KNS AUTUMN-2026

Preliminary Study of Xe-135 Reactivity Transient Analysis in a Natural-Circulation Molten Salt Reactor Using a GAMMA+ Coupled Mass Transport Model

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Session Room #300B, HICO, Gyeongju, Korea

CONTENTS

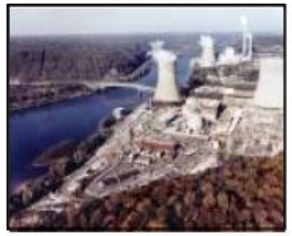
- Introduction
- Xenon transport modeling
- GAMMA+-Python framework
- Results and discussion
- Summary and conclusion

Introduction
Generation IV reactors

- Nuclear power has evolved since commercial deployment in the 1950s to meet changing needs
- Six advanced reactor systems were selected by the Generation IV International Forum (GIF)

Generation I

Early Prototype Reactors



- Shippingport
- Dresden, Fermi I
- Magnox

Generation II

Commercial Power Reactors



- LWR-PWR, BWR
- CANDU
- AGR

Generation III

Advanced LWRs



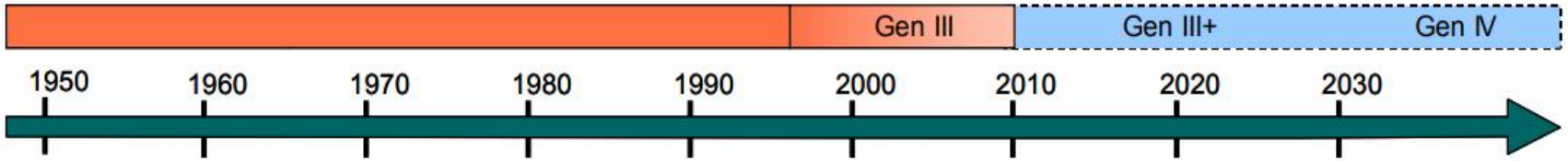
- ABWR
- System 80+

Generation III +

Evolutionary Designs Offering Improved Economics for Near-Term Deployment

Generation IV

- Highly Economical
- Enhanced Safety
- Minimal Waste
- Proliferation Resistant



Generation IV Reactors

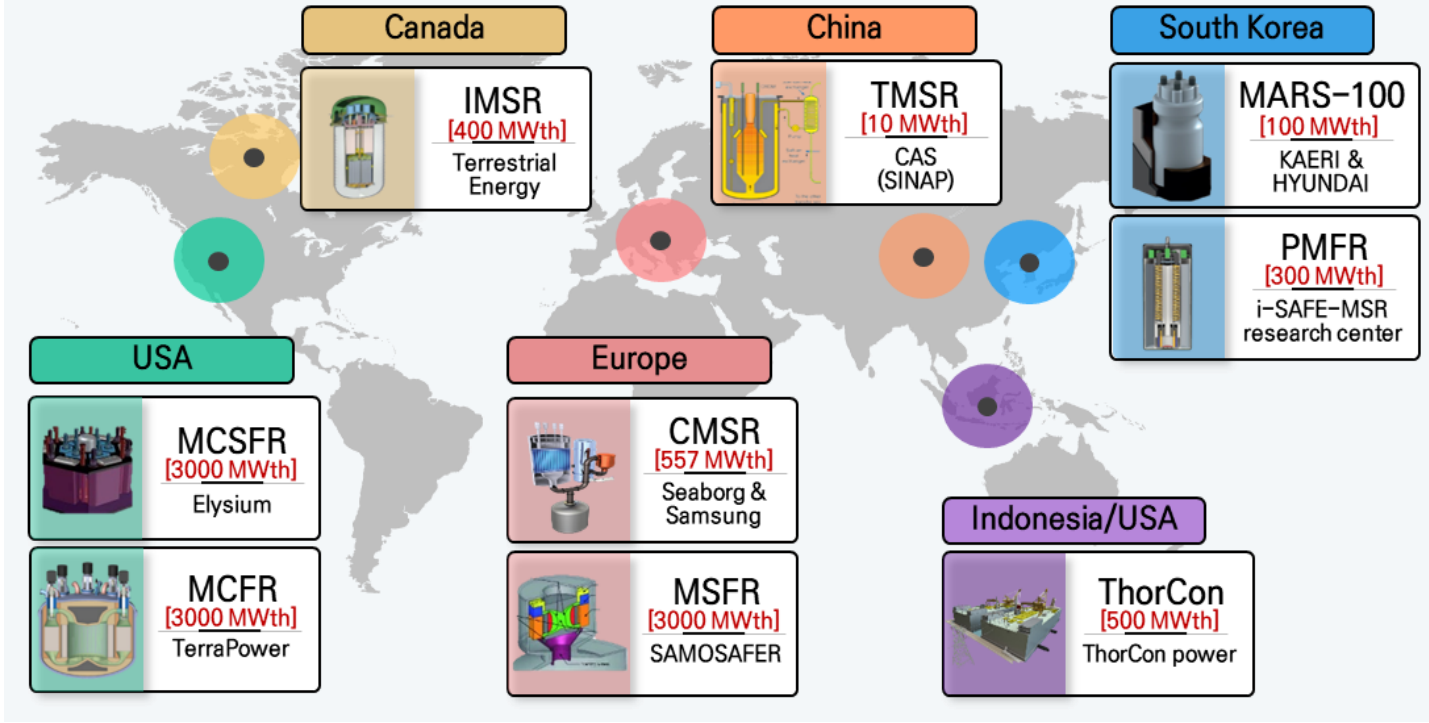
- VHTR (Very High Temperature Reactor)
- SFR (Sodium-cooled Fast Reactor)
- GFR (Gas-cooled Fast Reactor)
- SCWR (Supercritical Water-cooled Reactor)
- LFR (Lead-cooled Fast Reactor)
- **MSR (Molten Salt Reactor)**

Introduction
Molten salt reactor (MSR)

Major advantages of MSR

- **High thermal efficiency** (~40%)
  (High operating temperature)
- **Inherent safety feature**
  (1) Low release frequency of radioactive materials
  (2) Exclude core melting accident
- **Low pressure** operating
  (Simplification of system)
- Low radioactive waste
  (Long period operation and burning spent fuel)
- High utilization of **P2X**
  (Hydrogen, process heat, etc.)

Map on the development of MSR (Representative reactor)



(Reference: IAEA SMR booklet (2022))

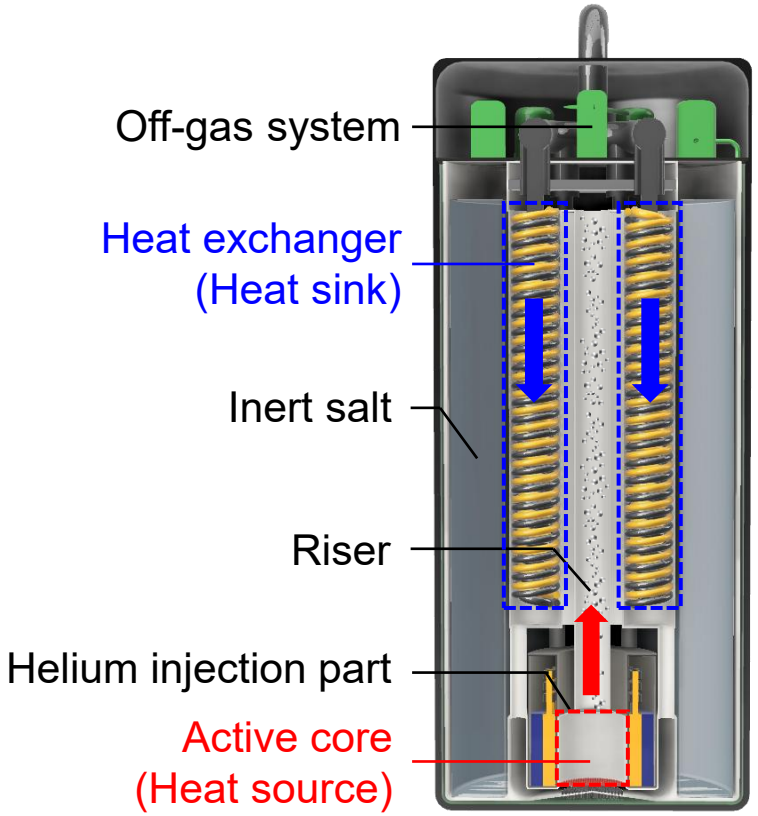
"Approximately 16 types of molten salt reactor types are being developed in 11 countries around the world (as of 2022)"
"Active interest from industry, academia, and research institutes"

1) Igor Pioro, Handbook of Generation IV Nuclear Reactors (Woodhead Publishing, 2016).

Introduction
Reference reactor

Reference reactor

Passive molten salt fast reactor (PMFR)



[Major features]

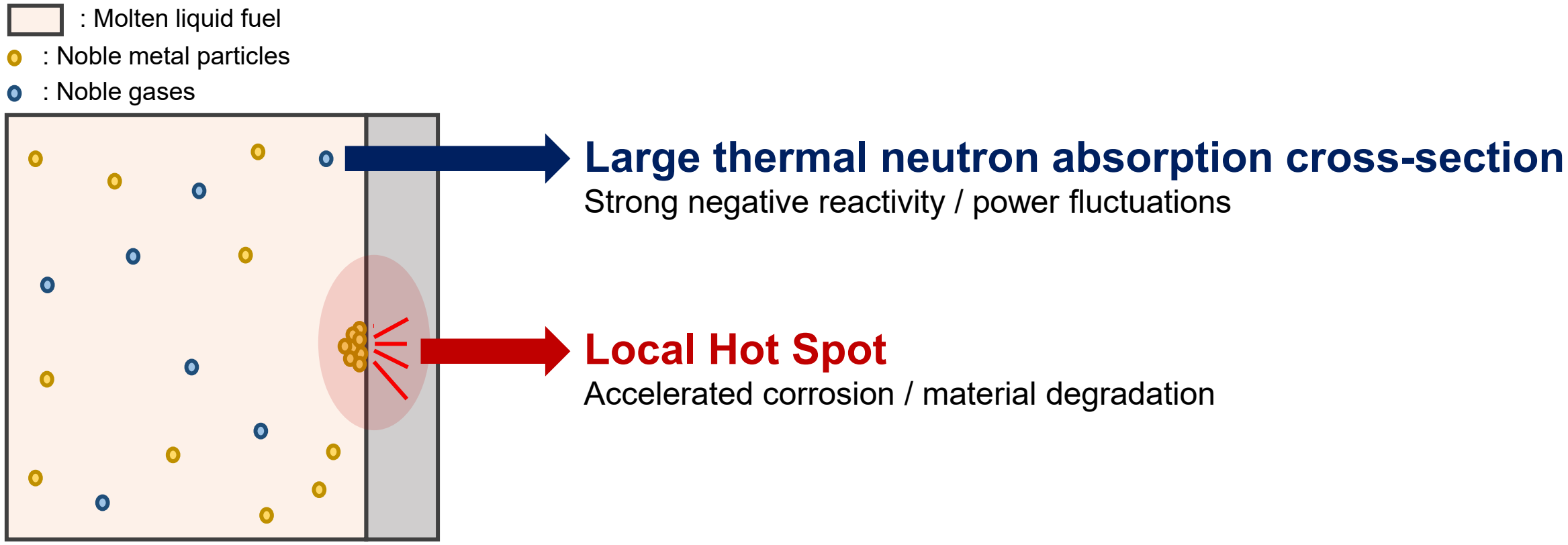
- Chloride-based molten fuel
- Fast spectrum MSR
- Long-term operation
- No drain tank
- **Natural circulation operation**
- Helium bubbling system

