1.03 |
| 1.06 | 1.05 | 0.97 | 1.15 | 0.95 | 1.02 | 0.90 | 0.98 | 0.90 | 0.98 | 0.90 | 1.02 | 0.96 | 1.15 | 0.98 | 1.05 | 1.06 |
| 0.94 | 1.07 | 1.13 | 0.96 | 1.11 | 0.91 | 1.10 | 0.90 | 1.06 | 0.90 | 1.10 | 0.92 | 1.11 | 0.97 | 1.13 | 1.08 | 0.94 |
| 0.74 | 1.01 | 0.97 | 1.04 | 0.93 | 1.01 | 0.91 | 1.02 | 0.93 | 1.02 | 0.92 | 1.01 | 0.93 | 1.05 | 0.97 | 1.02 | 0.74 |
| | 1.06 | 1.12 | 0.95 | 1.12 | 0.93 | 1.11 | 0.96 | 1.13 | 0.96 | 1.11 | 0.93 | 1.13 | 0.95 | 1.12 | 1.07 | |
| | 0.76 | 1.05 | 1.01 | 0.95 | 1.04 | 0.96 | 1.15 | 0.98 | 1.15 | 0.96 | 1.05 | 0.95 | 1.01 | 1.06 | 0.76 | |
| | | 0.79 | 1.05 | 1.12 | 0.97 | 1.13 | 0.97 | 1.05 | 0.97 | 1.13 | 0.97 | 1.12 | 1.06 | 0.79 | | |
| | | | 0.76 | 1.06 | 1.01 | 1.07 | 1.05 | 1.12 | 1.05 | 1.08 | 1.02 | 1.06 | 0.76 | | | |
| | | | | | 0.74 | 0.94 | 1.06 | 1.03 | 1.06 | 0.94 | 0.74 | | | | | |

t = 22.86 s

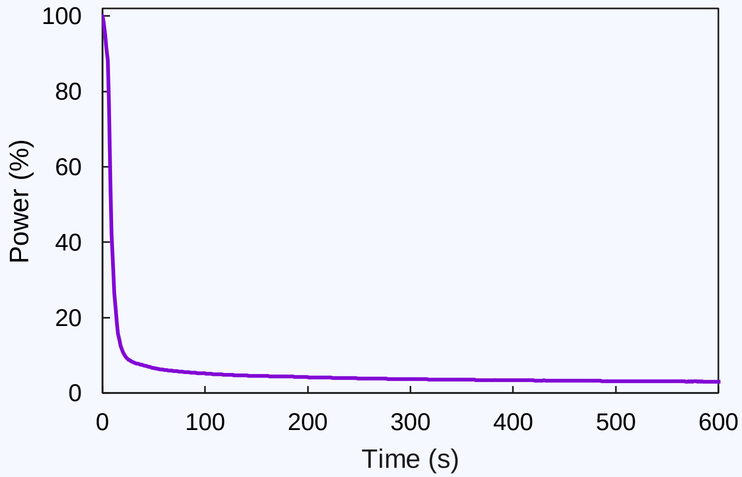
| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.88 | 1.12 | 1.21 | 1.02 | 1.22 | 1.13 | 0.88 | | | | | |
| | | | 0.89 | 1.20 | 1.01 | 1.17 | 1.02 | 1.17 | 1.02 | 1.17 | 1.02 | 1.21 | 0.89 | | | |
| | | 0.78 | 1.14 | 1.08 | 0.97 | 1.06 | 0.96 | 0.98 | 0.96 | 1.07 | 0.98 | 1.08 | 1.15 | 0.78 | | |
| | 0.89 | 1.14 | 0.96 | 0.94 | 0.97 | 0.95 | 1.05 | 0.94 | 1.05 | 0.95 | 0.97 | 0.94 | 0.97 | 1.15 | 0.89 | |
| | 1.20 | 1.08 | 0.94 | 1.04 | 0.91 | 1.12 | 0.93 | 1.01 | 0.93 | 1.12 | 0.92 | 1.04 | 0.94 | 1.08 | 1.21 | |
