ULSAN NATIONAL INSTITUTE OF
SCIENCE AND TECHNOLOGY

Anticipated Transient without Scram Assessment of SM-SFR using SAS4A/SASSYS-1

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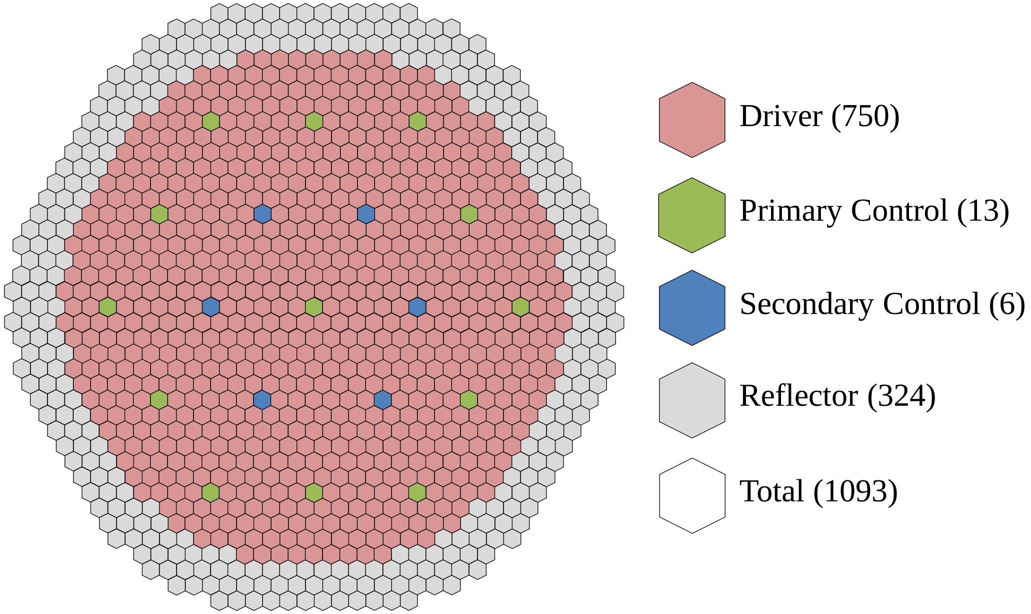
COmputational Reactor Physics & Experiment lab

Contents

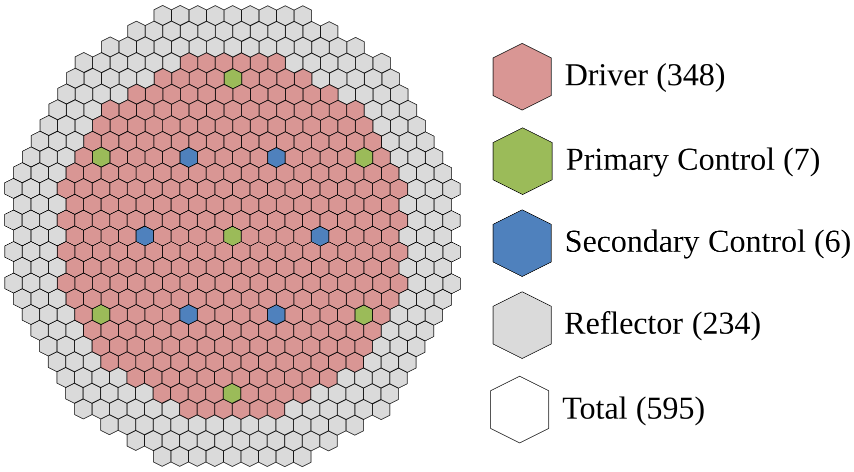
Introduction

▪ Fast Reactor Development in UNIST

- Ultra-long Cycle Operation: 60-year EFPD
- UCFR-1000 & UCFR-100
- Natural uranium for upper blanket
- Breeds in axial direction
- PWR spent fuel loading feasible
- Power flattening study with thorium blanket