Design parameters

Parameters	Values
Thermal target power [MW]	~200
Volumetric thermal power [MW/m^3]	31.8
Fuel salt	NaCl-KCl-UCl_3
Structural material	SUS based
Mean velocity of natural circulation [m/s]	0.215
Thermal center length (L_{hc}) [m]	16-17
Helium injection rate [m^3/s]	~0.003334
Operating pressure [atm]	~1
Initial temperature [°C]	~627
Diameter of core region [m]	2
Height of core region [m]	2

Introduction
Main issue of MSR

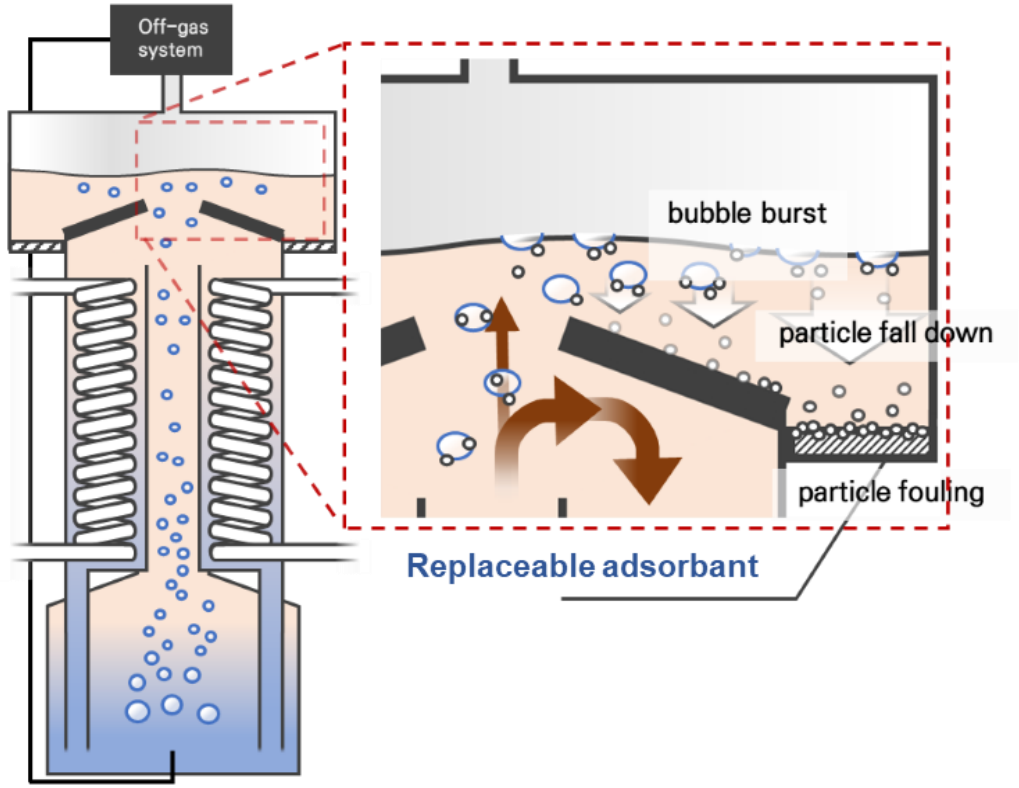
- Insoluble fission products (IFPs), consisting of noble metal particles and noble gases, occur during the operation
- Noble metal particles tend to deposit onto specific surfaces of the primary system and cause local hot spots
- Noble gases such as Xe-135 have a large neutron absorption cross-section and introduce strong negative reactivity



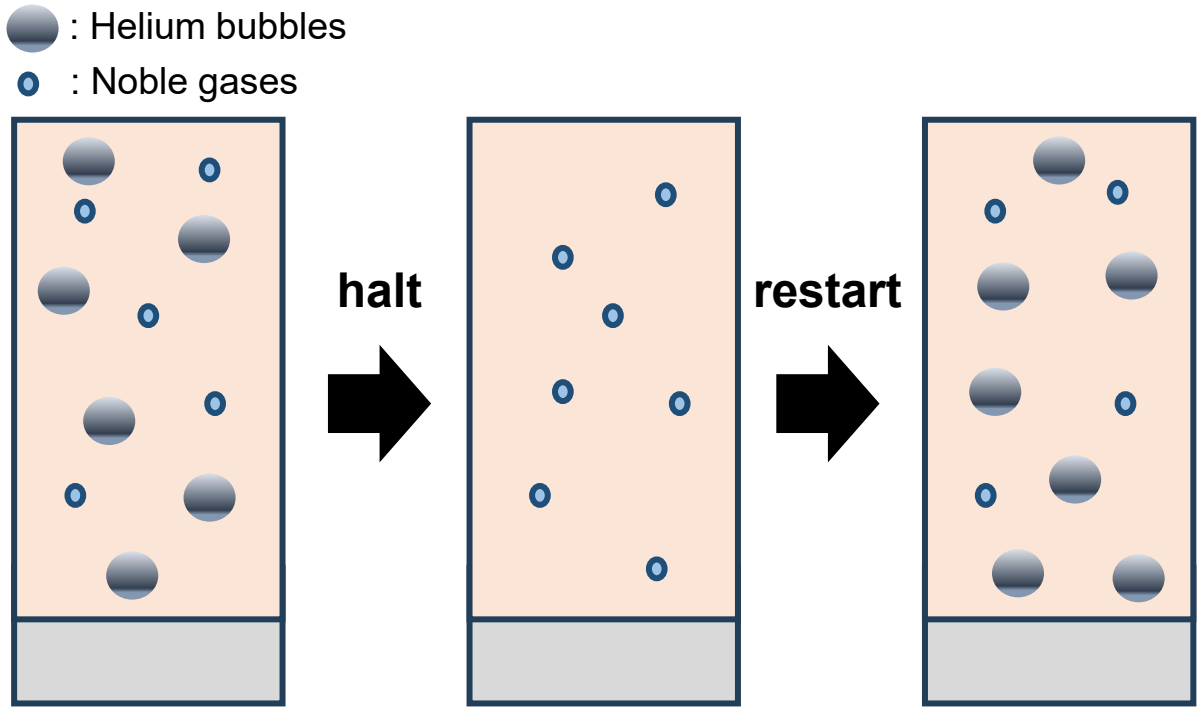
Introduction
Helium bubbling system

- To achieve the long-term operation without reprocessing, IFPs should be removed
- In the upper part, helium bubbles carrying IFPs burst at the free surface, and the IFPs are removed

Schematic of helium bubbling system



Sudden halt or injection of helium bubbles



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Introduction
Literature survey

Analysis of the Operational and Safety Features of the In-Core Bubbling System of the Molten Salt Fast Reactor

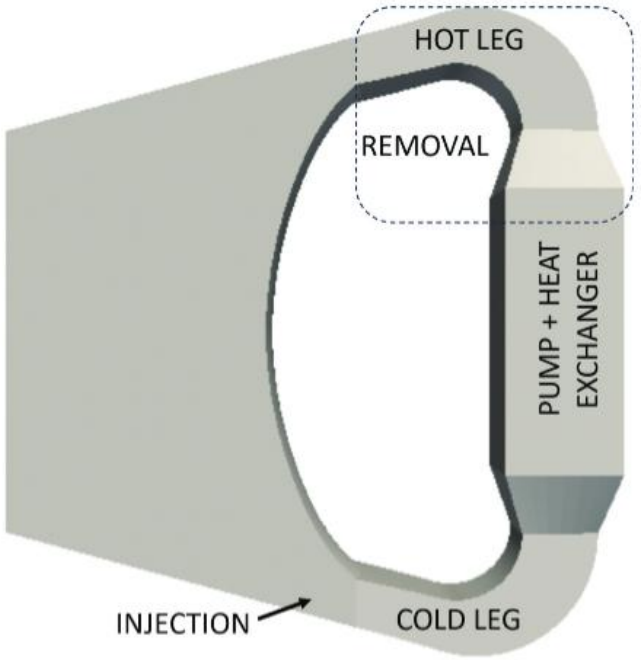
Polimi, 2023, Nuclear science and engineering

Governing equations used in the reference paper (3D CFD model)

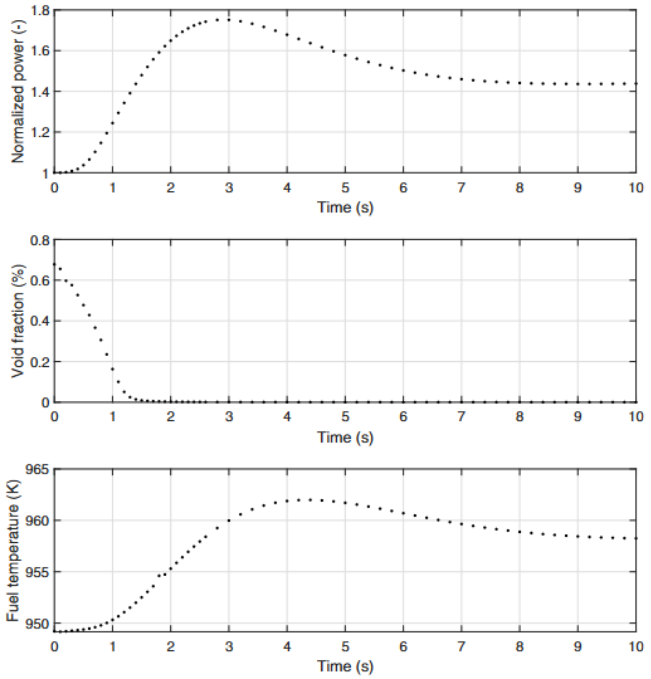
$$\dot{m}_{k,i} = K_{k,i} a_{k,k'} (C^*_{k,i} - C_{k,i})$$

$$\frac{\partial}{\partial t}(\alpha_k C_{k,i}) + \nabla \cdot (\alpha_k u_k C_{k,i}) - \nabla \cdot (\alpha_k D_{k,i} \nabla C_{k,i}) = \dot{m}_{k,i} + S_{k,i} \qquad S_{k,i} = \sum_j \Sigma_{f,i}\, \phi_i y_i \frac{M_i}{N_a} - \alpha_k \rho_k \left(\lambda_i + \sum_j \sigma_{a,j} \phi_j \right) Y_{k,i}$$

