2020 KNS Autumn Meeting

APR1400 MFLB Safety Analysis using MARS-KS CTF Subchannel Analysis Module and Parallelization Challenges

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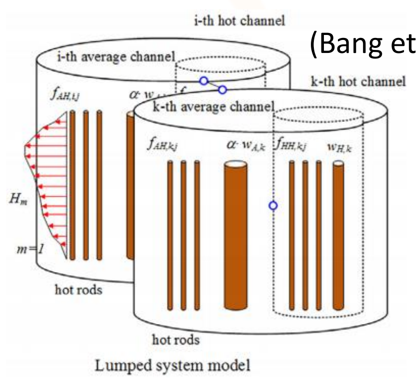
Contents

Introduction

- **Multi-dimensional, multi-physical reactor thermal-hydraulic phenomena that tightly couple with other physics (*e.g., neutronics, fuel perform., chemistry*)**
  - ✓ **Flow through the subchannels in fuel assemblies and downcomer**
  - ✓ **Core coolability ~ flow blockage, spacer grids**
  - ✓ **Fuel deformation, relocation, and rupture following LOCA**
- **Needs for highly-fidelity analysis methods for the realistic simulation of PWRs**

MARS-KS(CTF) = (system + subchannel) analysis code

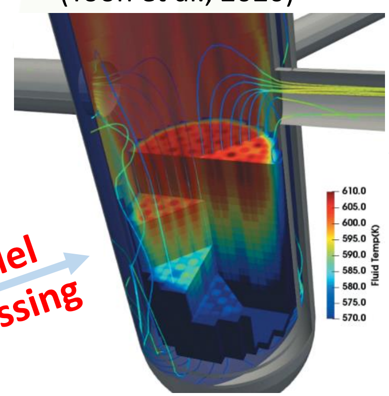
(Bang et al., 2019)



System codes
Multiple fuel rod modelling

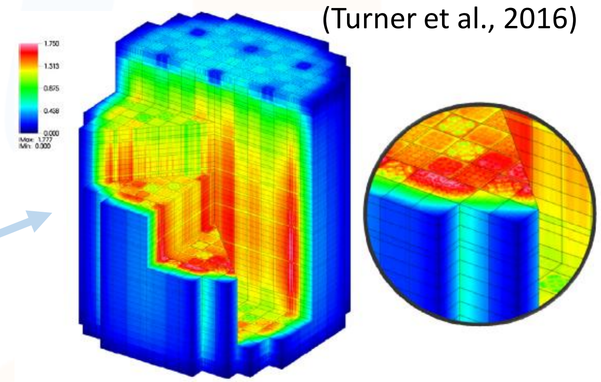
Parallel processing

(Yoon et al., 2020)



Coupled codes
(CUPID-RV)

(Turner et al., 2016)



Integrated platforms
(NURESIM, VERA-CS)

Multi-scale + Multi-physics

Introduction

❖ MARS-KS with CTF 3D subchannel analysis module

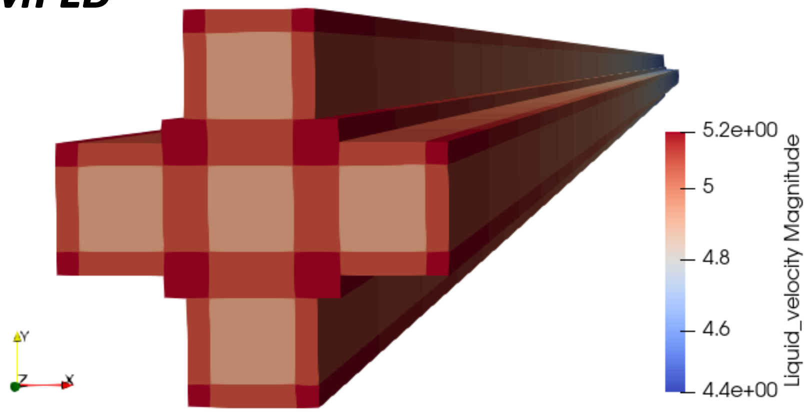
- ✓ Implicit pressure matrix coupling
- ✓ Coupling of point kinetics and 1D heat structure
- ✓ Parallel processing capability, towards the full core simulation
- ✓ Transient DNBR prediction
- ✓ Optimized storage, user-friendliness