UCFR-1000 Core Layout



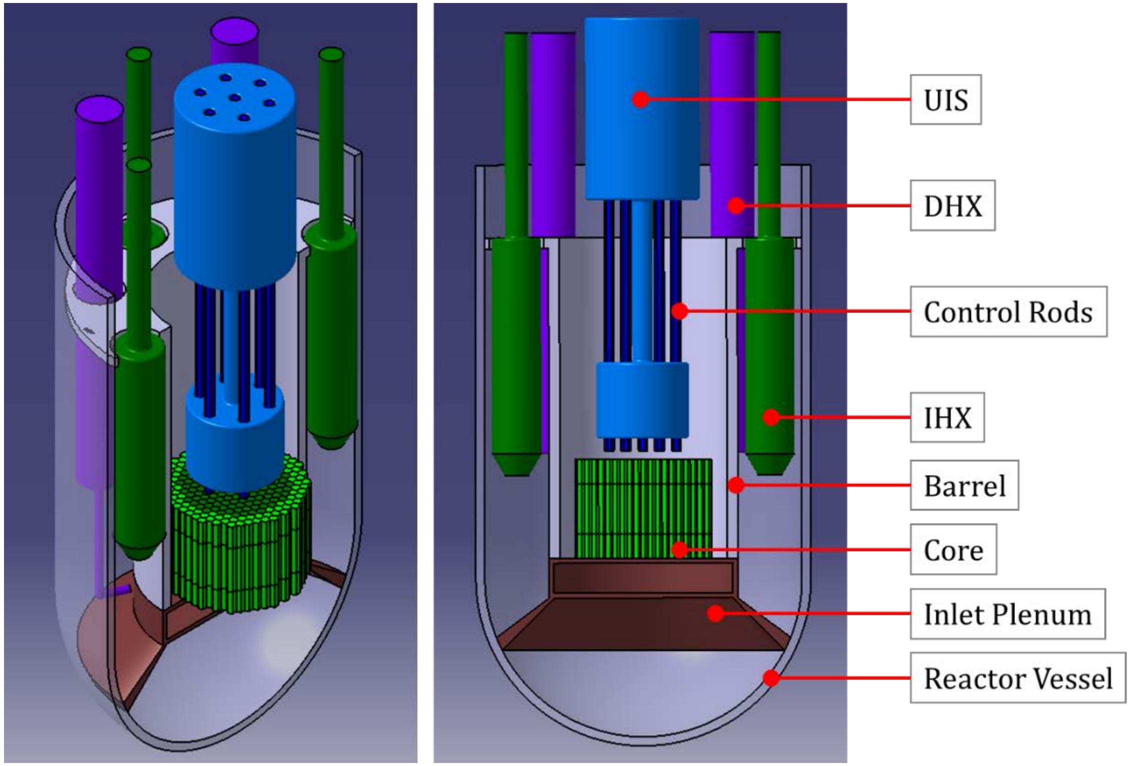
UCFR-100 Core Layout

Development of SM-SFR

SM-SFR

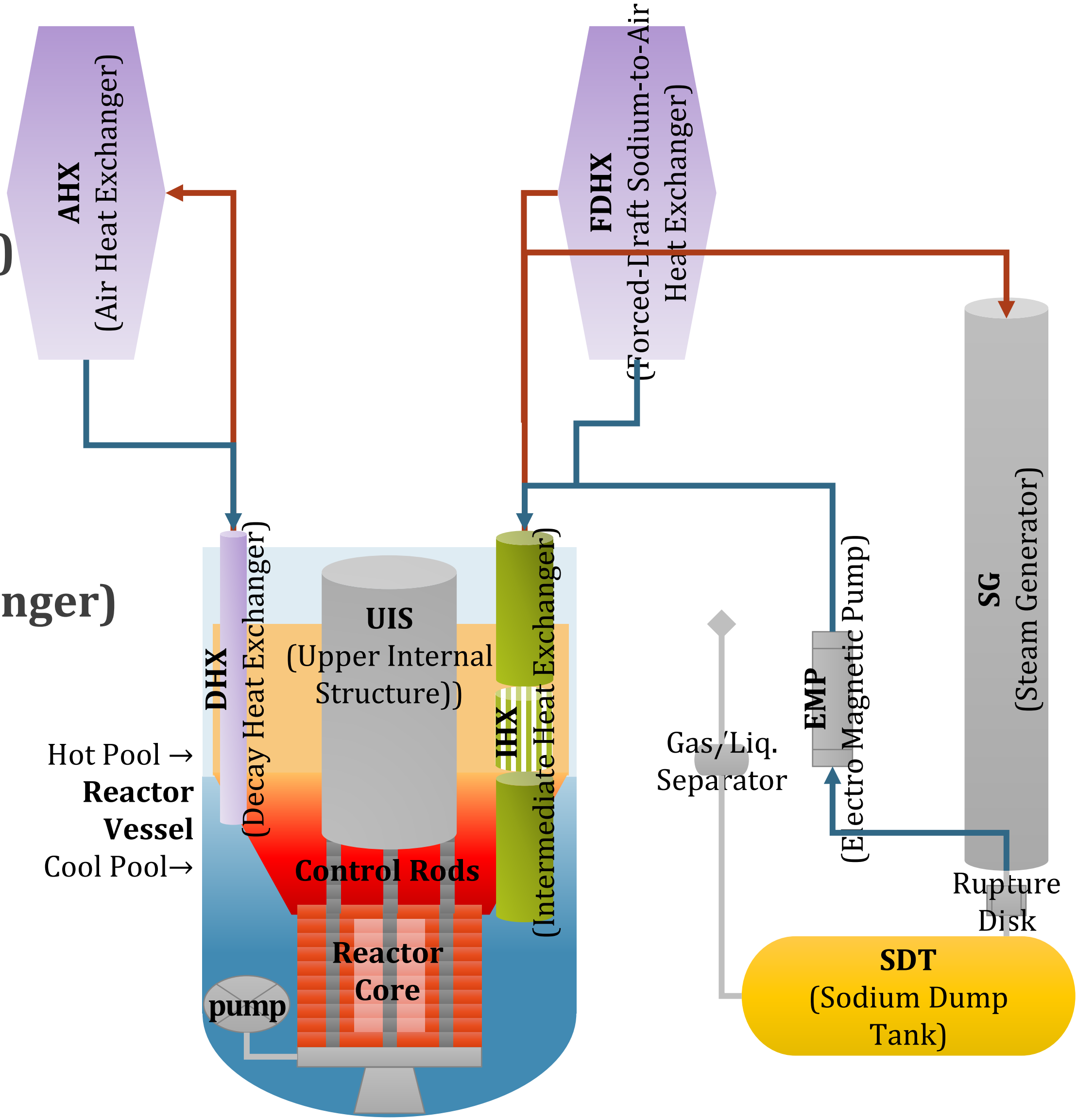
- A combination concept of SMR and SFR
- Ultra-long cycle operation in neutronics point of view
- Feasibility for PWR spent fuel loading as blanket material

Parameter	Value
Electric power [MW]	100
Thermal efficiency [%]	<42
Cycle length [year]	**30**
Core barrel diameter [m]	**<3**
Inlet temperature [°C]	355~395
Outlet temperature [°C]	510~550
Fuel form	**U-10Zr (SF-7Zr)**
Cladding material	HT-9
Fission Gas Emission	Venting
Fuel enrichment [%]	<20
Average burnup [at%]	10<
Average volumetric power density [kW/l]	30~80
Reactivity Swing [pcm]	**<1000**



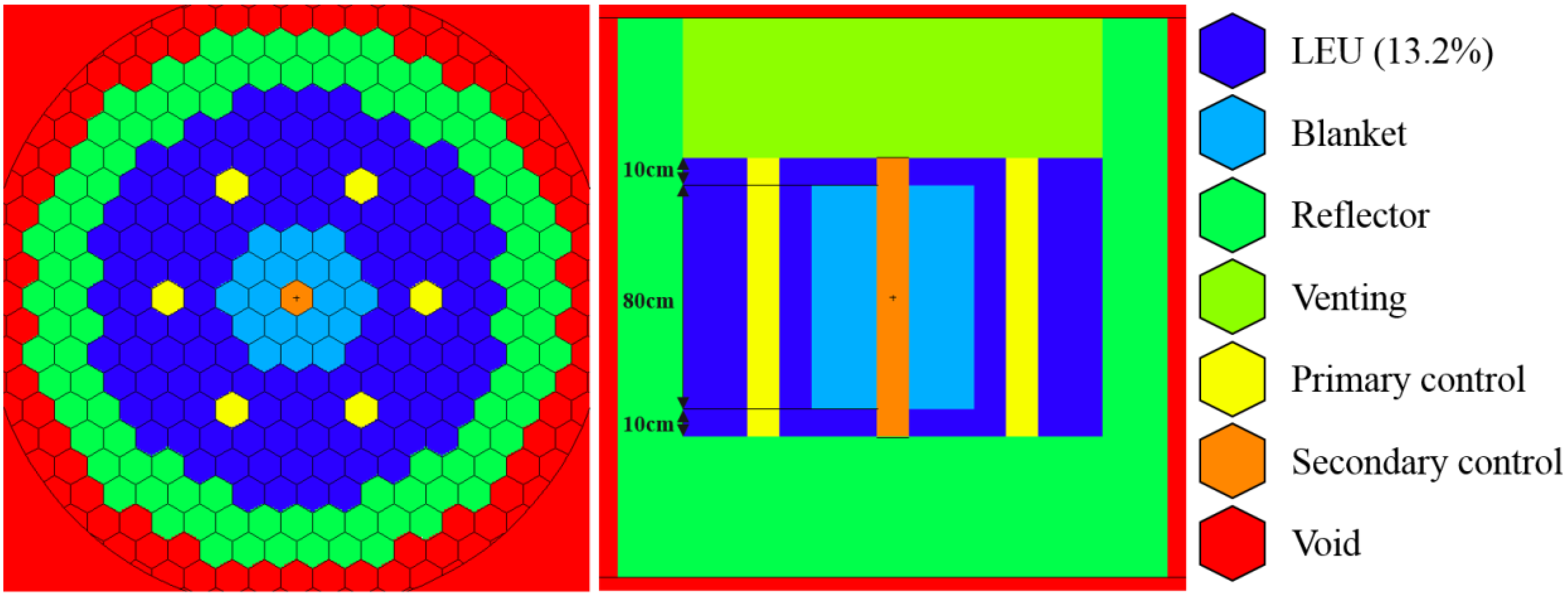
Development of SM-SFR

- **Reactor Components outside Core**
  - Around Core
    - Reactor Vessel
    - Core Support Plate
    - UIS (Upper Internal Structure)
    - Pump
  - Fluid System
    - DHX (Decay Heat Exchanger)
    - AHX (Air Heat Exchanger)
    - IHX (Intermediate Heat Exchanger)
    - FDHX (Forced-Draft Sodium -to-Air Heat Exchanger)
  - Secondary System
    - SG (Steam Generator)
    - EMP (Electro Magnetic Pump)
    - SDT (Sodium Dump Tank)