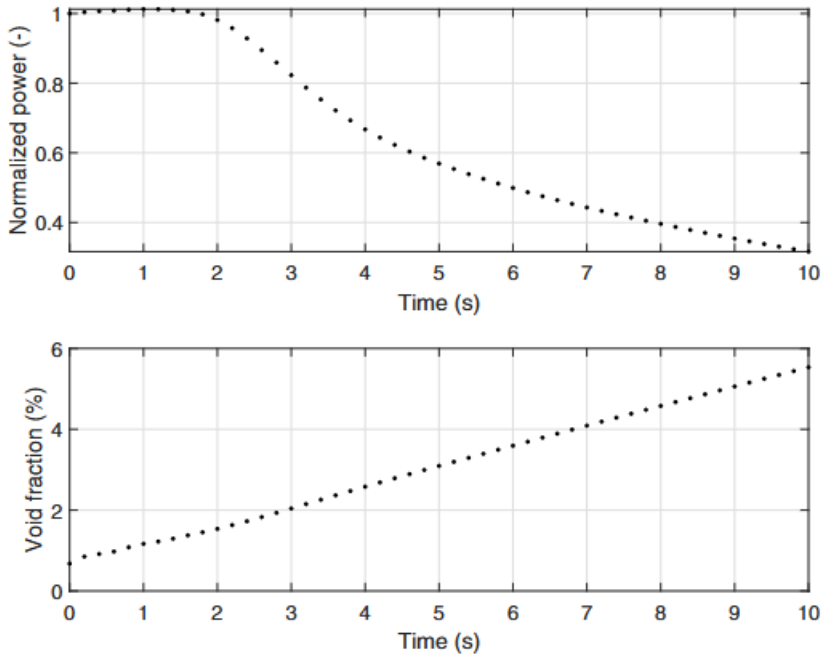
Geometry



Loss of helium injection



Restart of helium injection



Introduction
Research goals

Quantification and sensitivity assessment of Xe-135 poisoning effects

GAMMA+ code → **One-way coupling (Present study)** → **Python module**

[1] GAMMA+ calculation

- Thermal-hydraulic analysis based on the helium injection effect (single- and two-phase flow)
- Steady-state analysis under helium injection conditions
- Transient analysis such as a sudden halt and start of helium injection

[2] Development of the Python in-house code (One-way coupling)

Step 01. GAMMA+ Two-phase thermal-hydraulics analysis → Extract $\boldsymbol{\alpha(t)}$, $\boldsymbol{Q_{salt}(t)}$

Step 02. Python module In-house ODE solver → $\boldsymbol{C(t)}$, $\boldsymbol{\rho(t)}$

Step 03. Evaluate the sensitivity Sensitivity analysis under the steady-state and transient conditions

Xenon transport modeling

Governing equations

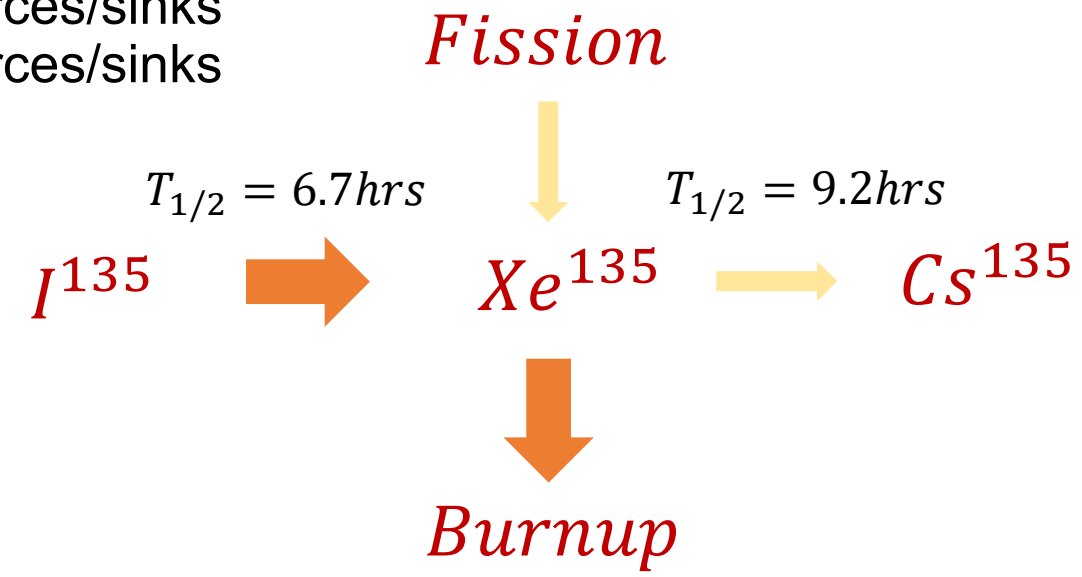
Balance equation

$$\frac{dN_{I-135}}{dt} = \gamma_{I-135}\Sigma_f\phi - \lambda_{I-135}N_{I-135}$$

$$\frac{dN_{Xe-135}}{dt} = \gamma_{Xe-135}\Sigma_f\phi + \lambda_{I-135}N_{I-135} - \lambda_{Xe-135}N_{Xe-135} - \sigma_c^{Xe-135}N_{Xe-135}\phi + \dot{m}_{k,i}$$

Mass transfer term

➡ : Major sources/sinks
➡ : Minor sources/sinks



MITR

Parameter	Value
Σ_f [cm^{-1}]	1.74
γ_{I-135} [-]	0.0639
γ_{Xe-135} [-]	0.00237
λ_{I-135} [s^{-1}]	2.93×10^{-5}
λ_{Xe-135} [s^{-1}]	2.11×10^{-5}
σ_c^{Xe-135} [b]	2.6×10^{6}

*Sm-149 → Negligible in the short term
Xe-135 → Focusing on the transient analysis

Xenon transport modeling
Spontaneous diffusion

[1] Spontaneous diffusion

The concentration of a gas dissolved in a liquid at equilibrium can be calculated by Henry's Law

$$C_i = K_H P_i$$

C_i: Concentration of gas i dissolve in the liquid
K_H: Henry's constant
P_i: Partial pressure of gas i in the gas phase above the liquid

C_g: Xenon concentration in the gas-phase

Salt-cover gas interface

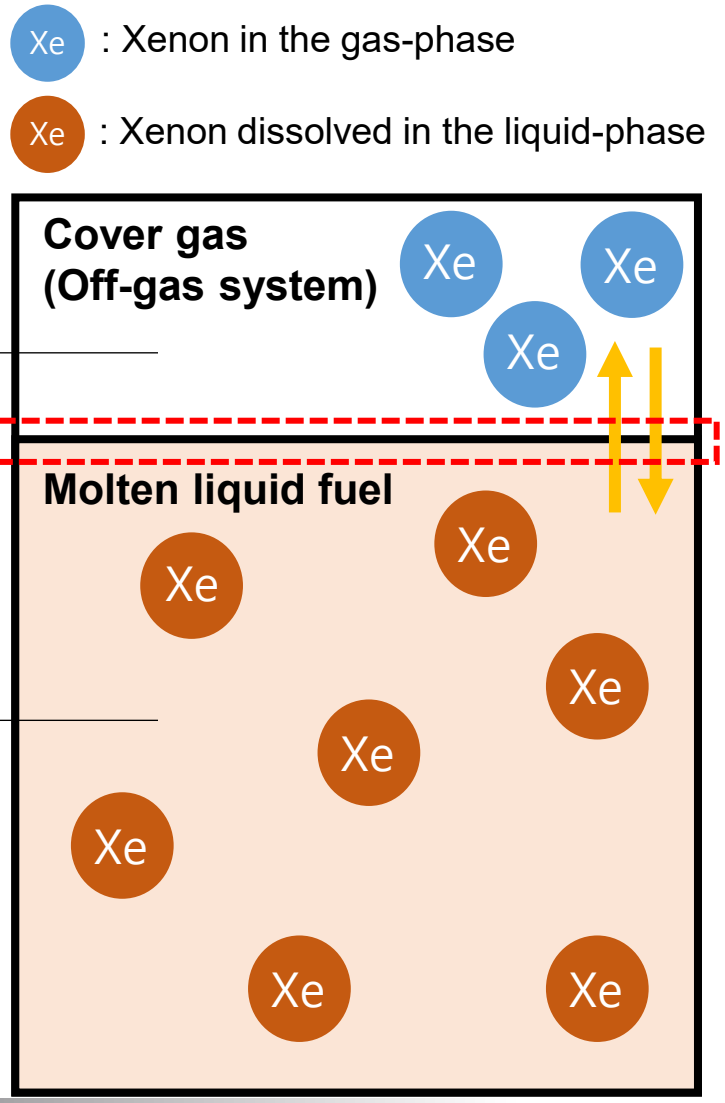
Semi-empirical equation on the Gibbs free energy for calculating the Henry's constant

$$\Delta G = RTln(K_H) = 4\pi r^2 \alpha \sigma_s(T) + \frac{4}{3}\pi r^3 \beta RT$$

G: Gibbs free energy
T: Temperature
α, β: Empirical constants
R: Ideal gas constant
σ_s: Surface tension coefficient

C_l: Xenon concentration in the liquid-phase

Even if there is no helium sparging,
Xe can be eliminated spontaneously
based on the differences in equilibrium concentration



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Xenon transport modeling

Two-film model

[2] Two-Film Model for Sparging Bubbles (e.g., helium bubbling)

$$J_{bubble} = -D\nabla C = -D\frac{(C_{bulk} - C_{interfacial})}{\delta_i} \text{ (Fick's Law)}$$

$$k_{i,bubble} = \frac{D}{\delta_i} \ (i = l \ or \ g) \text{ (Two film model)}$$

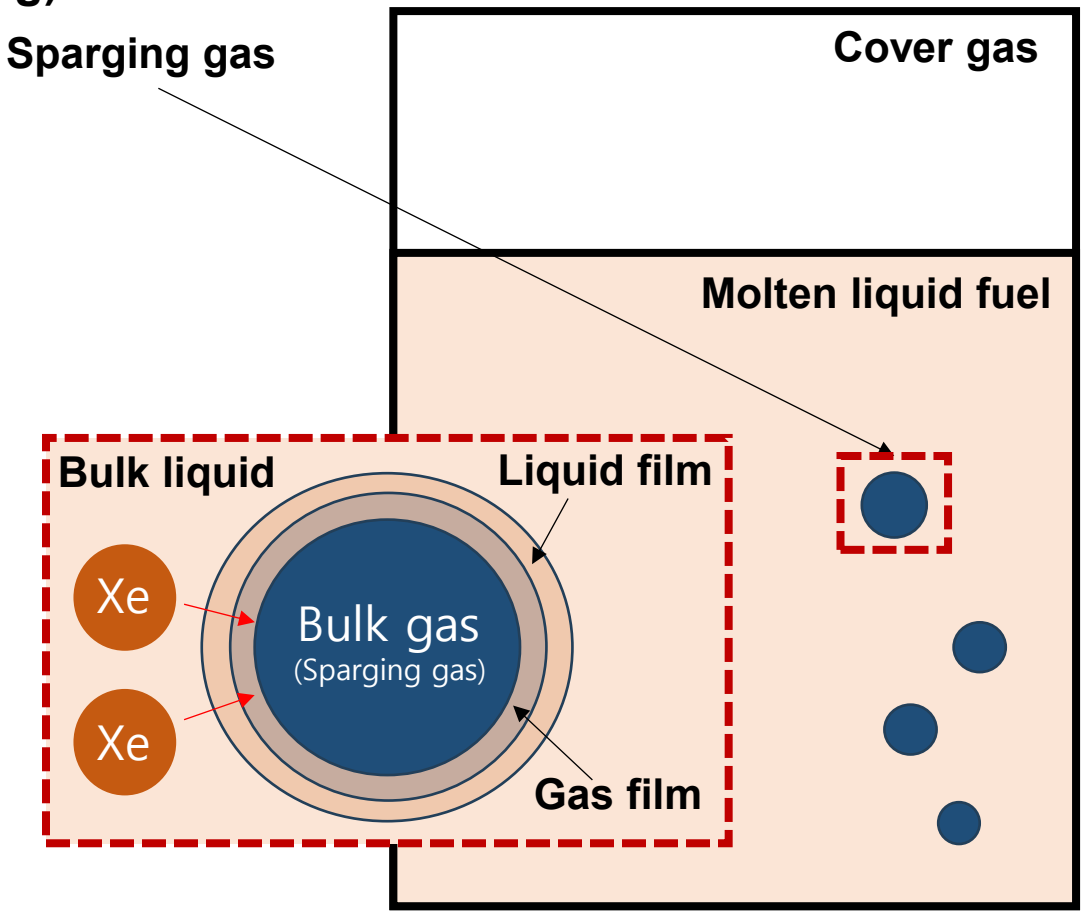
$$J_{bubble} = -k_{l,bubble}(C_l - C_{li}) = -k_{g,bubble}(C_{gi} - C_g)$$

$$= K_{l,bubble}(C_l^* - C_l) = K_{g,bubble}(C_g - C_g^*)$$

D: Diffusivity of the species
C: Concentration of the species
C_i: Concentration of the species at the interface
C^*: Concentration of the species in equilibrium
$k_{i,bubble}$: Interfacial mass transfer coefficient
$\boldsymbol{K_{i,bubble}}$: **Mass transfer coefficient**
δ: Interfacial length