| 0.87 | 1.01 | 0.97 | 0.97 | 0.91 | 0.92 | 0.89 | 0.92 | 0.89 | 0.92 | 0.89 | 0.92 | 0.92 | 0.97 | 0.98 | 1.02 | 0.88 |
| 1.12 | 1.17 | 1.06 | 0.95 | 1.12 | 0.89 | 0.98 | 0.86 | 1.05 | 0.86 | 0.98 | 0.89 | 1.12 | 0.96 | 1.07 | 1.17 | 1.13 |
| 1.21 | 1.02 | 0.96 | 1.05 | 0.93 | 0.92 | 0.86 | 0.87 | 0.84 | 0.87 | 0.86 | 0.92 | 0.93 | 1.05 | 0.96 | 1.02 | 1.22 |
| 1.02 | 1.17 | 0.98 | 0.94 | 1.01 | 0.89 | 1.05 | 0.84 | 0.80 | 0.84 | 1.05 | 0.89 | 1.02 | 0.94 | 0.98 | 1.17 | 1.02 |
| 1.21 | 1.02 | 0.96 | 1.05 | 0.93 | 0.92 | 0.86 | 0.87 | 0.84 | 0.87 | 0.86 | 0.92 | 0.93 | 1.05 | 0.96 | 1.02 | 1.22 |
| 1.12 | 1.17 | 1.06 | 0.95 | 1.12 | 0.89 | 0.98 | 0.86 | 1.05 | 0.86 | 0.98 | 0.89 | 1.12 | 0.95 | 1.07 | 1.17 | 1.13 |
| 0.87 | 1.01 | 0.97 | 0.97 | 0.91 | 0.92 | 0.89 | 0.92 | 0.89 | 0.92 | 0.89 | 0.92 | 0.92 | 0.97 | 0.98 | 1.02 | 0.88 |
| | 1.20 | 1.08 | 0.94 | 1.03 | 0.91 | 1.12 | 0.93 | 1.01 | 0.93 | 1.12 | 0.92 | 1.04 | 0.94 | 1.08 | 1.21 | |
| | 0.89 | 1.14 | 0.96 | 0.94 | 0.97 | 0.95 | 1.05 | 0.94 | 1.05 | 0.95 | 0.97 | 0.94 | 0.97 | 1.15 | 0.89 | |
| | | 0.78 | 1.14 | 1.08 | 0.97 | 1.06 | 0.96 | 0.98 | 0.96 | 1.07 | 0.98 | 1.08 | 1.15 | 0.78 | | |
| | | | 0.89 | 1.20 | 1.01 | 1.17 | 1.02 | 1.17 | 1.02 | 1.17 | 1.02 | 1.21 | 0.89 | | | |
| | | | | | 0.87 | 1.12 | 1.21 | 1.02 | 1.22 | 1.13 | 0.88 | | | | | |