▪ Design of SM-SFR Core

- Operation: 100MWe, 30-year operation time
- Geometry: core barrel <3 m, vented fuel concept
- Fuel: binary metallic, enrichment <20%
- Depletion: Avg. burnup >10%, reactivity swing < 1000 pcm

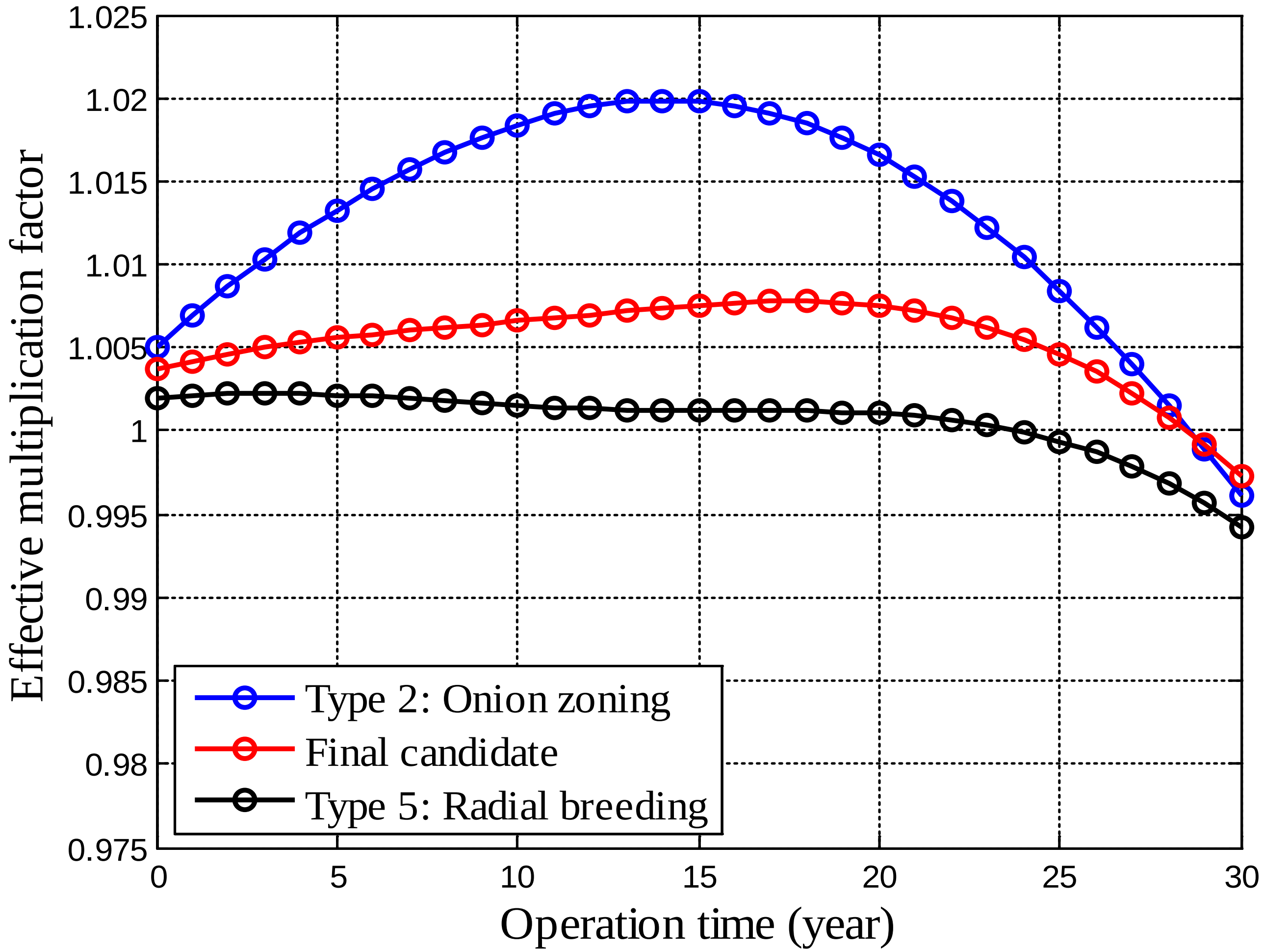


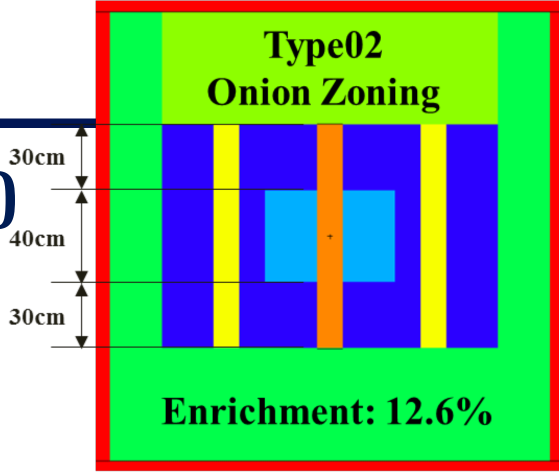
Core radial view

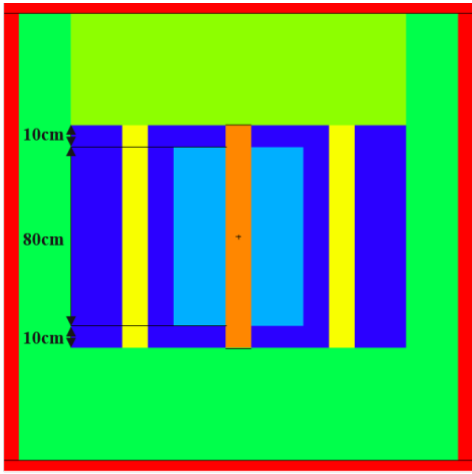
Core axial view

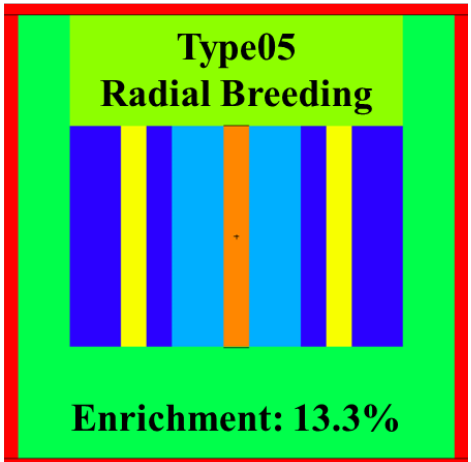
Development of SM-SFR

- **Multiplication Factor (Operation Feasibility)**
  - **Minimized reactivity swing by model combination**