$*K_{k,i} \sim 1.0\times10^{-4}$ m/s
$d_b \sim 3.0\times10^{-3}$ m

$$\therefore \dot{m}_{k,i} = K_{k,i}\frac{6\alpha_g}{d_b}N_{Xe-135}$$



$$\frac{dN_{Xe-135}}{dt} = \gamma_{Xe-135}\Sigma_f\phi + \lambda_{I-135}N_{I-135} - \lambda_{Xe-135}N_{Xe-135} - \sigma_c^{Xe-135}N_{Xe-135}\phi + \dot{m}_{k,i}$$

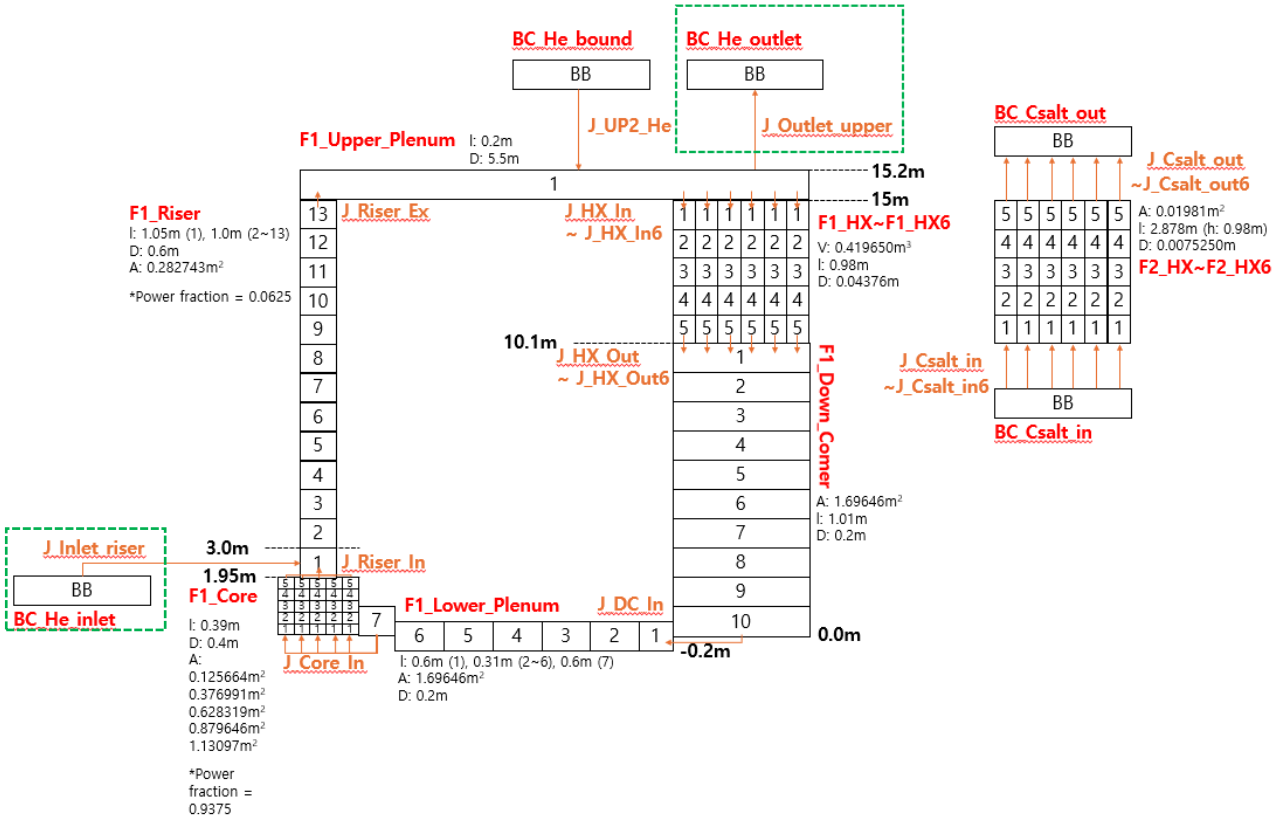
1) Evans, A., Rakib, G. S., & Vergari, L. (2026). Physics and engineering review of gas sparging in molten salt reactors. *Nuclear Engineering and Design*, *446*, 114624.
2) Scioscioli, F., Cammi, A., & Lorenzi, S. (2024). Analysis of the operational and safety features of the In-Core bubbling system of the Molten Salt Fast Reactor. *Nuclear Science and Engineering*, *198*(6), 1288-1307.

GAMMA+-Python framework

Input deck for the reference reactor

- The void fraction calculated from the GAMMA+ code is transferred to the Python module
- Python module can calculate the Xe concentration and corresponding Xe worth

Input deck for the reference reactor



GAMMA+ analysis conditions

Parameter	Value
Analysis conditions	
Code version	GAMMA+ 2.01
Thermal power	200 MW_{th}
Power fraction (core / riser)	0.9375 / 0.0625
Operating pressure	~1 atm
Flow condition	Natural circulation
Heat sink	Coolant salt HX (BC)
He injection velocity	0.7442 / 7.442 m/s
Transient initiation	10,000 s
Two-phase flow model	
Field equations	1T-2V (5 equations)
Phase assumption	Equilibrium, non-homogeneous
Non-condensable gas	Helium (single species)
Interfacial friction	Drift-flux + drag method
Wall friction multiplier	HTFS correlation

GAMMA+-Python framework

Assumptions and test matrix

ATHENA

Test matrix for evaluating the sensitivity

Case	Remarks
01	Sudden injection of helium at *10,000 s (0 → 0.7442 m/s)
02	Sudden injection of helium at 10,000 s (0 → 7.442 m/s)
03	Sudden halt of helium injection at 10,000 s (0.7442 → 0 m/s)
04	Sudden halt of helium injection at 10,000 s (7.442 → 0 m/s)

***10,000 s = 2.78 hr**

Major assumptions

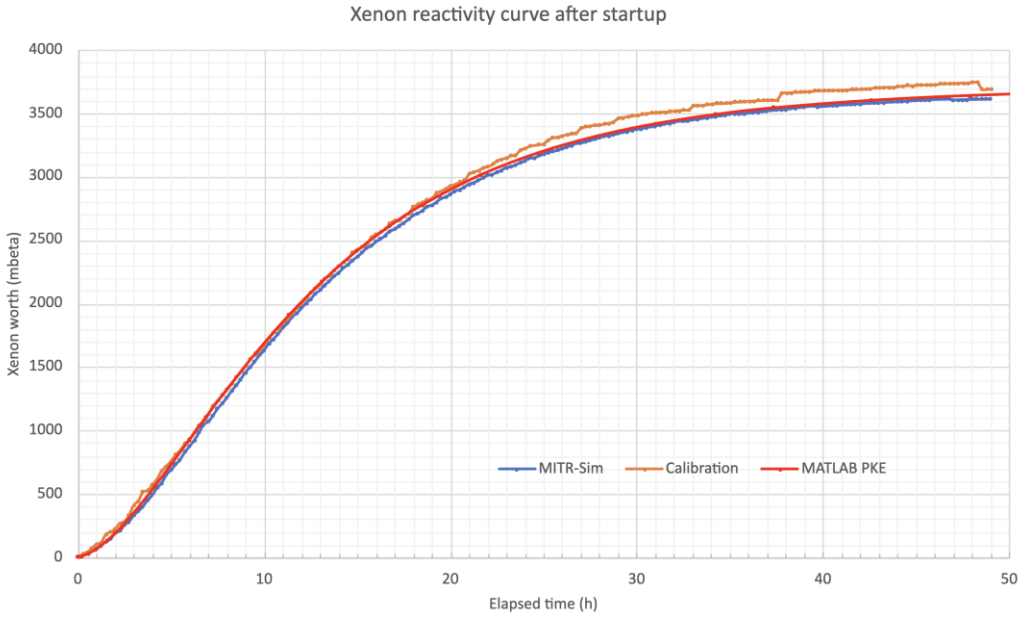
Index	Assumption
01	No temperature feedback effect was considered
02	No void feedback effect was considered
03	Only Xe-135 was considered among the xenon isotopes
04	Validated thermal-spectrum nuclear data were used for the Xe-135 absorption cross section
05	Only one-way coupling between GAMMA+ and the Xe bubble-interface mass transport model was considered
06	Spontaneous diffusion of Xe-135 through the free liquid surface was neglected
07	The liquid-phase Xe-135 concentration in equilibrium with the bubble gas was assumed negligible
08	Advection and diffusion of Xe-135 through the circulating fuel salt were neglected
09	Natural circulation system

Results and discussion

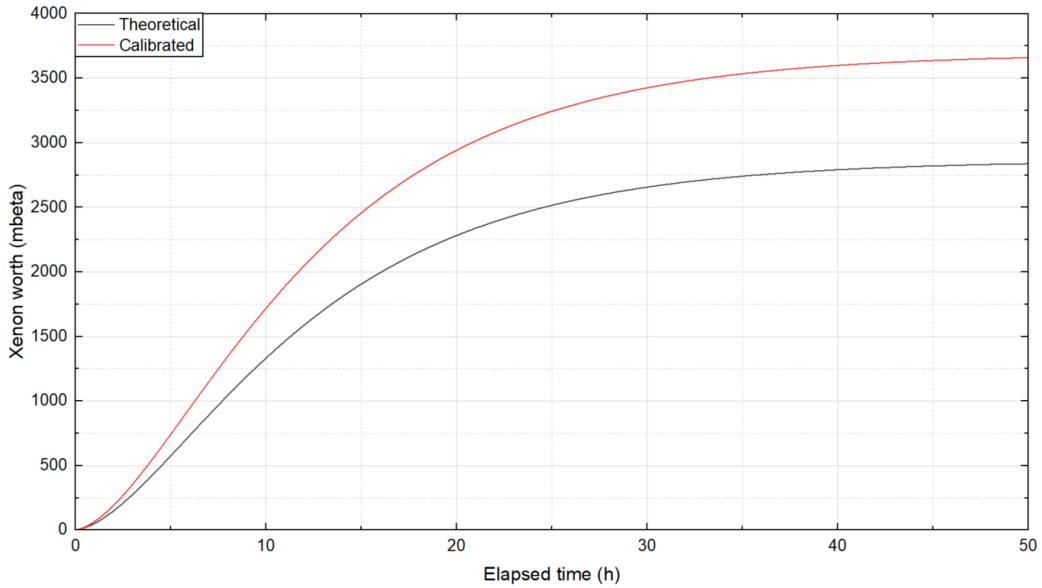
Validation of the balance equation

Xe reactivity curve after startup

Reference data (MITR)