❖ *Study objectives*

- ✓ ***MARS-KS(CTF) analysis for APR1400 MFLB***
  - Lumped core model
  - Transient DNBR prediction
- ✓ ***Full-core analysis challenges***
  - Parallel processing
  - Applications to SMRs and MRs

CASL 3x3 Hot Full Power Problem

MARS-KS(CTF) Parallelization Simulation



APR1400 MFLB Analysis Modeling

Subject case

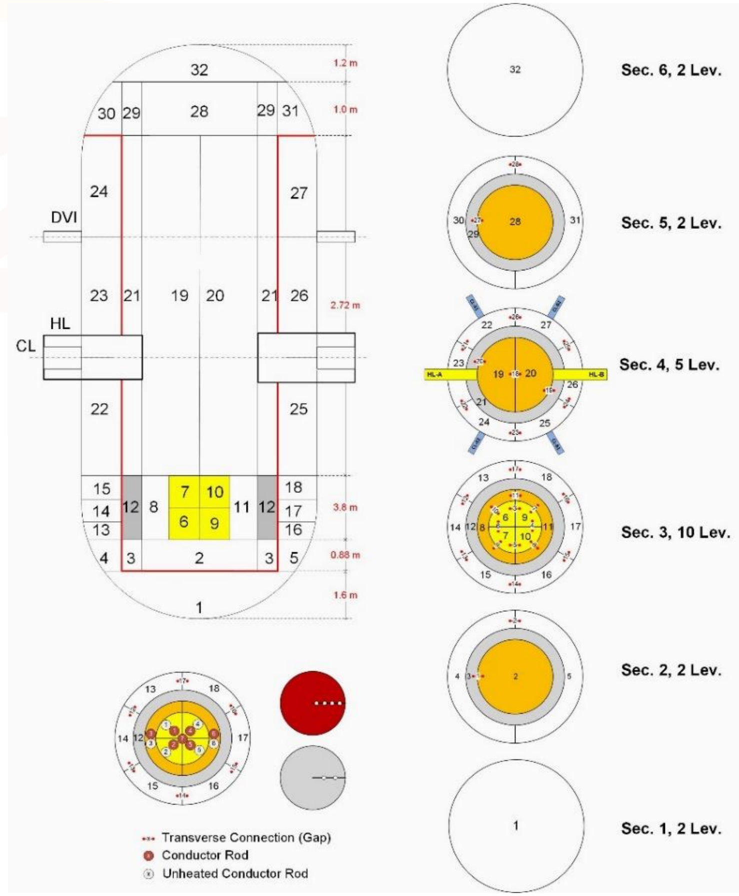
- ✓ **The limiting MFLB with the break size of 0.0372 m^2 downstream of the check valves with LOOP assumption**
- ✓ **Reversed flow from the nearest SG, resulting in rapid RCS heat-up and pressurization**