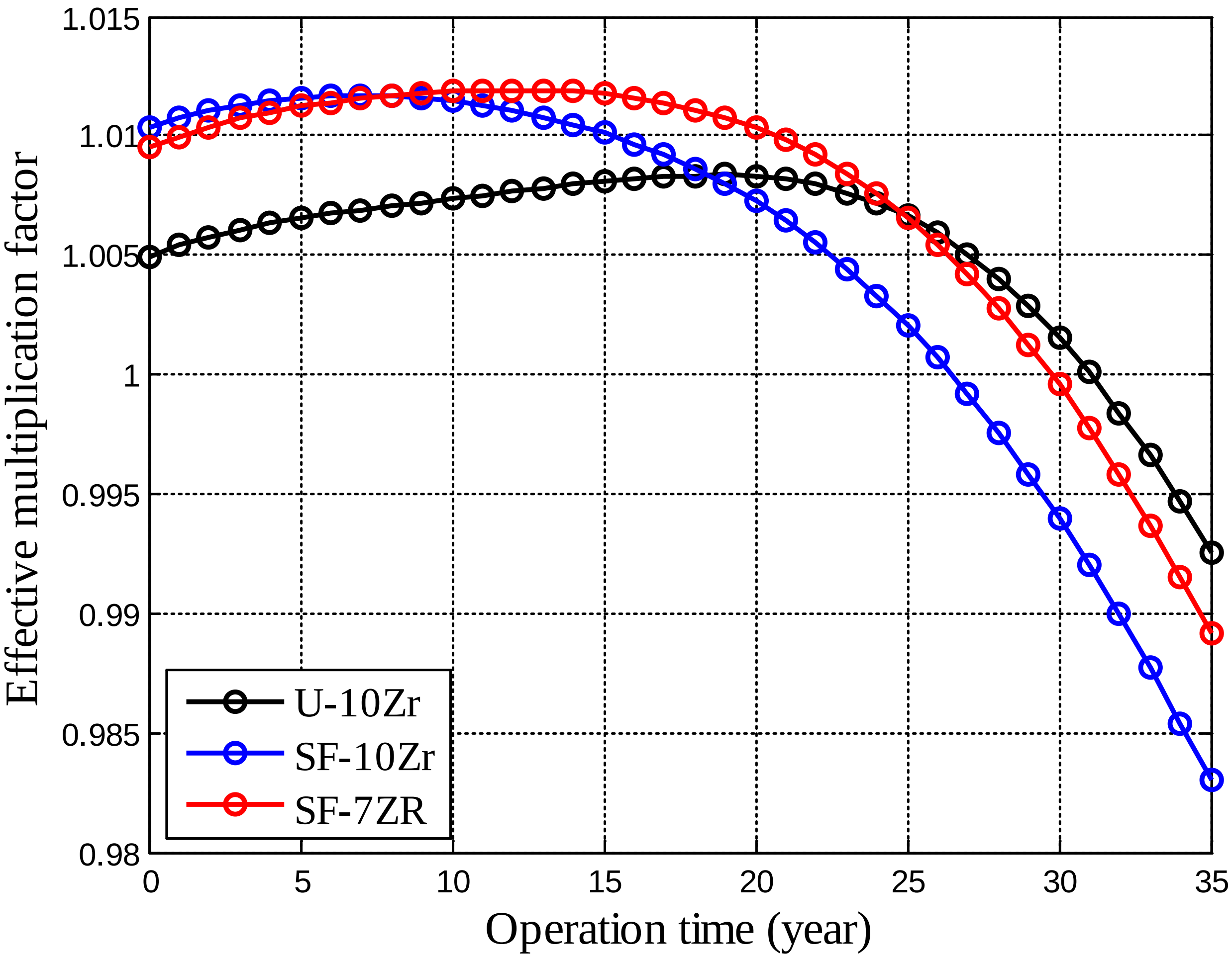
Kinetics Parameters and Reactivity Feedback Coefficients

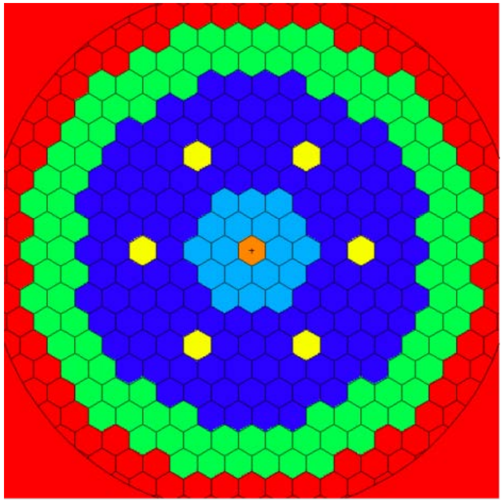
- Negative sodium and expansion reactivity

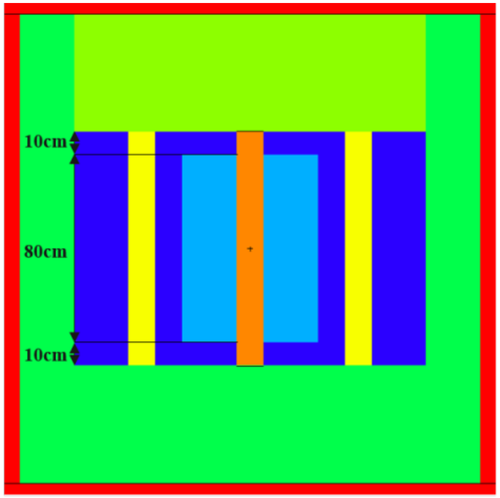
		BOL	MOL	EOL
Effective Multiplication Factor, k_{eff}		1.00373	1.00761	0.99735
Effective Delayed Neutron Fraction, β_{eff}		**0.00719**	**0.00535**	**0.00428**
Prompt Lifetime	μsec	0.279	0.267	0.245
Sodium Void Worth (85% void)	**$**	**-2.160**	**-0.819**	**-0.559**
Fuel Density Coefficient	¢/ °C	-0.173	-0.230	-0.298
Structure Density Coefficient	¢/ °C	0.011	0.030	0.046
Sodium Density Coefficient	¢/ °C	-0.043	0.011	0.070
Doppler Coefficient	**¢/ °C**	**-0.300**	**-0.272**	**-0.220**
Radial Expansion Coefficient	**¢/ °C**	**-0.158**	**-0.190**	**-0.225**
Axial Expansion Coefficient	**¢/ °C**	**-1.186**	**-0.998**	**-0.920**
Primary Control Rod Worth	pcm/cm	-78.286	-71.052	-56.458
Secondary Control Rod Worth	pcm/cm	-3.368	-12.500	-24.741

▪ PWR Spent Fuel Loading in Blanket

- More ^{235}U, Less ^{238}U
- Greater initial k_{eff}, less breeding, shorter cycle length







Safety Analysis of SM-SFR

Safety Analysis of SM-SFR

▪ Anticipated Transient Without Scram (ATWS)

- **ULOF: Unprotected Loss of Flow**
- **ULOHS: Unprotected Loss of Heat Sink**
- **UTOP: Unprotected Transient Over Power**

	Cause	Initial Transient	Response
ULOF	-Power loss -Piping fault	-Flow reduction -Inlet T fixed	-Flow coast down -Power/flow increase -Negative reactivity
ULOHS	-IHX failure -Heat sink loss	-Inlet T increase -Primary flow fixed	-Negative reactivity -Power/flow decrease
UTOP	-Single control rod withdrawal	-Flow fixed -Inlet T fixed	-Positive reactivity -Power/flow increase

Safety Analysis of SM-SFR

- **SAS4A/SASSYS-1**
  - Developed in Argonne National Laboratory
  - Thermal-hydraulic & neutronic (point kinetics) analysis of power and flow transient for liquid metal cooled fast reactor (LMR)
  - Analyze severe accidents transient or core disruption with coolant boiling and fuel melting
  - Assess design basis accident (DBA) analysis and beyond design basis accident (BDBA) analysis

- **Mini-SAS**
  - Limited version
  - 5 channels
  - Without severe accident capability