Python module (this study)



Parameter	MITR-Sim value	Measurement value	PKE predicted value	Python module (theoretical)	Python module (calibrated)
Startup worth @ 48h	3610 mβ	3743 mβ	3604 mβ	2832 mβ	3652 mβ

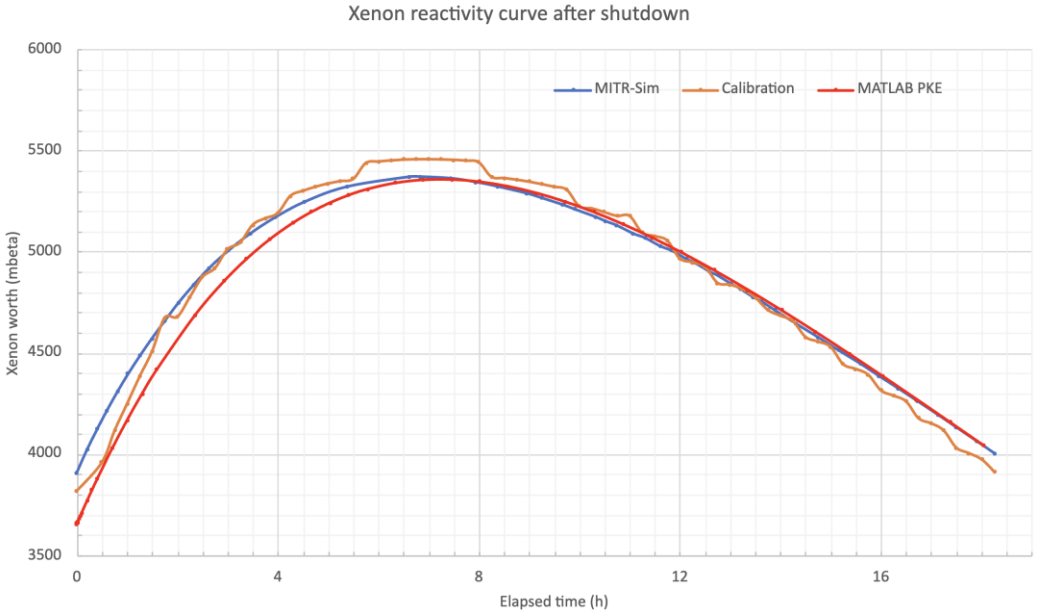
1) L. Tan, L. Hu, "Verification and Validation of the MITR Simulator for Xenon Transients", *Transactions of the American Nuclear Society*, vol. 133, November 2025.

Results and discussion

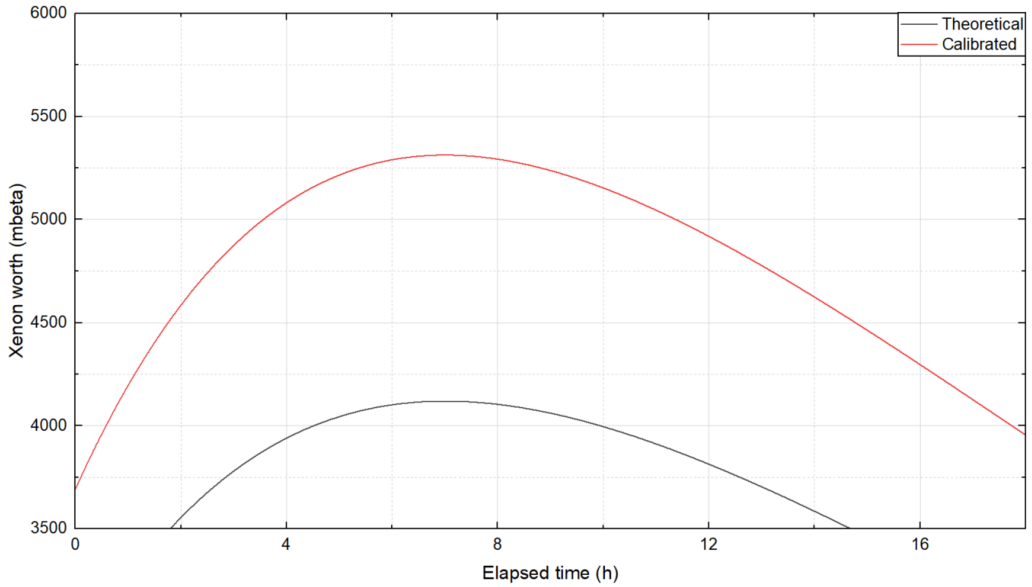
Validation of the balance equation

Xe reactivity curve after shutdown

Reference data (MITR)



Python module (this study)



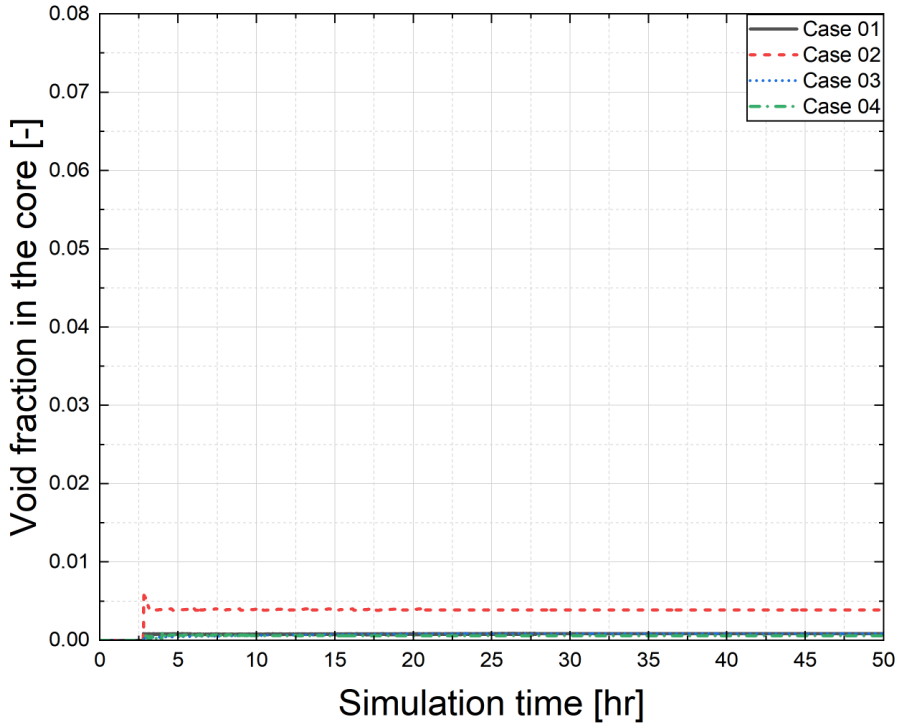
Parameter	MITR-Sim value	Measurement value	PKE predicted value	Python module (theoretical)	Python module (calibrated)
Shutdown peak worth	5371 mβ	5457 mβ	5357 mβ	4119 mβ	5312 mβ
Shutdown peak time	6h 50m	6h 52m	7h 12m	7h	7h

1) L. Tan, L. Hu, "Verification and Validation of the MITR Simulator for Xenon Transients", *Transactions of the American Nuclear Society*, vol. 133, November 2025.

Results and discussion

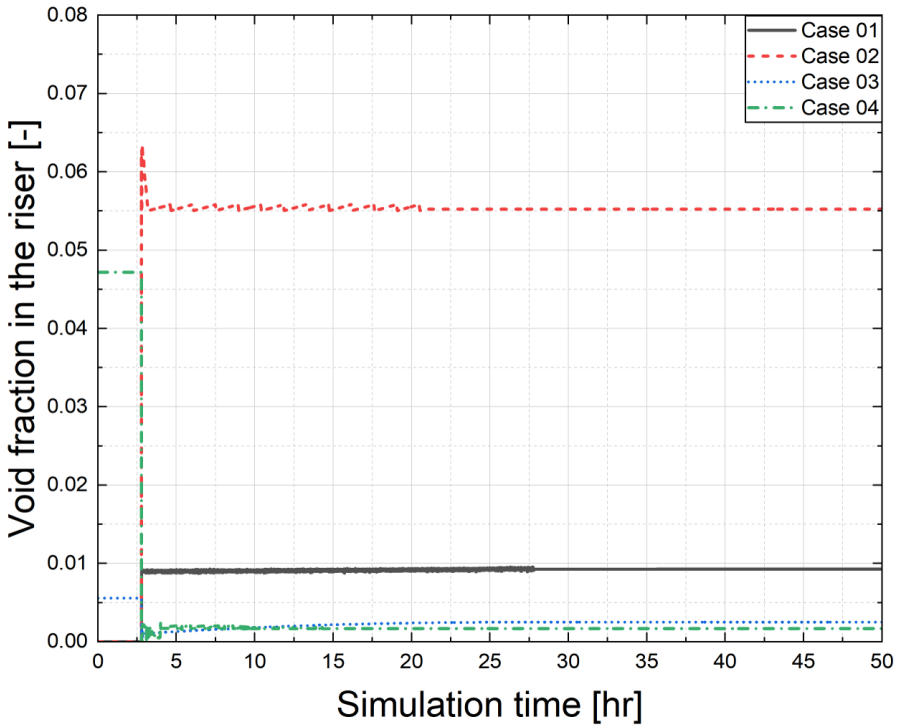
Void fraction in the riser and active core

(a) Void fraction in the active core



Case	Pre void fraction [%]	Post void fraction [%]
Case 01	0	0.08
Case 02	0	0.4
Case 03	0	0.08
Case 04	0	0.08

(b) Void fraction in the riser

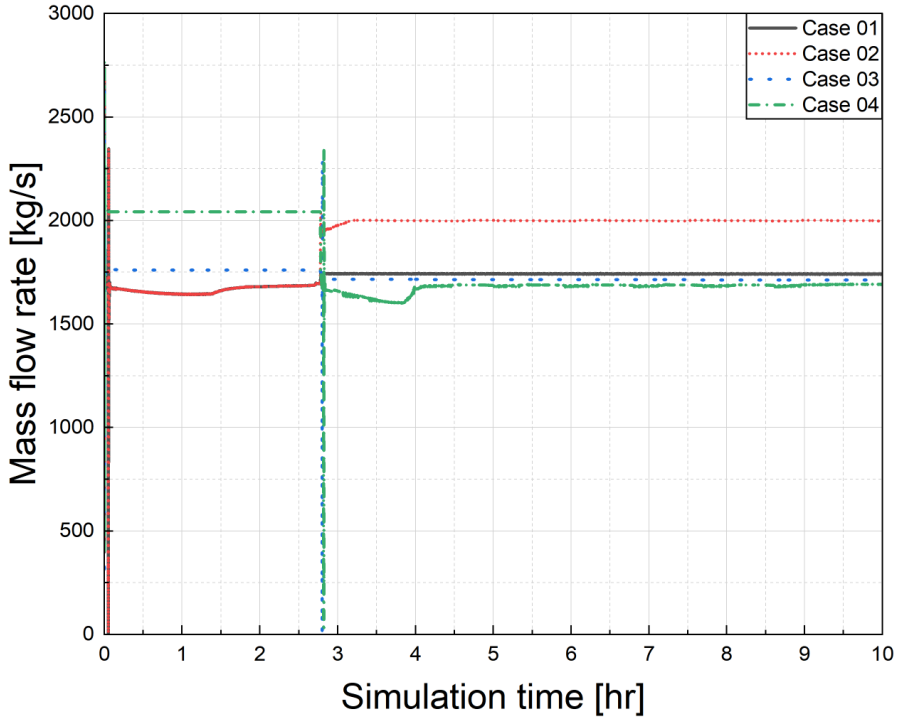


Case	Pre void fraction [%]	Post void fraction [%]
Case 01	0	0.9
Case 02	0	5.5
Case 03	0.56	0.25
Case 04	4.72	0.17