MARS-KS(CTF) 3D Core Model

- ✓ **32 lumped hydrodynamic channels**
- ✓ **7 lumped fuel rods**

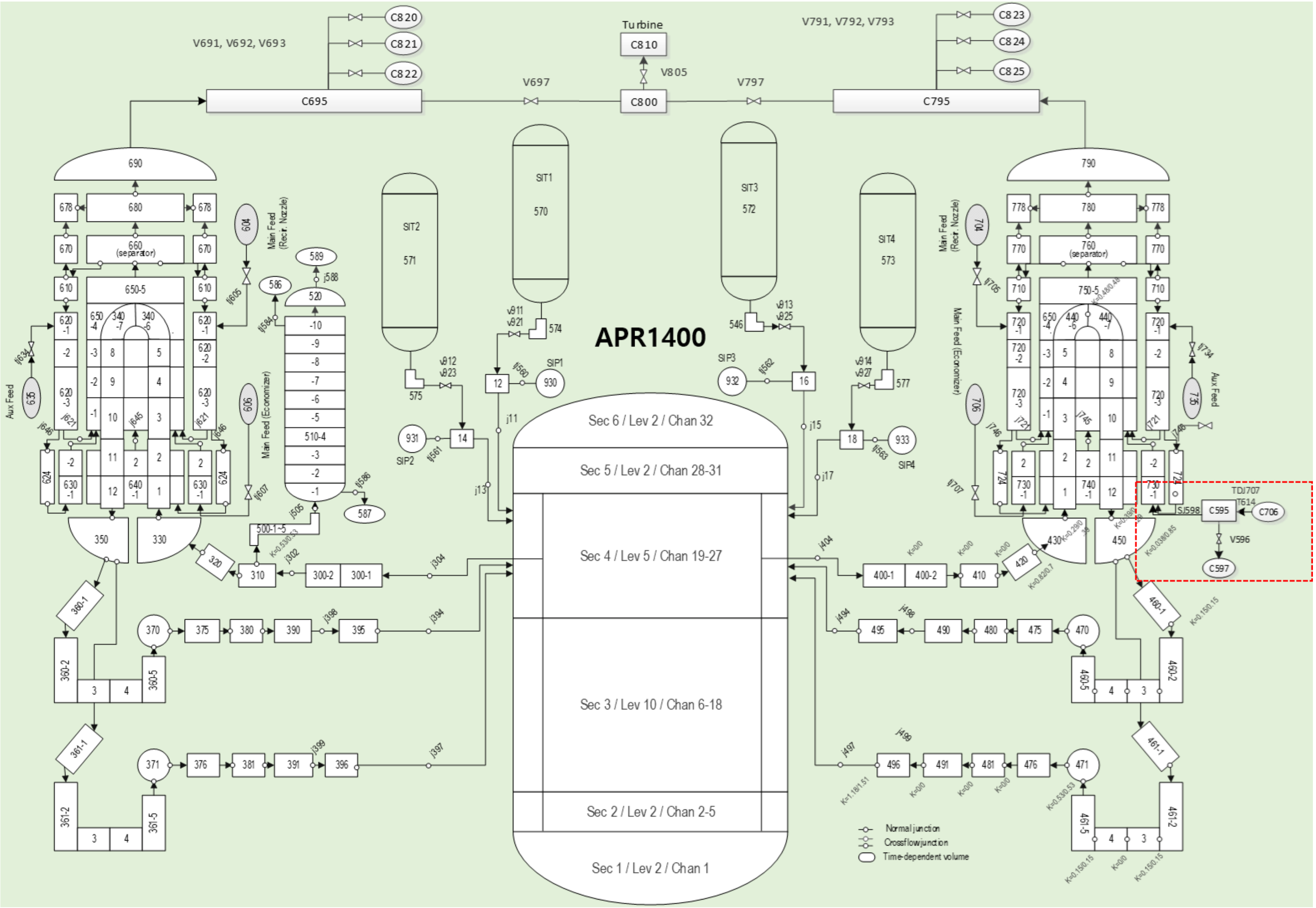
Initial and boundary conditions

Parameter	FSAR [3]	MARS/CTF
Thermal power, MWt	4062.66	4062.66
Core inlet temp. (K)	569.25	569.11
Core outlet temp. (K)	-	604.18
Core inlet flow (kg/s)	19,344	19,344
PRZ pressure (MPa)	15.65	15.65
PRZ volume (m^3)	39.91	39.91
Main steam flow (kg/s)	-	1143
SG pressure (MPa)	-	7.7
SG water level (m)	-	12.53
SG water inventory (kg)	97,046	97,046
CEA worth at trip (%Δρ)	-8.0	-8.0
MTC (10^{-4} %Δρ/°C)	0	0
Doppler reactivity	Least negative	Least negative