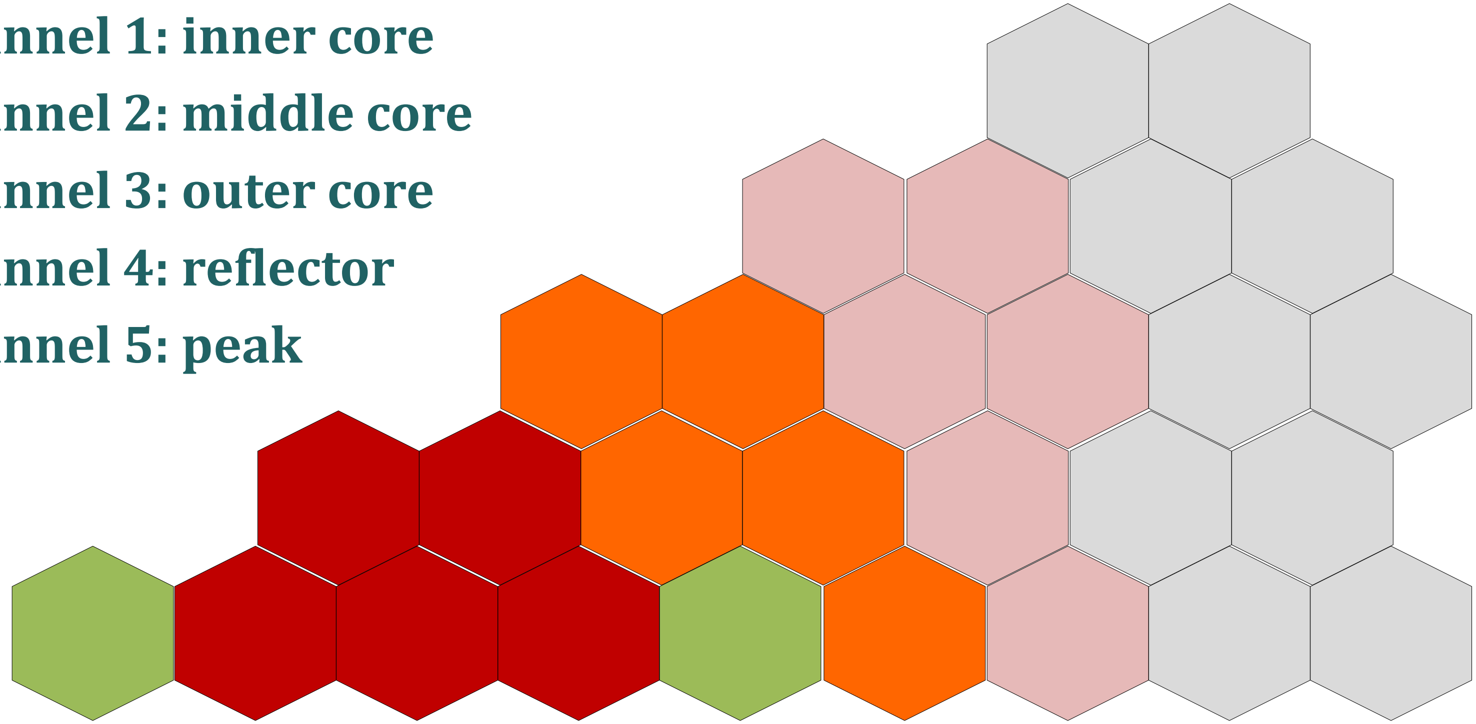
Safety Analysis of SM-SFR

▪ Reactor Parameters

- Primary flow rate (average): 1224 kg/s, (0.093 kg/s per pin)
- Average linear power density: 17.3 kW/m

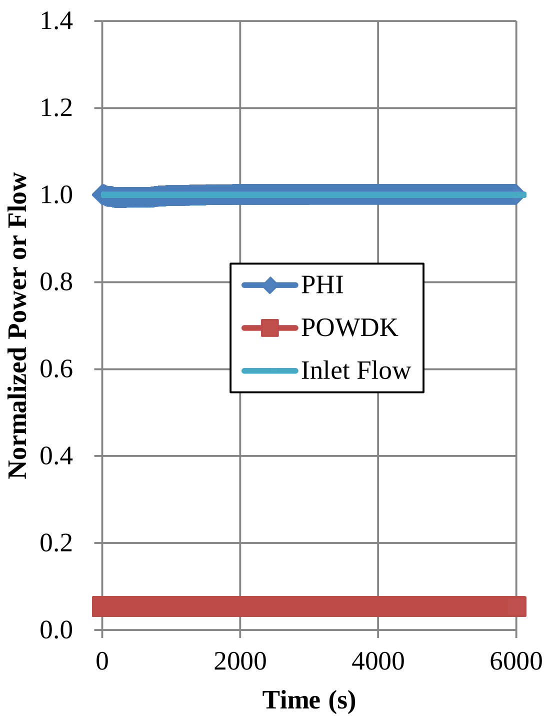
▪ Channel Assignment

- Channel 1: inner core
- Channel 2: middle core
- Channel 3: outer core
- Channel 4: reflector
- Channel 5: peak

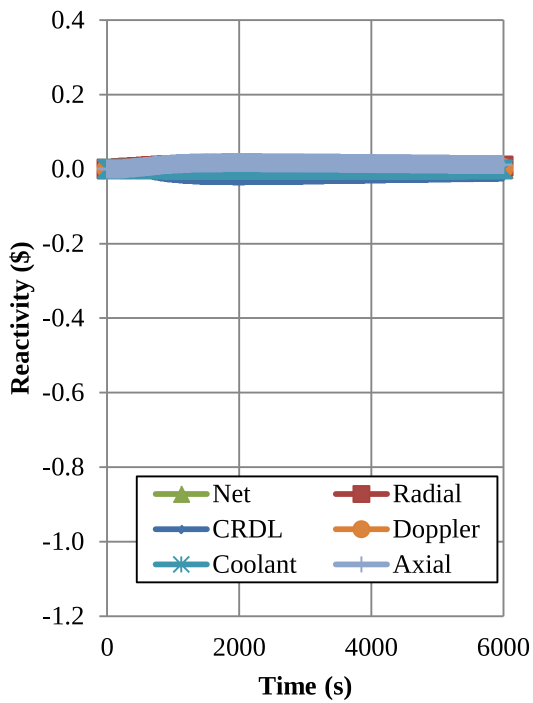


▪ Steady State Condition at Full Power

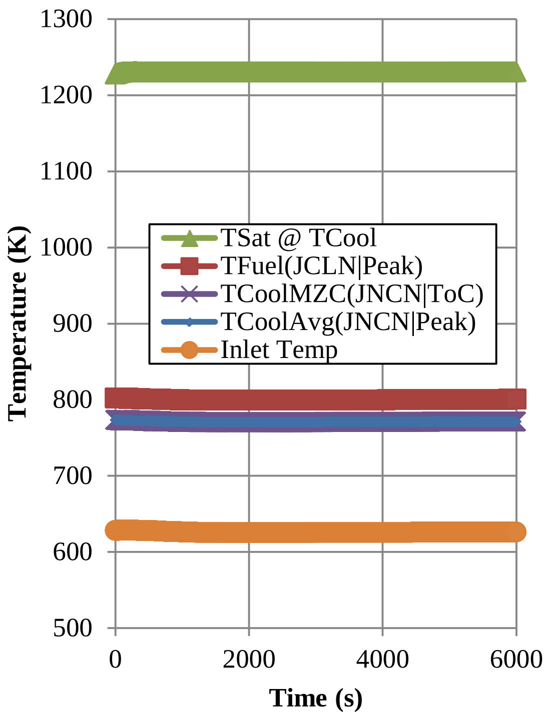
- Confirmed code get steady with null transient for the reactor design
- Power, flow, reactivity, temperatures from channel data file