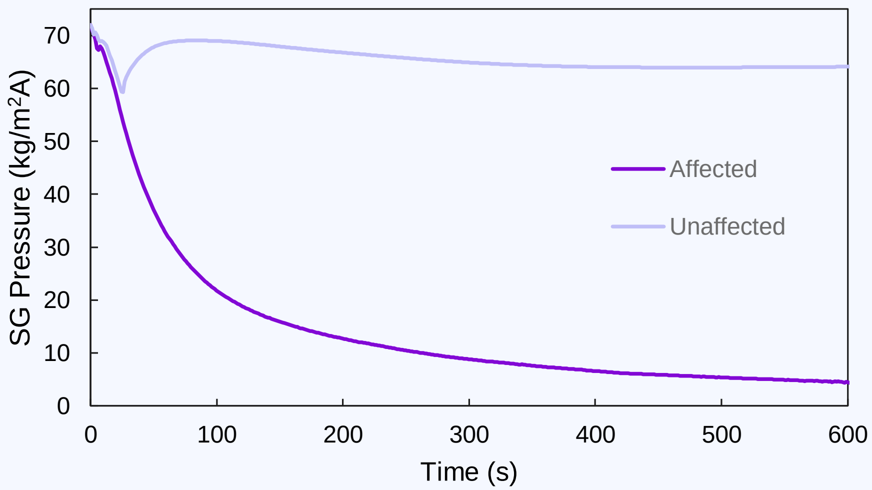
t = 600 s

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 0.79 | 1.01 | 1.13 | 1.07 | 1.13 | 1.01 | 0.79 | | | | | |
| | | | 0.80 | 1.12 | 1.04 | 1.11 | 1.07 | 1.16 | 1.07 | 1.11 | 1.04 | 1.12 | 0.80 | | | |
| | | 0.82 | 1.09 | 1.14 | 0.97 | 1.13 | 0.97 | 1.05 | 0.97 | 1.14 | 0.97 | 1.14 | 1.09 | 0.82 | | |
| | 0.80 | 1.09 | 1.02 | 0.94 | 1.03 | 0.95 | 1.13 | 0.96 | 1.13 | 0.95 | 1.03 | 0.94 | 1.02 | 1.09 | 0.80 | |
| | 1.12 | 1.14 | 0.94 | 1.11 | 0.91 | 1.08 | 0.92 | 1.09 | 0.92 | 1.08 | 0.91 | 1.11 | 0.94 | 1.14 | 1.12 | |
| 0.79 | 1.04 | 0.97 | 1.03 | 0.91 | 0.98 | 0.88 | 0.97 | 0.88 | 0.97 | 0.88 | 0.98 | 0.91 | 1.03 | 0.97 | 1.04 | 0.79 |
| 1.01 | 1.11 | 1.13 | 0.95 | 1.08 | 0.88 | 1.05 | 0.85 | 1.00 | 0.85 | 1.05 | 0.88 | 1.08 | 0.95 | 1.14 | 1.11 | 1.01 |
| 1.13 | 1.07 | 0.97 | 1.13 | 0.92 | 0.97 | 0.85 | 0.92 | 0.84 | 0.92 | 0.85 | 0.97 | 0.92 | 1.13 | 0.97 | 1.07 | 1.13 |
| 1.07 | 1.16 | 1.05 | 0.96 | 1.09 | 0.88 | 1.00 | 0.84 | 0.86 | 0.84 | 1.00 | 0.88 | 1.09 | 0.96 | 1.05 | 1.16 | 1.08 |
| 1.13 | 1.07 | 0.97 | 1.13 | 0.92 | 0.97 | 0.85 | 0.92 | 0.84 | 0.92 | 0.85 | 0.97 | 0.92 | 1.13 | 0.97 | 1.07 | 1.13 |
| 1.01 | 1.11 | 1.13 | 0.95 | 1.08 | 0.88 | 1.05 | 0.85 | 1.00 | 0.85 | 1.05 | 0.88 | 1.08 | 0.95 | 1.13 | 1.11 | 1.01 |
| 0.79 | 1.04 | 0.97 | 1.03 | 0.91 | 0.98 | 0.88 | 0.97 | 0.88 | 0.97 | 0.88 | 0.98 | 0.91 | 1.03 | 0.97 | 1.04 | 0.79 |
| | 1.12 | 1.14 | 0.94 | 1.11 | 0.91 | 1.08 | 0.92 | 1.09 | 0.92 | 1.08 | 0.91 | 1.11 | 0.94 | 1.14 | 1.12 | |
| | 0.80 | 1.09 | 1.02 | 0.94 | 1.03 | 0.95 | 1.13 | 0.96 | 1.13 | 0.95 | 1.03 | 0.94 | 1.02 | 1.09 | 0.80 | |
| | | 0.82 | 1.09 | 1.14 | 0.97 | 1.13 | 0.97 | 1.05 | 0.97 | 1.13 | 0.97 | 1.14 | 1.09 | 0.82 | | |
| | | | 0.80 | 1.12 | 1.04 | 1.11 | 1.07 | 1.16 | 1.07 | 1.11 | 1.04 | 1.12 | 0.80 | | | |
| | | | | | 0.79 | 1.01 | 1.13 | 1.08 | 1.13 | 1.01 | 0.79 | | | | | |

# 05. Results

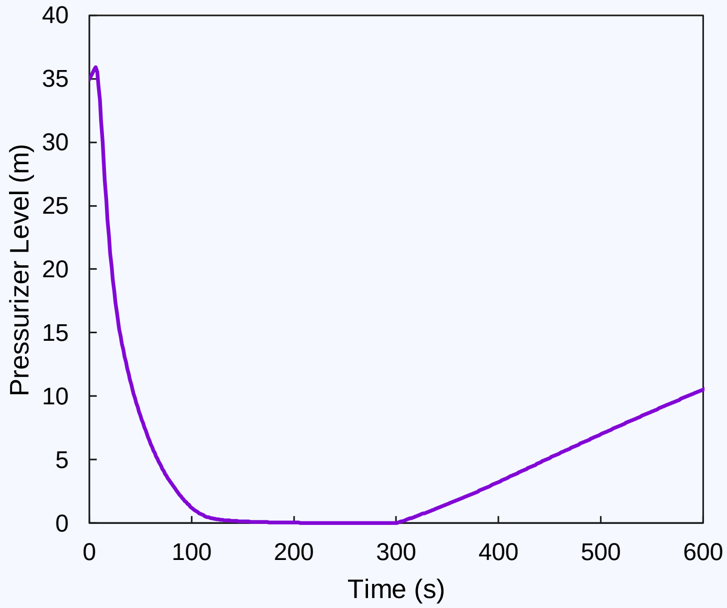
**Nodal Kinetics Model – Transient Response**