3D lumped APR1400 core model

APR1400 MFLB Analysis Modeling



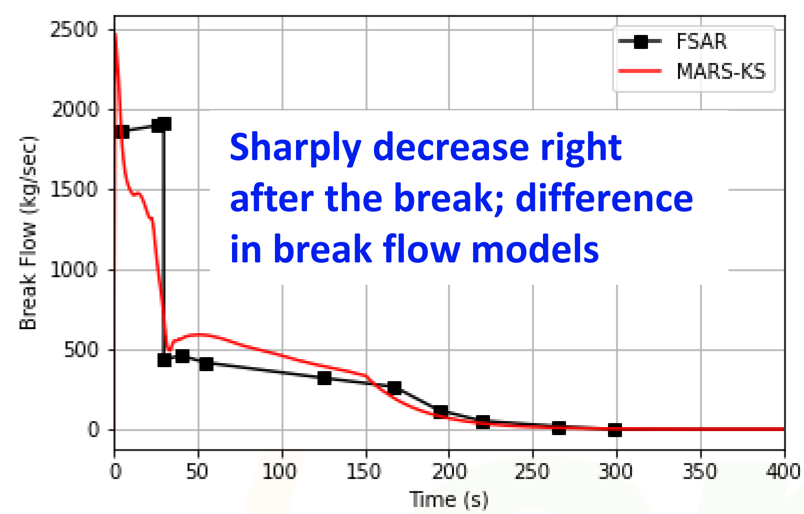
Results and Discussion

Sequence of Events

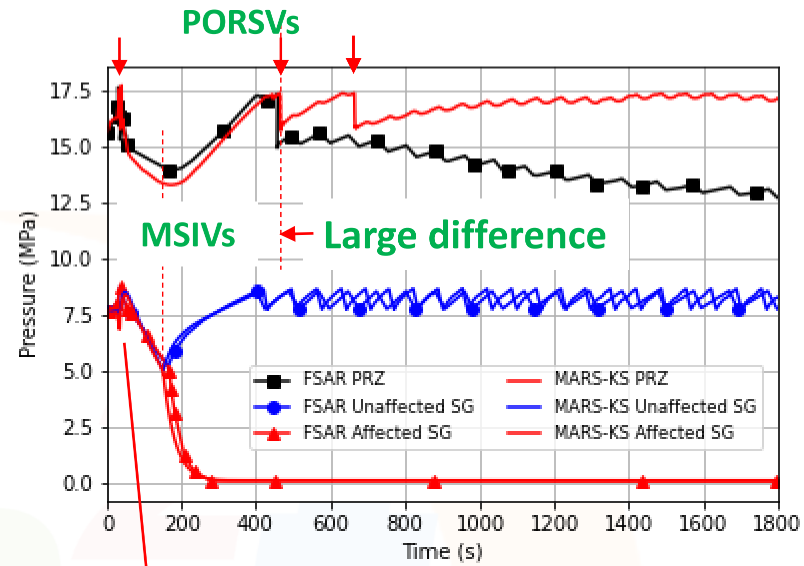
- **MARS-KS shows events with some delays in comparison with those of APR1400 FSAR (CESEC-III code).**
- **Meanwhile, AFWS starts earlier for MARS-KS => SG level faster decreases**
- **FSAR: MSSVs still open after 401.4s**
- **MARS-KS: Two more times short opening of POSRVs**

FSAR	MARS-KS	Events	Setpoints
0.0	0.0	Break initiates	0.0372 m2
26.38	32.15	High PRZ pressure signal	16.98 Mpa
27.13	32.90	Reactor trip; RCP trip Turbine valve closes	0.75s delay
-	33.00	RCP coastdown	0.1s delay
-	33.75	Rod drops	0.85s delay
27.37	35.00	POSRV opens	17.37 MPa
29.95	-	MSSVs open (unaff. SG)	8.59 MPa
38.0	37.00	POSRV closes	15.62 MPa
29.43	39.00	Maximum RCS pressure *(PORSV quickly open/close)*	17.73 MPa / 19.28 MPa
54.64	42.15	AFWS actuation signal	5% SG Level
116.1	103.6	AFW injection (unaff. SG)	41.01 kg/s
159.1	144.6	MSIVs closing signal (P_{SG})	5.17 Mpa
165.6	151.0	MSIVs close	
401.4	422.0	MSSVs open	
-	431.0	MSSVs close	8.59 MPa
457.3	466.0	POSRV opens	
459.7	468.0	POSRV closes	
-	666.0	PORSVs open/close	
1800	1800	END	