Normalized power and inlet flow



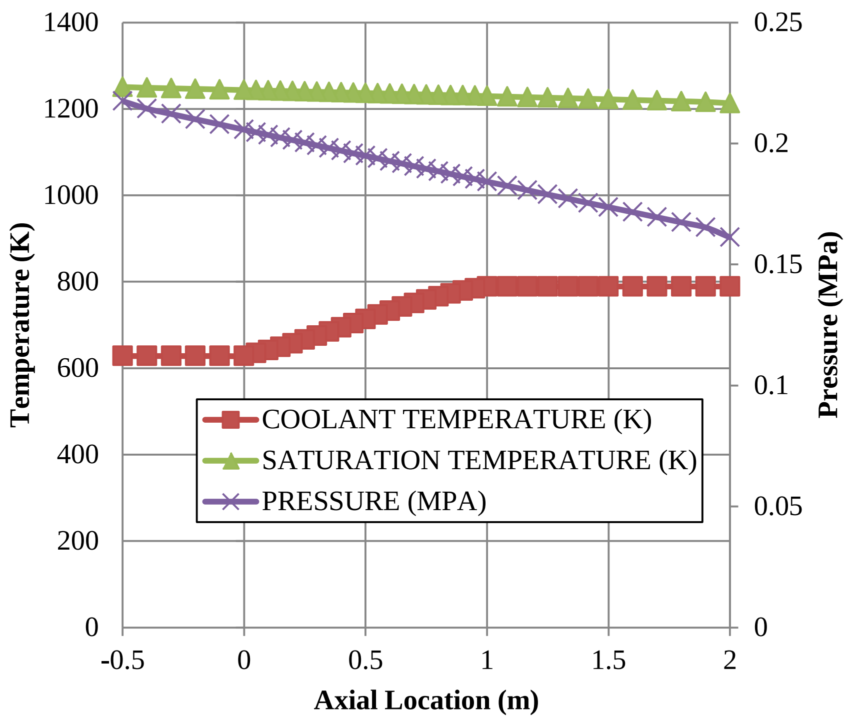
Reactivity profile



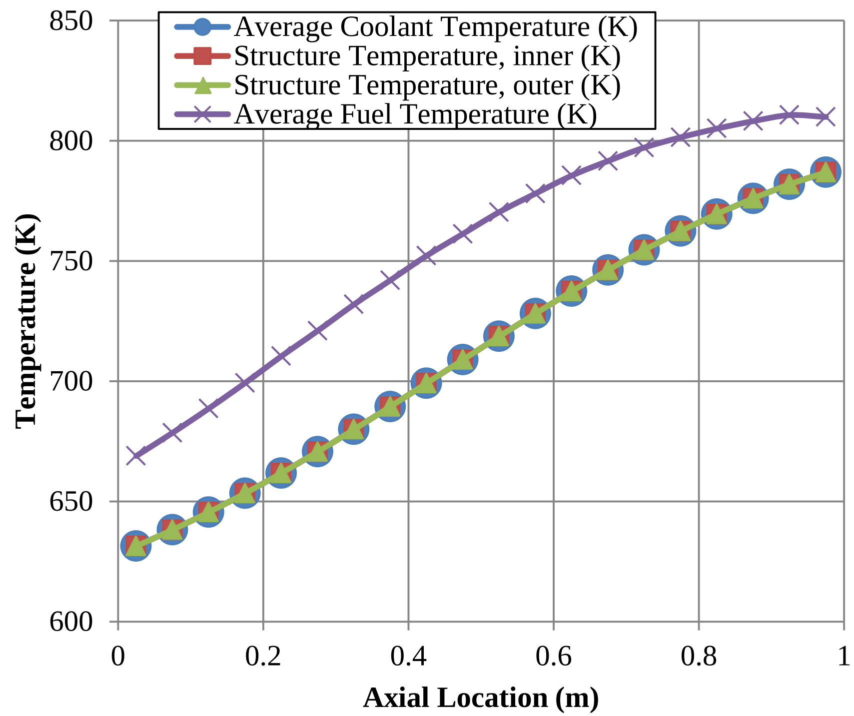
Temperature change

▪ Steady State Condition at Full Power

- Confirmed code get steady with null transient for the reactor design
- Channel temperature profile from output



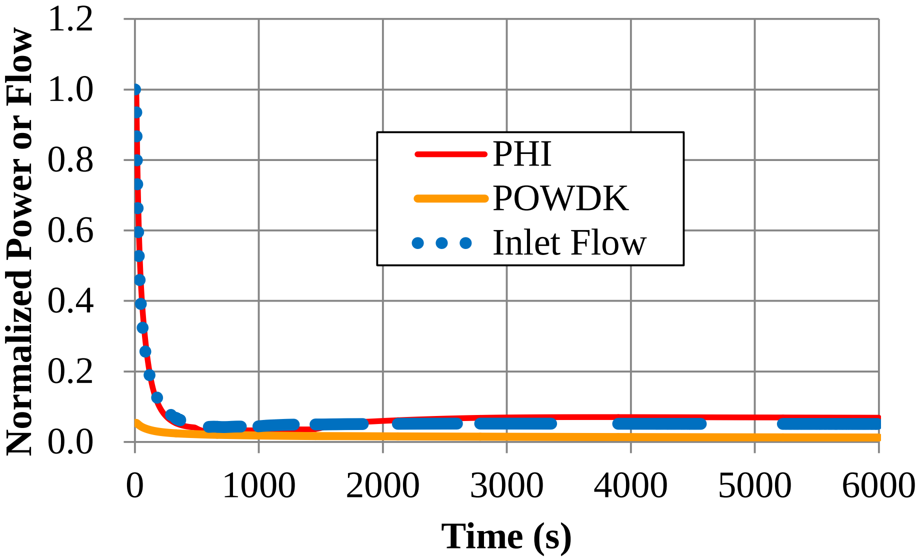
Peak channel condition along axial level