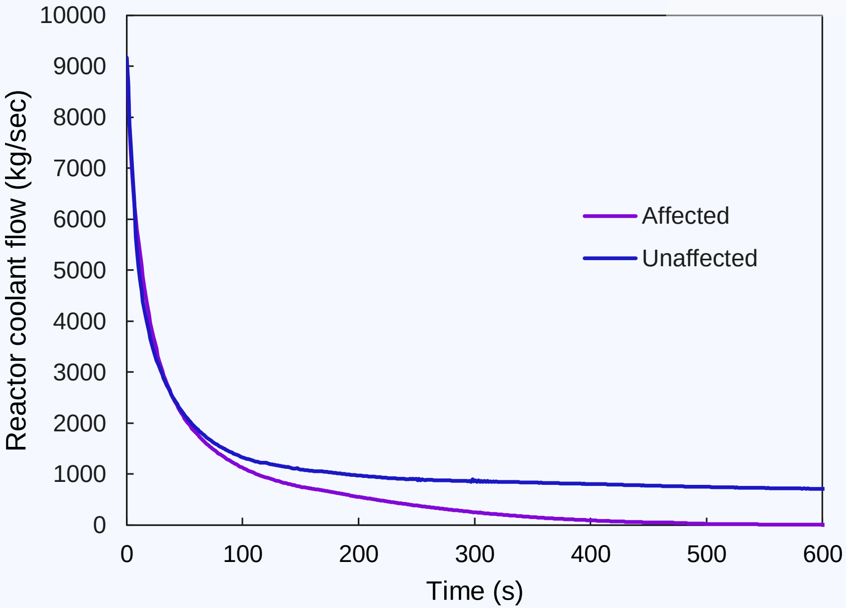


# 05. Results

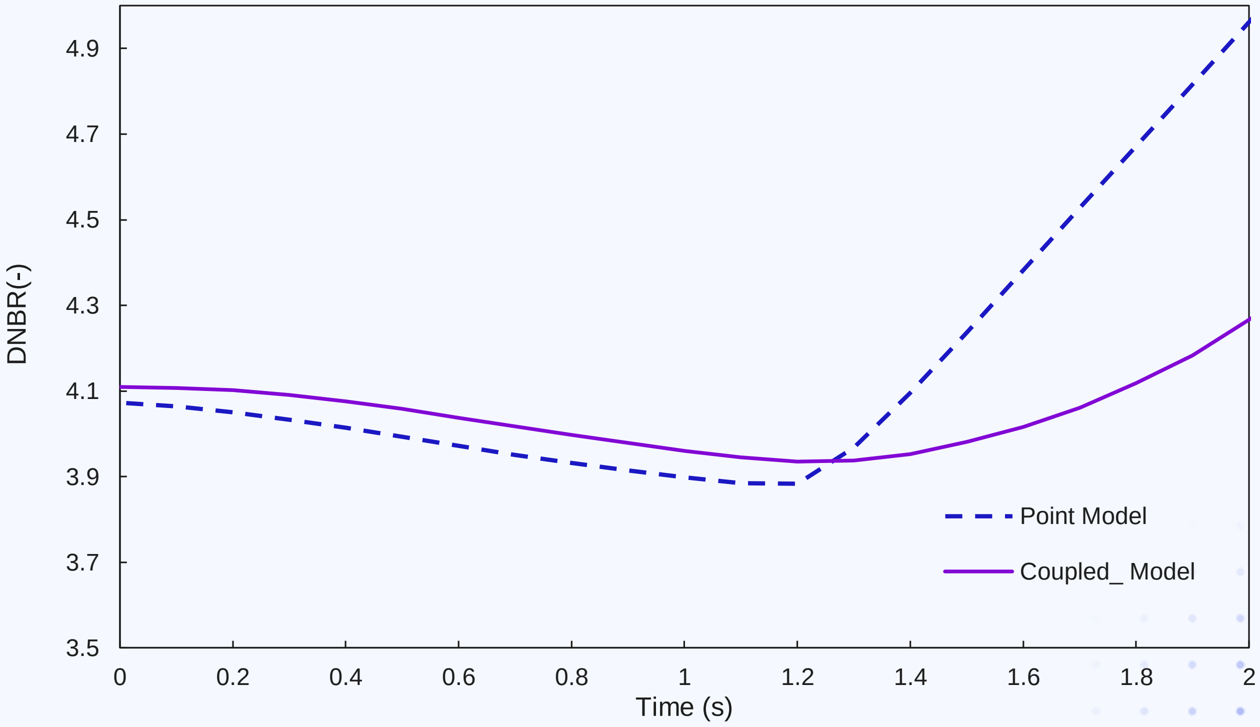
**Nodal Kinetics Model – Transient Response**



# 05. Results

**Transient Response DNBR**



# 06. Conclusion

- This project modelled the MSLB (inside the containment at full power operation + LOOP concurrent + single failure and a stuck CEA) on the APR1400
- As the initial step of this study, one way coupling of thermal hydraulics model with point kinetics is conducted to provide insight into the behavior of the core.
- Next is modelling of the MSLB using multi-physics approach using nodal kinetics for a high-fidelity simulation.
- The results show that multi-physics approach can show the asymmetric behaviour of the core during transients.
- The results also indicate that both the point and nodal kinetics are good tools to model the transient, and can reveal different aspects of the transient.

# Questions and answers

# Acknowledgements

This research was supported by the 2023 Research Fund of the KEPCO International Nuclear Graduate School (KINGS), the Republic of Korea