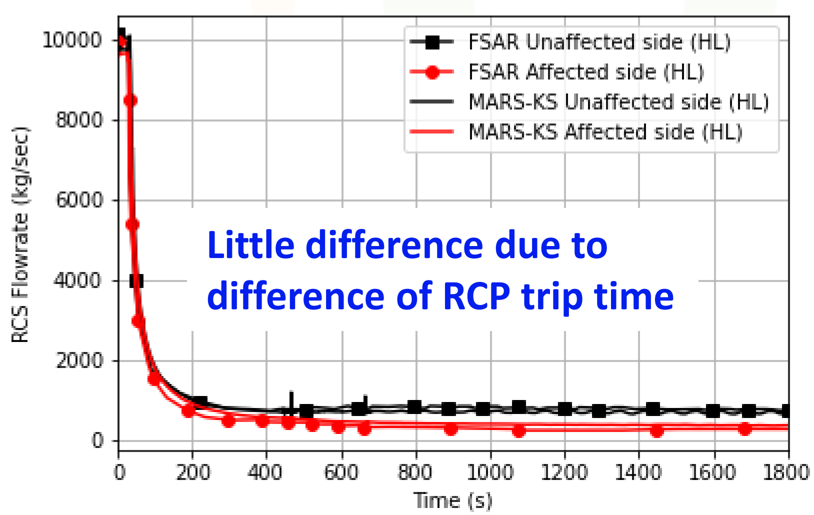
Results and Discussion



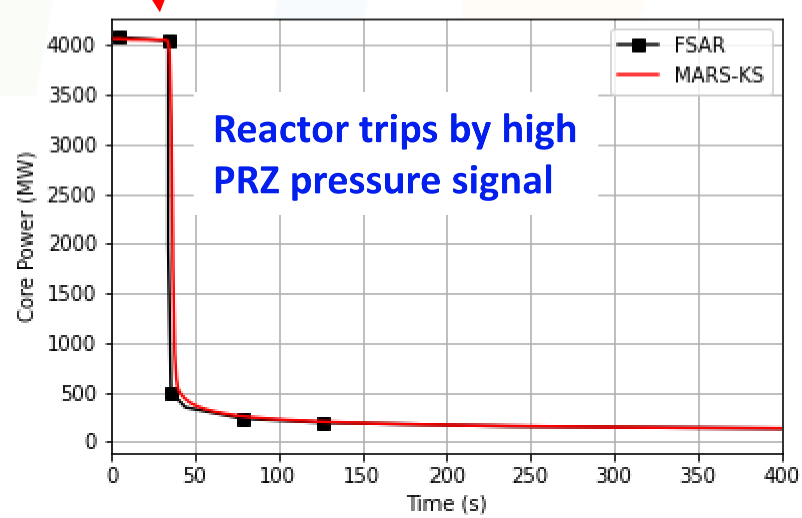
<Break Flow>



<System Pressure>

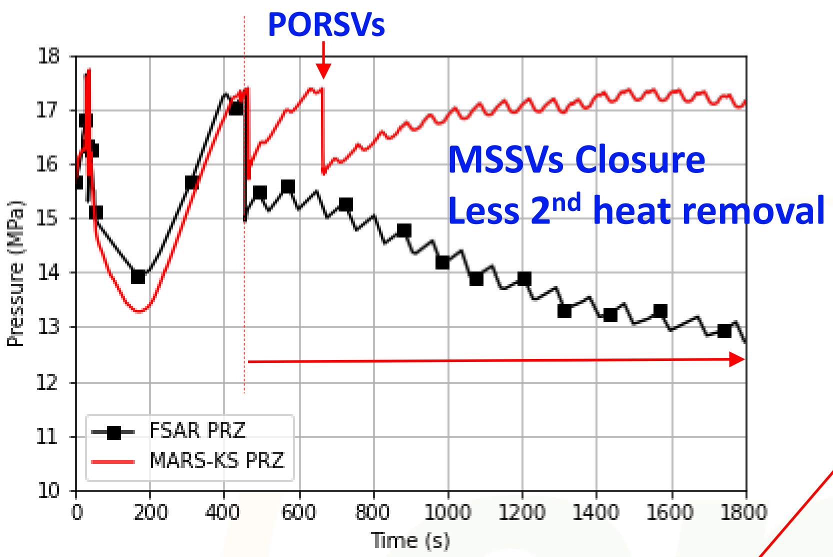


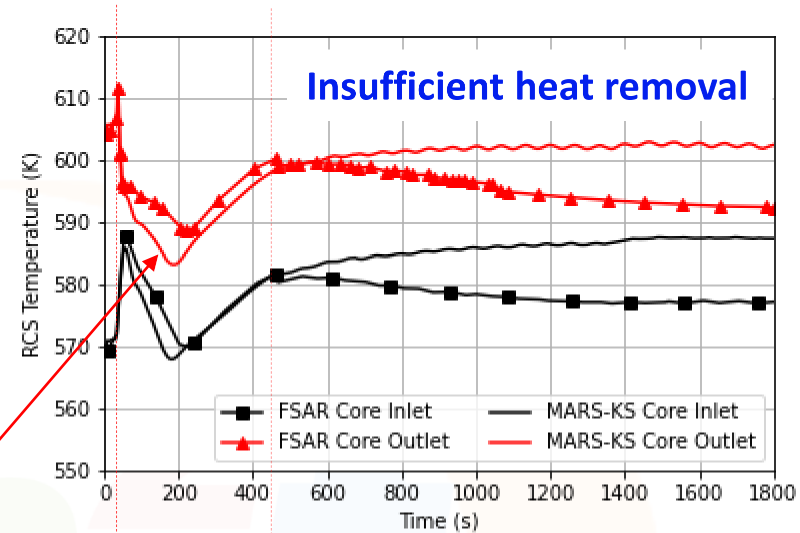
<RCS Flow>



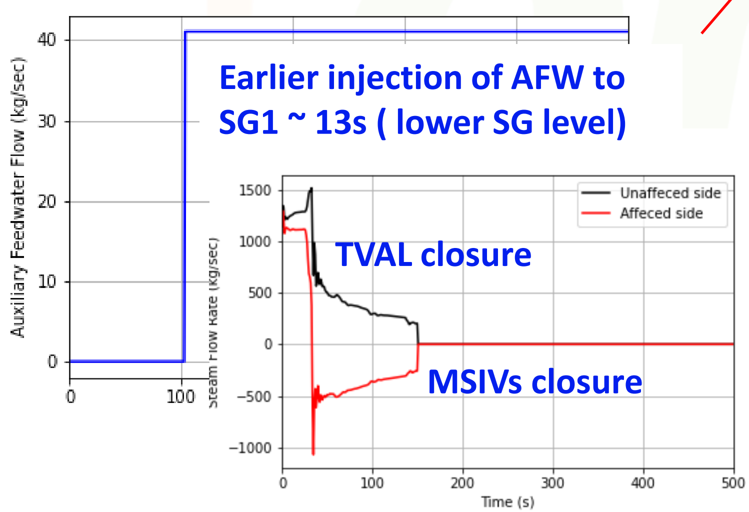
<Power>

Results and Discussion

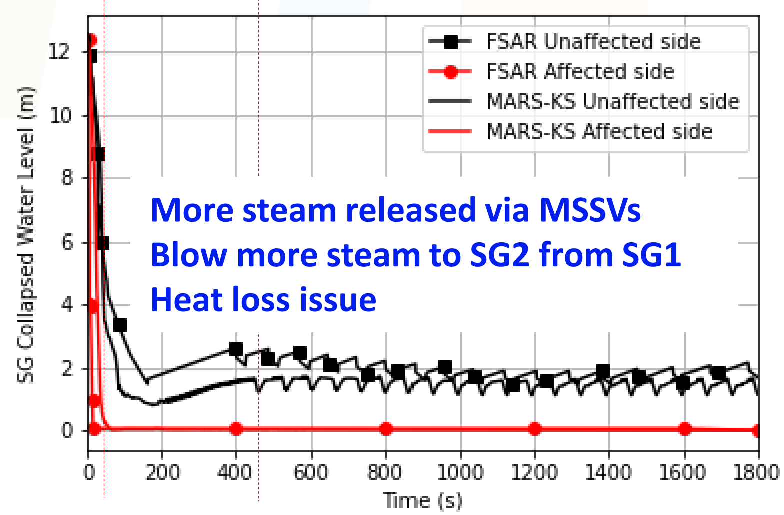




<Coolant Temperature>



<AFW & Steam flow>



<SG Level>

Results and Discussion