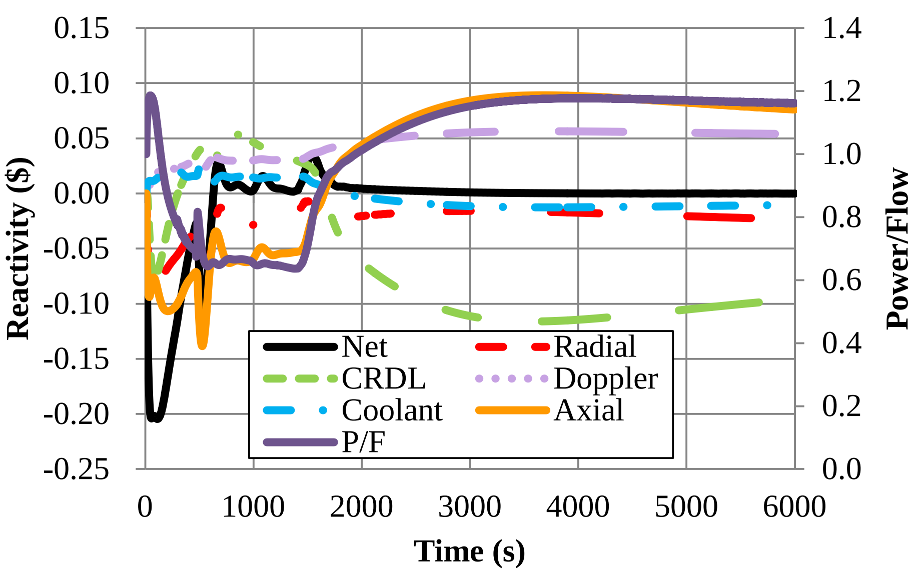


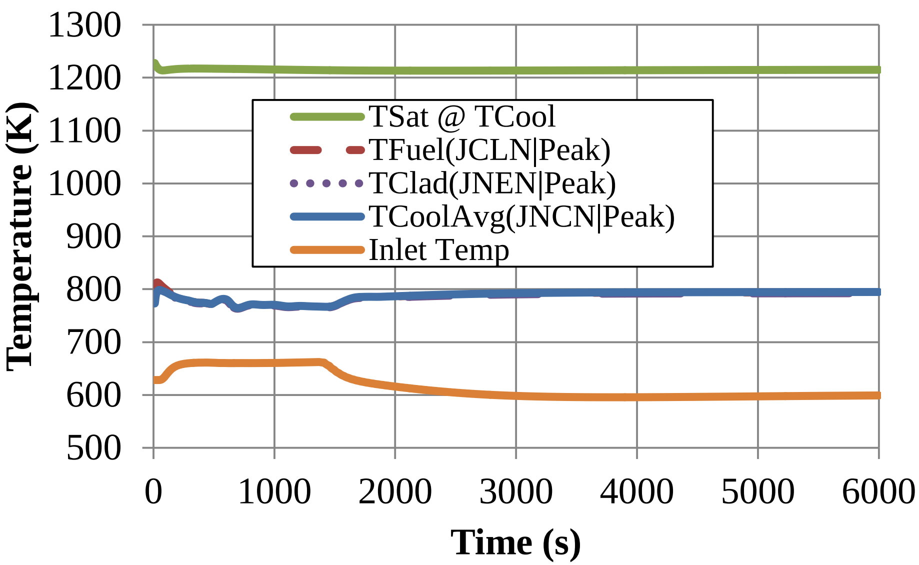
Peak channel temperature along axial level

Safety Analysis of SM-SFR

- **ATWS analysis**
  - **ULOF**
    - P/F greater than unity until 142 s
    - Temperatures increase temporary
    - Strong negative reactivity
    - Core temperature decrease

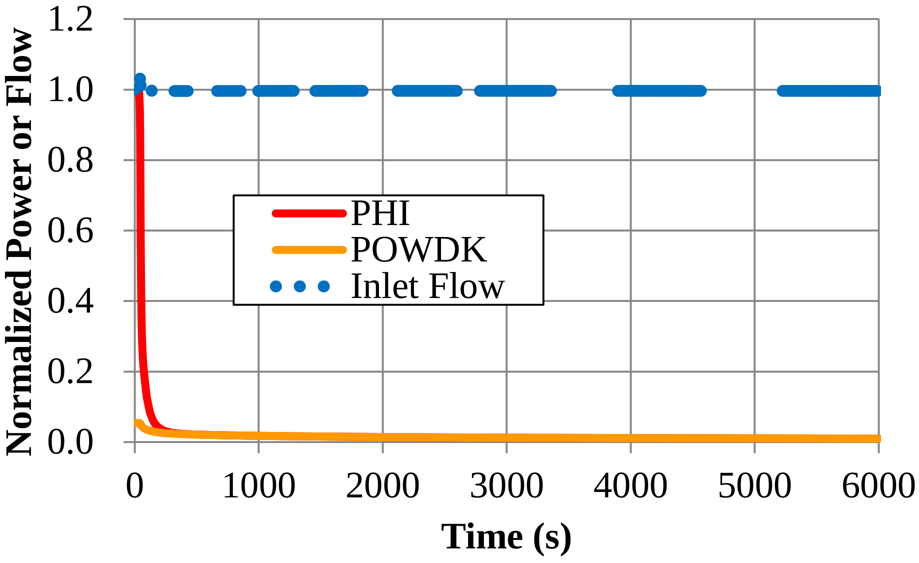


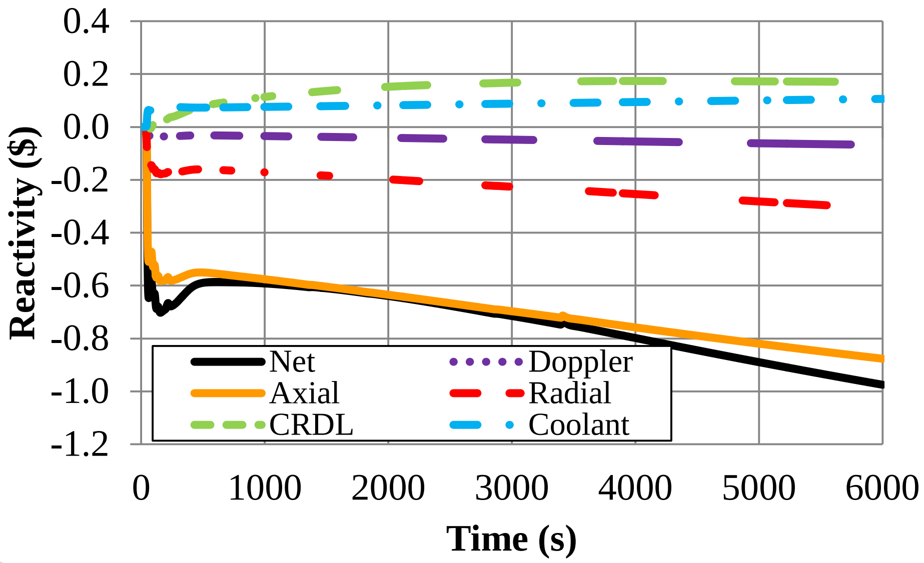


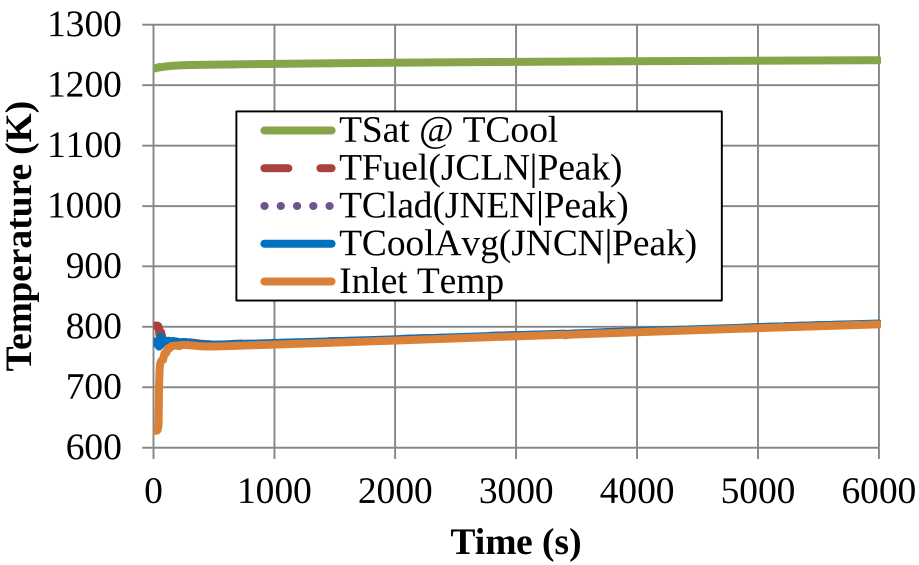


Safety Analysis of SM-SFR

- **ATWS analysis**
  - **ULOHS**
    - Inlet temperature increase
    - Net negative reactivity
    - Power decrease