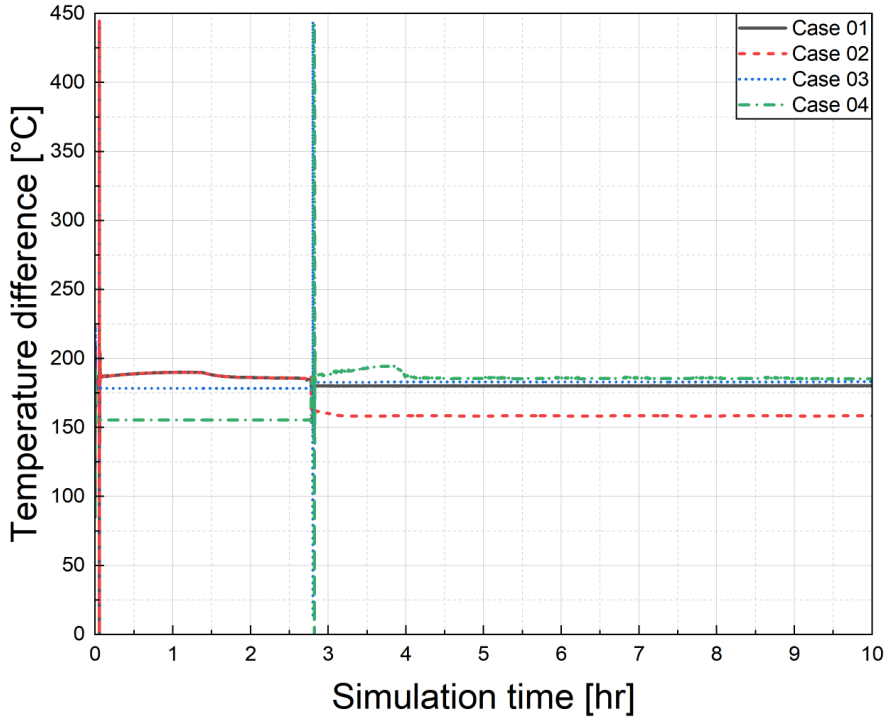
Results and discussion

Mass flow rate and temperature difference

(a) Mass flow rate [kg/s]



(b) Temperature difference (Core in/out) [°C]



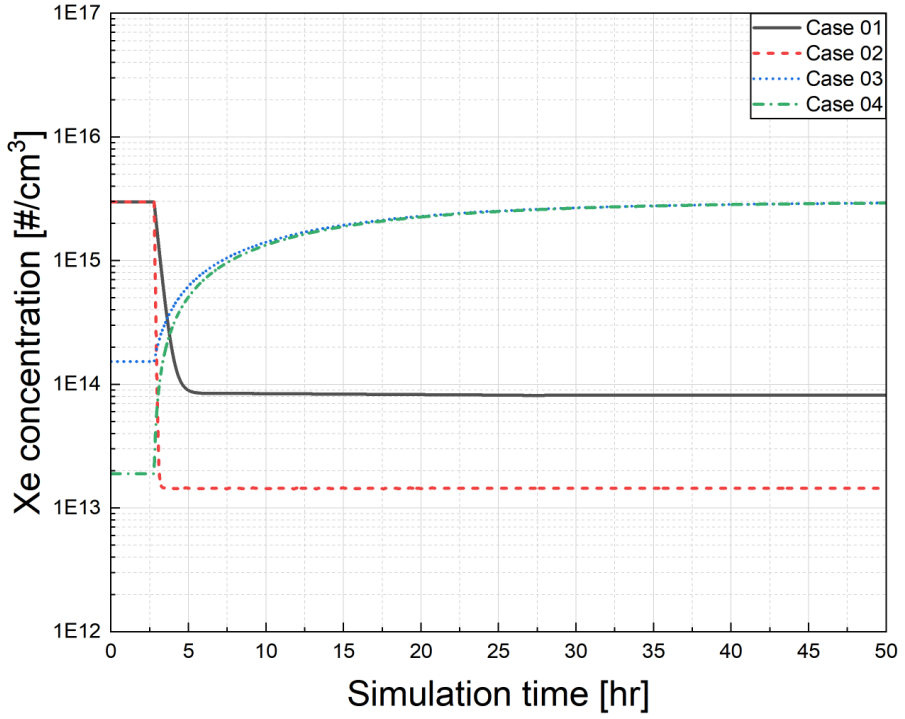
Case	Pre mass flow [kg/s]	Post mass flow [kg/s]	Change [%]
Case 01	1686	1733	+2.8%
Case 02	1686	2001	+18.7%
Case 03	1762	1710	-3.0%
Case 04	2043	1692	-17.2%

Case	Pre T difference [°C]	Post T difference [°C]	Change [%]
Case 01	185	180	-2.7%
Case 02	185	158	-14.6%
Case 03	179	183	+2.2%
Case 04	155	185	+19.4%

Results and discussion

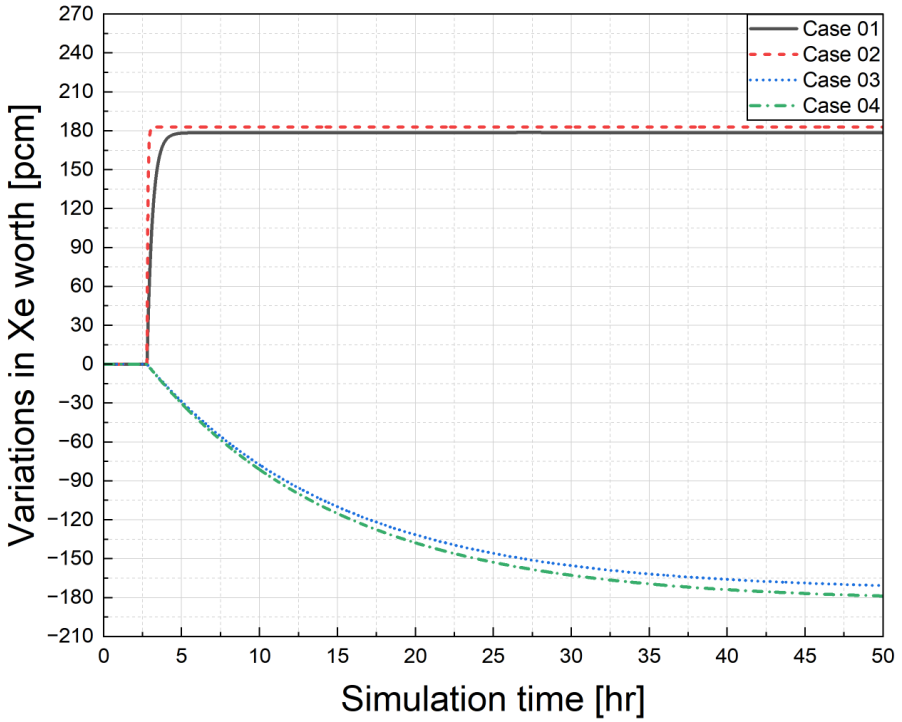
Xe concentration and Xe worth

(a) Xe concentration [#/cm3]



Case	Pre Xe con. [#/cm3]	Post Xe con. [#/cm3]
Case 01	2.99×10^{15}	8.19×10^{13}
Case 02	2.99×10^{15}	1.45×10^{13}
Case 03	1.53×10^{14}	2.99×10^{15}
Case 04	1.89×10^{13}	2.99×10^{15}

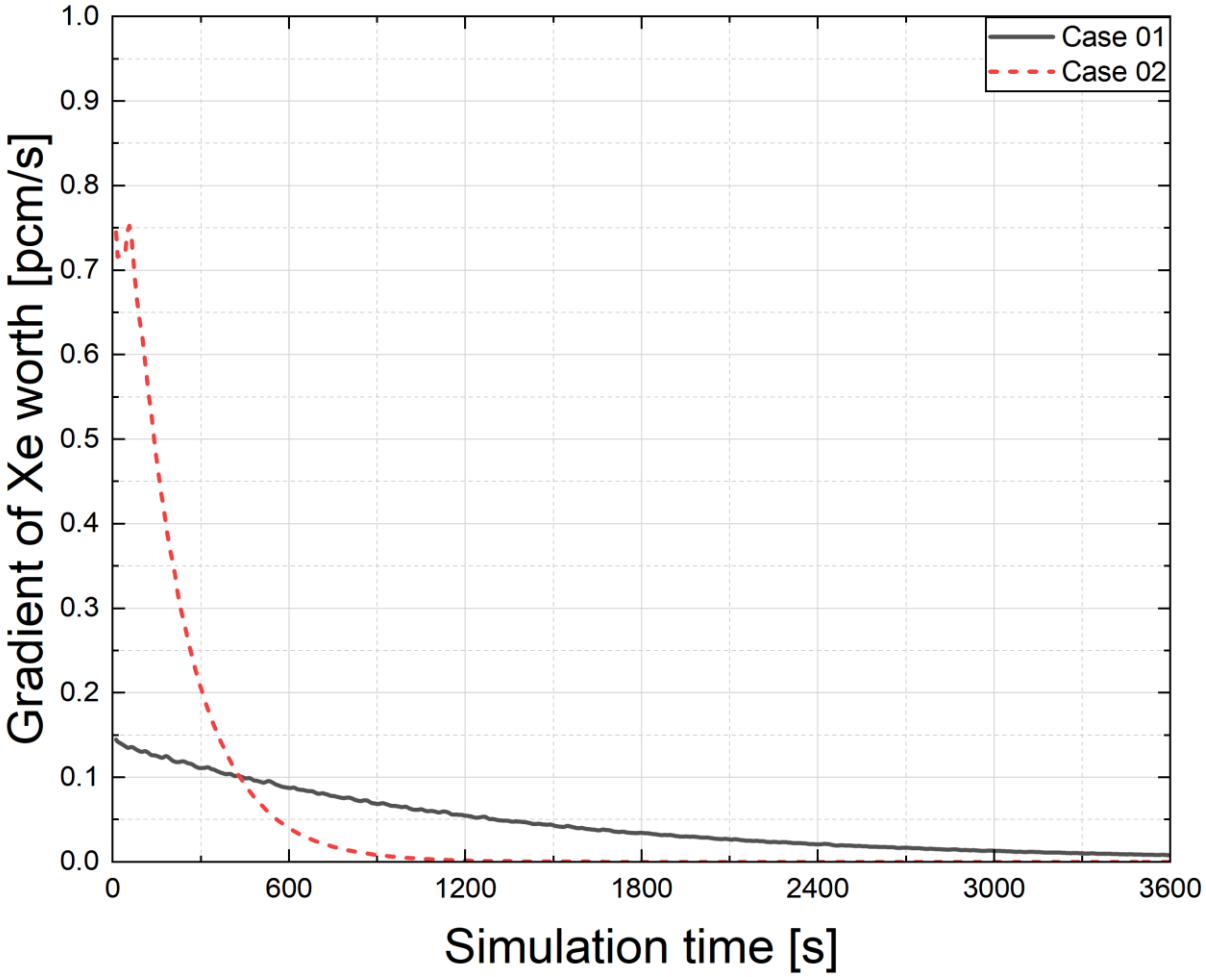
(b) Variations in Xe worth [pcm]