❖ APR1400 MDNBR limit of 1.29

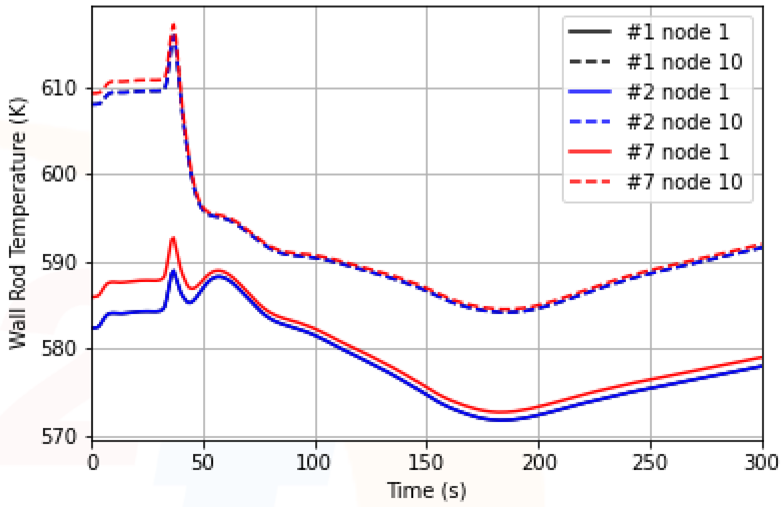
✓ MARS-KS(CTF)

- MNDBR = 1.32 at 37 seconds
- 3D CTF subchannel module
- Groenevel look-up table for CHF

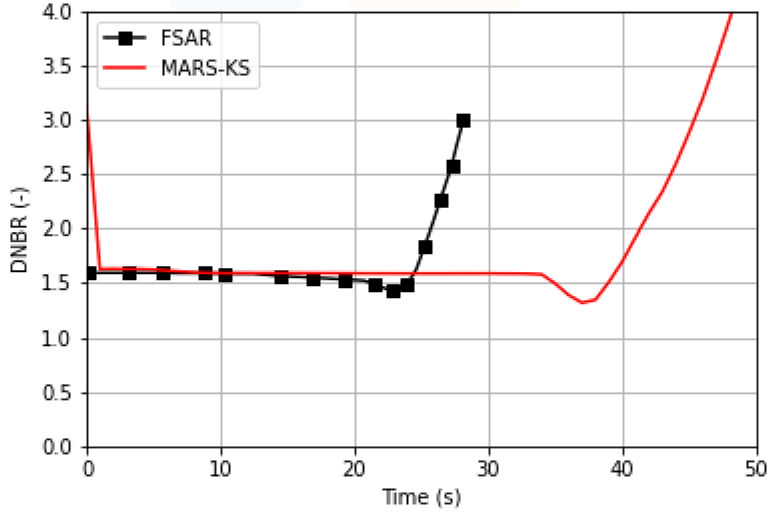
✓ APR1400 FSAR

- Almost the same
- KCE-1 CHF correlation
- CETOP-D code: DNBR calculation
  - ✓ External link

<Fuel rod temperature>



<MDNBR>



MARS-KS Parallelization Challenges

❖ Parallel processing for full core modelling

- ✓ A large number of subchannels, gaps, and rods (~ million-cells mesh)
- ✓ A realistic and high-resolution of core thermal-hydraulic behaviors
- ✓ Benefit for SMRs and MRs: SMART, Badi-S
- ✓ Expensive computational cost (impossible with serial calculation)

MARS-KS Parallel processing for CASL 3x3 HFP
64 channels, 108 gaps, 45 rods, 3136 cells

MARS-KS(CTF): 46.72 secs / 1 sec transient calc.