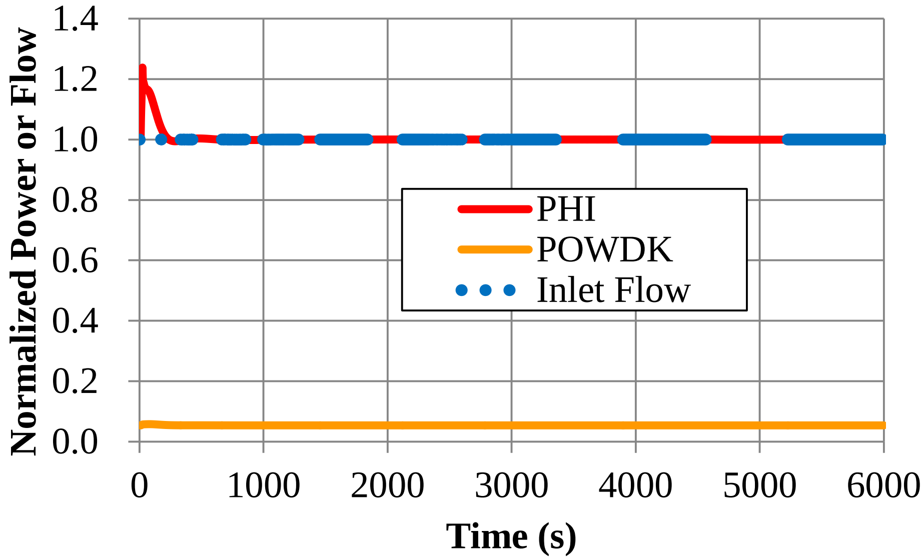


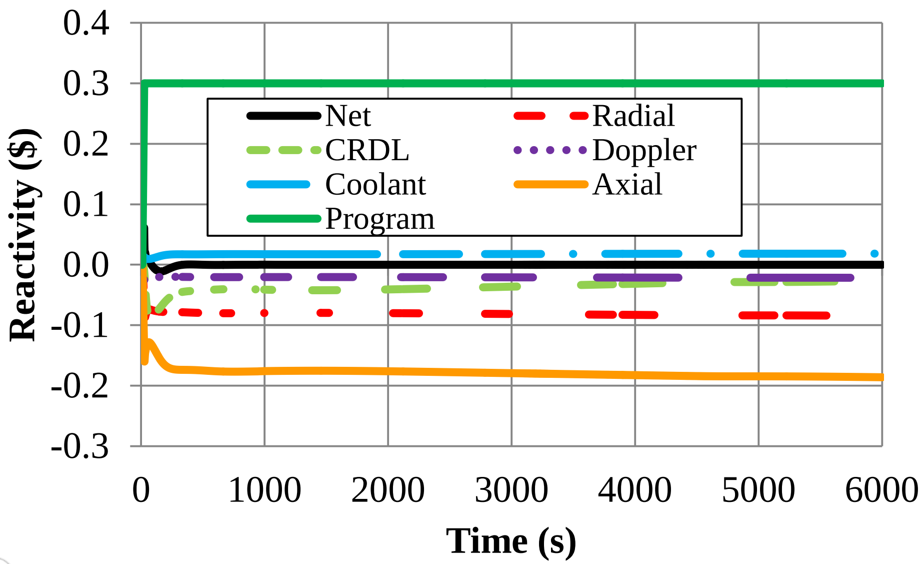


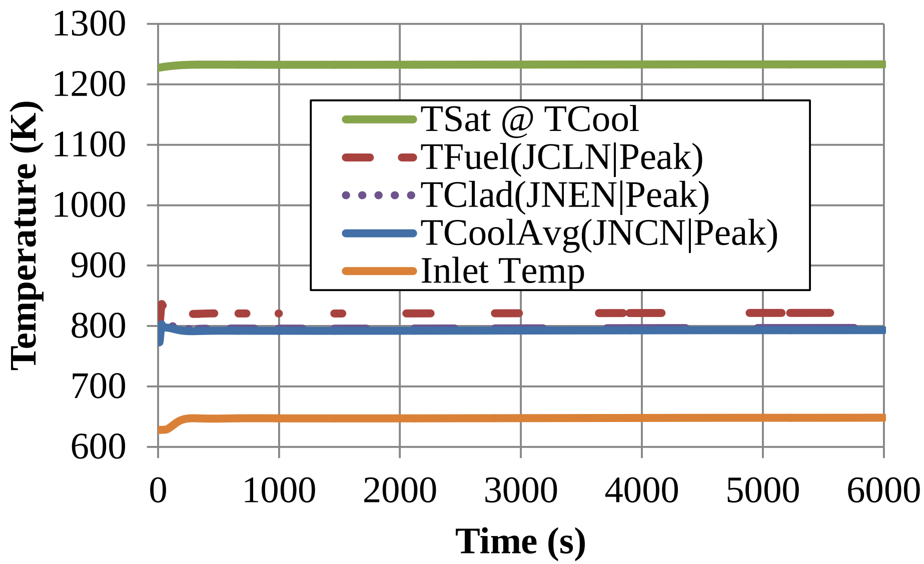


Safety Analysis of SM-SFR

- **ATWS analysis**
  - **UTOP**
    - 30 cents through 15 seconds
    - Drastic power increase temporary
    - Strong negative reactivity
    - Power decrease back







▪ Quasi-static Reactivity Balance

$$A = \left(\alpha_D + \alpha_{Ax}\right)\Delta T_f,$$

$$B = \left(\alpha_D + \alpha_{Ax} + \alpha_{Na} + 2\alpha_{CR} + 2\alpha_{Ra}\right)\frac{\Delta T_c}{2},$$

$$C = \alpha_D + \alpha_{Ax} + \alpha_{Na} + \alpha_{Ra},$$

α_D: Doppler coefficient
α_{Ax}: Fuel axial expansion reactivity coefficient
α_{Na}: Sodium density reactivity coefficient
α_{CR}: Control rod driveline thermal expansion reactivity coefficient
α_{Ra}: Core radial expansion reactivity coefficient
ΔT_f: incremental temperature increase in the fuel
ΔT_C: full power, steady-state coolant temperature increase

	BOL	MOL	EOL
A: Power coefficient, ¢	-30.99	-35.63	-39.97
B: Power/flow coefficient, ¢	-45.01	-48.71	-52.37
C: Inlet temperature coefficient, ¢/ °C	-0.41	-0.42	-0.42
$\Delta\rho_{TOP}$: Transient over power initiator, ¢	8.61	23.52	10.60
Required conditions to attain inherent safety			
$A/B < 1$	0.69	0.73	0.76
$1 < C\Delta T_c/B < 2$	1.40	1.33	1.25
$\Delta\rho_{TOP}/\lvert B\rvert < 1$	0.19	0.48	0.20

Conclusion

- **Reactor Core Development in UNIST**
  - **Ultra-long Cycle Fast Reactor**
  - **Small Modular Sodium-cooled Fast Reactor**

- **Safety Analysis for SM-SFR**
  - **Kinetics parameters and reactivity feedback coefficients**
  - **Negative sodium and expansion reactivity**
  - **Transient evaluation for ATWS scenarios; ULOF, ULOHS, UTOP**
  - **Quasi-static reactivity balance analysis**

- **Inherent Safety Confirmed for SM-SFR Core**

UNIST CORE

Thank You for Your Attention!