Case	Xe worth change [pcm]
Case 01	179
Case 02	183
Case 03	-172
Case 04	-181

Results and discussion

Gradient of Xe worth



◀ **Gradient of the Xe-135 reactivity worth (Case 01 and Case 02)**

Case	Peak gradient of the Xe worth [pcm/s]
Case 01	**0.15**
Case 02	**0.75**

- The helium injection rate does not significantly affect the Xe-135 worth
- However, it can significantly affect the rate of Xe worth change

Results and discussion

Prediction of thermal power

- Based on the prompt jump approximation, reactor thermal power was roughly predicted

$$P = P_0 \frac{\beta}{\beta - \Delta\rho(t)}$$

Variable Definitions

P : reactor power

P_0 : reference power ~ 200 MWth

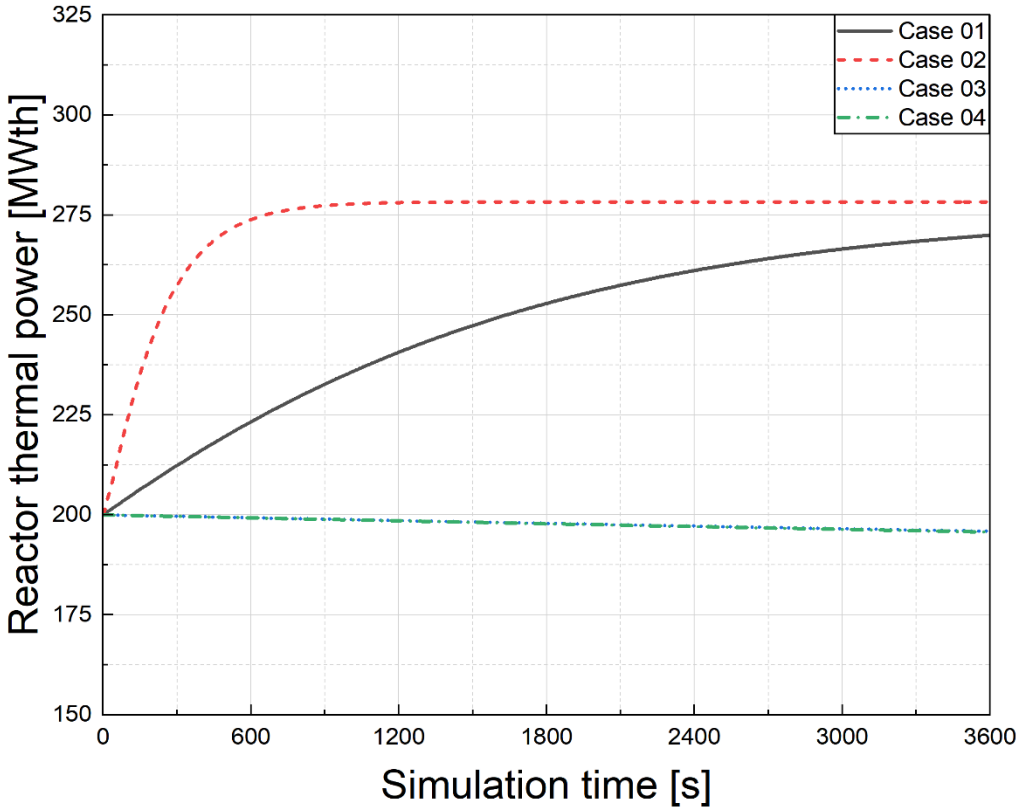
β : total delayed neutron fraction

$\Delta\rho(t)$: Xe-135 reactivity worth

Assumptions

β =0.0065 (650 pcm)

Corresponds to the delayed neutron fraction of U-235



Reactor thermal power levels corresponding to the Xe-135 reactivity worth for four transient cases during the first 3,600 s of the simulation

Summary and conclusion

Summary and conclusion

ATHENA

[Summary & conclusion]

- A methodology coupling the GAMMA+ system code and bubble-interface mass transport model is being developed to analyze Xe-135 reactivity transient
- The Xe-135 concentration decreased rapidly from 2.99×10^{15} cm^{-3} to 8.19×10^{13} cm^{-3} and 1.45×10^{13} cm^{-3} upon injecting helium bubbles at 0.7442 m/s and 7.442 m/s, respectively
- The timescale to reach Xe equilibrium without gas sparging is on the order of 10's of hours, indicating a very slow transient similar to solid fuel light water reactors
- Upon re-starting gas sparging, positive reactivity insertion due to Xe removal drives a power increase on the order of seconds in the absence of reactivity feedback
- In the absence of corrective action and reactivity feedback, rapid reactor power level increase upon starting gas sparging system is predicted to exceed overpower scram setpoint, typically 110% of full power, within minutes.
- The thermal-hydraulic performance and the Xe-135 response to helium sparging cannot be treated independently in a natural-circulation MSR

[Future work]

- Future work will focus on obtaining MSR system design specific information such as nuclear data using OpenMC or Serpent
- Beyond these, the present one-way coupling will be extended to a two-way scheme in which the Xe-135 reactivity worth is passed to a point kinetics solver and the resulting power is returned to GAMMA+ at each time step

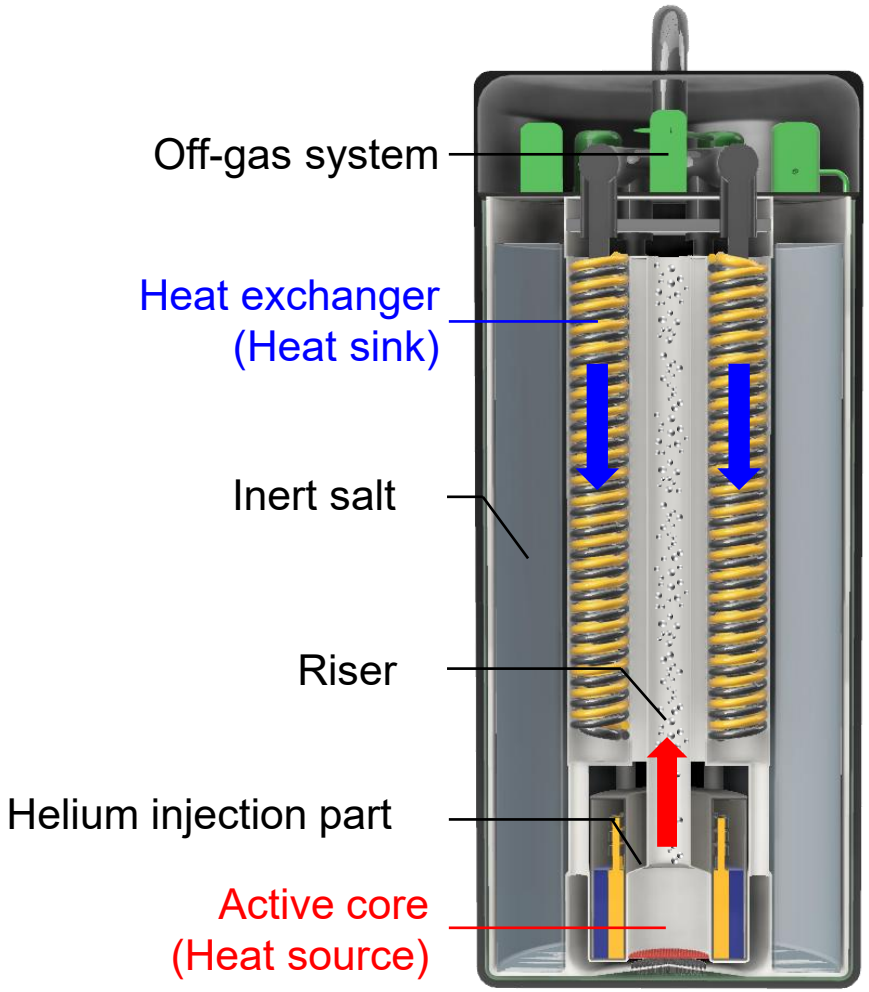
Thank you for your attention

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Appendix

A. Reference reactor

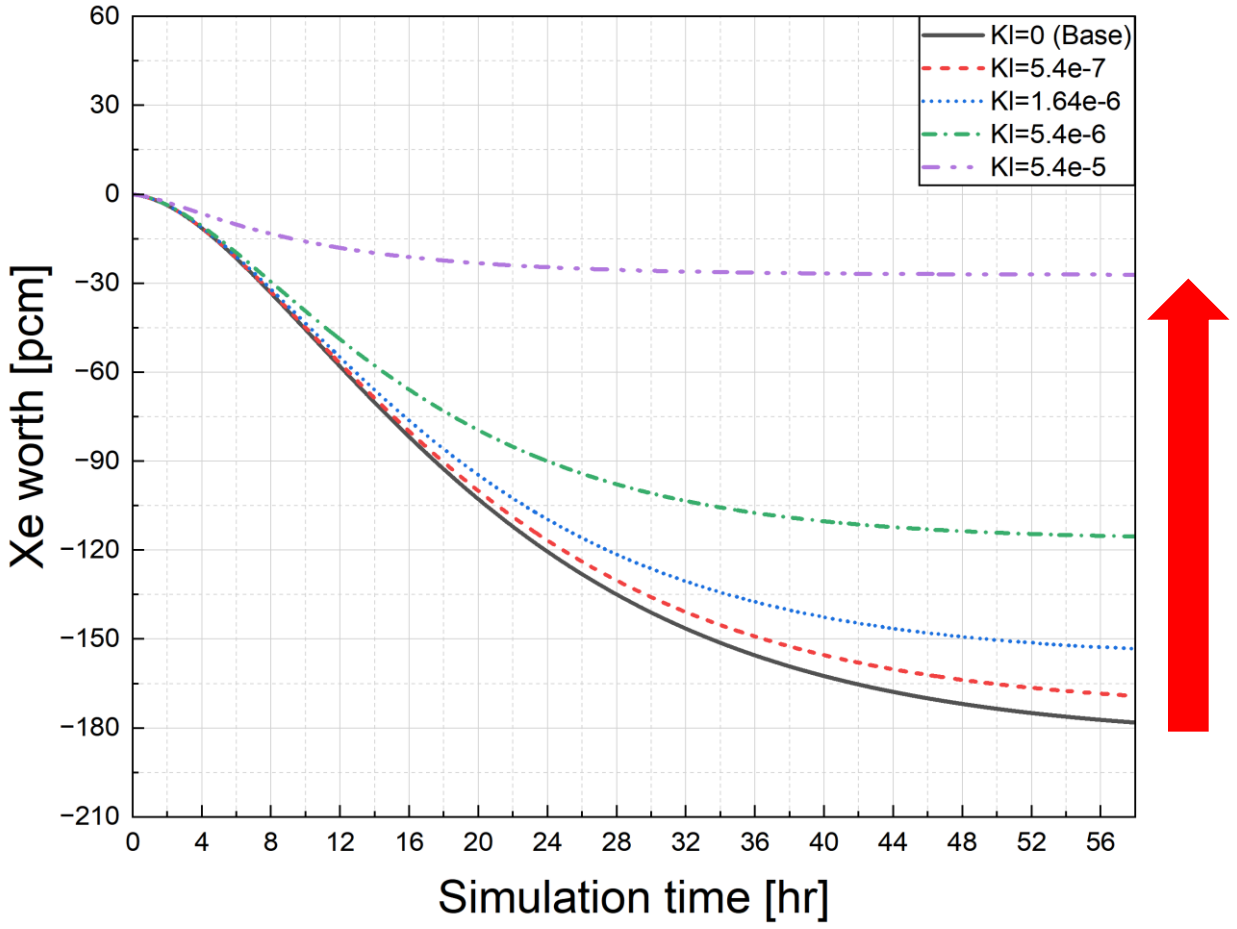


[Design parameters of PMFR]