CTF : 44.36 secs / 1 sec transient calc.

Challenges

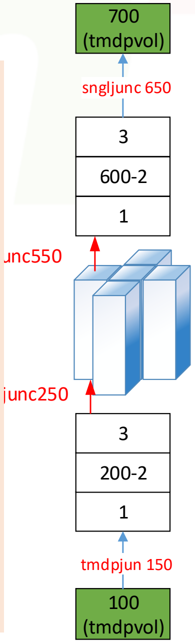
1) Reactor vessel meshing

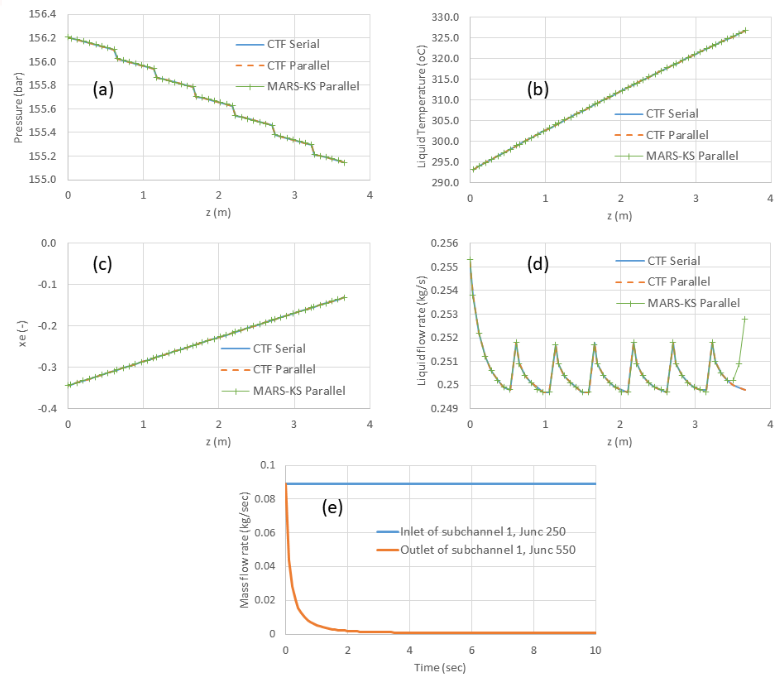
- Extend core region to whole RV (lower & upper plenums, DC)

2) Use of 3D reactor kinetics

- Point kinetics give the same power distribution for every time step

3) Insufficiency of 3D input data





Conclusions & Remarks

- **MARS-KS calculation results for APR1400 MFLB are comparable with the APR1400 FSAR**
  - ✓ **Most T/H parameters are well matched**
  - ✓ **However, considerable differences were observed for primary pressure, RCS temperature, and SG collapsed level**
- **Parallelization of MARS-KS is necessary for full core safety analysis, but faces some challenges**
  - ✓ **Generate a mesh for whole reactor vessel**
  - ✓ **Core power simulation**
  - ✓ **Need specific 3D input data**
- **Applications for MARS-KS Parallel Processing with CTF 3D Subchannel Module**
  - ✓ **Multi-Scale, Multi-Physics simulation of the Reactor : Full Core Safety Analysis**
  - ✓ **Transient DNBR Evaluation for Full Core Safety Analysis**
  - ✓ **Developments of Real-time Safety, Accident Prevention & Mitigation Management Platform**
  - ✓ **Development of real-time Self-driving platform for SMRs and MRs**

THANK YOU

Acknowledgement

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