Parameters	Values
Thermal target power [MW]	~200
Volumetric thermal power [MW/m^3]	31.8
Fuel salt	NaCl-KCl-UCl_3
Structural material	SUS based
Mean velocity of natural circulation [m/s]	0.215
Thermal center length (L_{hc}) [m]	16-17
Helium injection rate [m^3/s]	~0.003334
Operating pressure [atm]	~1
Initial temperature [°C]	~627
Temperature differences [°C]	190
Core inlet temperature [°C]	500~530
Riser outlet temperature [°C] (≅ Core outlet T)	650~680
Transverse area [m^2]	0.002-0.05
Height of reactor [m]	20
Diameter of riser channel [m]	0.6
Height of riser channel [m]	18
Diameter of core region [m]	2
Height of core region [m]	2

Appendix

B. Spontaneous diffusion



$$K_{l,covergas} = D_{Xe}/\delta \qquad \dot{m} = K_{l,covergas} A(C_l - C_{sol})$$

D_{Xe}(Stokes-Einstein) ~ 5.36e-10 m²/s

As Kl increases,
absolute value of Xe equilibrium concentration
(or Xe equilibrium worth) gets lower

However, it is limited to find the appropriate
Kl values..

Assumption 06:
Spontaneous removal takes tens of hours,
whereas helium sparging takes only tens of minutes.
→ This could justify the assumption.

Appendix

B. Spontaneous diffusion

When fission gases (Xe, etc.) are present in excess of the solubility limit, transfer from the salt to the cover gas occurs spontaneously, at a rate described by

$$\dot{m} = K_{l,covergas} A (C_l - C_{sol}) = K_{g,covergas} A (C_{sol} - C_g)$$

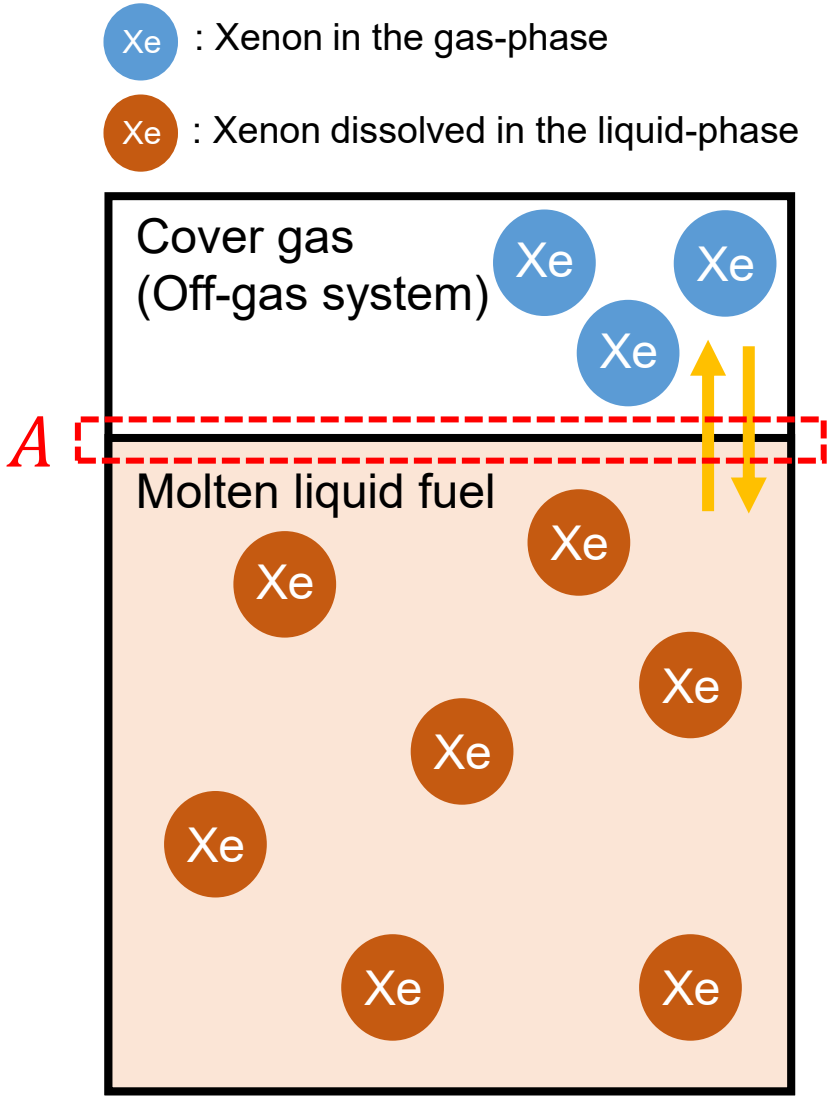
$\dot{m}$: Mass flow rate of the species transferring from the salt to the cover gas
$K_{l,covergas}$: Liquid-phase mass transfer coefficient at the salt surface (Predicted via Sh correlation)
$K_{g,covergas}$: Gas-phase mass transfer coefficient at the salt surface (Predicted via Sh correlation)
A: Liquid-gas surface area (Design parameter)
C_l: Liquid phase concentration of the gas (From Python code)
C_g: Gas phase concentration of the gas (From Python code)
C_{sol}: Solubility limit (Calculated from Henry's Law (But for now, we can assume C_{sol} is zero))

We can assume that C_{sol} is zero for simplification of the calculation

$$C_{sol} = K_H P_{sol} = 0$$

If so, we don't have to consider K_H and P_{sol}

At the same time, $\dot{m} = K_{l,covergas} A (C_l - C_{sol})$ can be simplified to $\dot{m} = K_{l,covergas} A C_l$



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Appendix

C. Two-film model

$$J_{bubble} = K_{l,bubble}(C_l^* - C_l) = K_{g,bubble}(C_g - C_g^*) \quad \cdots (1)$$

$$\dot{m} = A\dot{N}t_{lifetime}J_{bubble} \quad \cdots (2)$$

$$\dot{m} = A\dot{N}t_{lifetime}K_{l,bubble}(C_l^* - C_l) = A\dot{N}t_{lifetime}K_{g,bubble}(C_g - C_g^*) \quad \cdots (3)$$

$\dot{m}$: Mass transfer rate of the species from the liquid to the gaseous phase
C^*: Concentration of the species in equilibrium

$$C_l^* = \frac{C_g}{RTK_H},\ C_g^* = C_l RTK_H,\ \Delta G = RTln(K_H) = 4\pi r^2\alpha\sigma_s(T) + \frac{4}{3}\pi r^3\beta RT$$

C: Concentration of the species
$K_{l,bubble}$: Liquid-phase mass transfer coefficient (Predicted via Sh correlation)
$K_{g,bubble}$: Gas-phase mass transfer coefficient (Predicted via Sh correlation)
A: Average surface area of the sparging bubbles (Using equation)

$$A = \frac{6\alpha_g}{d_b}$$

d_b: bubble diameter
α_g: phase fraction of the gas (void fraction)

$\dot{N}$: Injection rate of the sparging bubbles
$t_{lifetime}$: Average time that a bubble spends in the salt

Appendix

D. Solving the balance equation

Calculate the xenon worth using the theoretical equation derived from the definition of k

$$\rho = \frac{k-1}{k} = 1 - \frac{1}{k} \qquad k = \nu\frac{\Sigma_f}{\Sigma_a}$$

$$\rho = 1 - \frac{1}{k} = 1 - \frac{\Sigma_a}{\nu\Sigma_f} = \frac{\nu\Sigma_f - \Sigma_a}{\nu\Sigma_f}$$

$$\rho = \frac{\nu\Sigma_f - \Sigma_a}{\nu\Sigma_f} = \frac{\nu\Sigma_f - \Sigma_{a(w/o\ Xe)} - \Sigma_{a(w/\ Xe)}}{\nu\Sigma_f}$$

$$= \frac{\nu\Sigma_f - \Sigma_{a(w/o\ Xe)}}{\nu\Sigma_f} - \frac{\Sigma_{a(w/\ Xe)}}{\nu\Sigma_f}$$

$$= \rho_0 - \frac{\Sigma_{a(w/\ Xe)}}{\nu\Sigma_f}$$

$$\therefore \rho - \rho_0 = -\frac{\Sigma_{a(w/\ Xe)}}{\nu\Sigma_f} = \Delta\rho_{Xe}$$

$$\Delta\rho_{Xe} = -\frac{\Sigma_{a(w/\ Xe)}}{\nu\Sigma_f} = \frac{-\sigma_{aXe}N_{Xe}}{\nu\Sigma_f}$$

$-\sigma_{aXe}$: Xe absorption cross section $[cm^2]$

N_{Xe}: Xe concentration $[\#/cm^3]$

$\nu\Sigma_f$: Neutron production cross-section $[\#\ cm^{-1}]$

- Calculate and obtain the Xe concentration (N_{Xe})
- Nuclear data (σ_{aXe}, $\nu\Sigma_f$) was utilized by referring to the MITR data

This was the first attempt (the theoretical method), but It showed relatively large errors when compared with the MITR data

Appendix

D. Solving the balance equation

Xenon reactivity transients for startup and shutdown were modeled by solving Equations 1 through 4 with appropriate initial conditions. The reactivity worth to atoms ratio of ^{135}Xe was derived to be $1.22 \cdot 10^{-13}$ mβ n^{-1} by dividing the obtained equilibrium xenon worth by the number density as determined by the model. By taking the

How to obtain the Xe worth?

Step 01.
Calibrate the reactivity worth per 1 cm of control rod movement

Step 02.
As the reactor operates, Xe-135 builds up, and the control rod is withdrawn to compensate for the resulting negative reactivity

Step 03.
The reactivity change is obtained from the recorded rod position using the calibration curve

Step 04.
At the same time, core and coolant temperatures are measured to track the temperature feedback effect

Step 05.
Subtracting the temperature feedback effect from the total reactivity change isolates the pure Xe effect (Xe worth)

Step 06.
The balance equation is solved using nuclear data corresponding to 5.7 MW operation to obtain the Xe-135 concentration

Step 07.
Dividing the measured worth [mβ] by the modeled equilibrium Xe concentration [atoms/cm³] gives a worth-per-atom ratio, which is then multiplied by the time-dependent Xe concentration to obtain the worth curve.

Appendix

E. Xe research under the fast-spectrum condition

Analysis of the Operational and Safety Features of the In-Core Bubbling System of the Molten Salt Fast Reactor

Polimi, 2023, Nuclear science and engineering

1. We perform single-phase eigenvalue calculations to determine the effective multiplication factor k_{eff} of the system in the absence of helium and with all GFPs present. Then, we repeat the calculation removing the GFP term from the neutronics equation. The difference in k_{eff} is ascribed to the poisoning effect of GFPs.

2. We calculate the variation in k_{eff} from the beginning to the end of the GFP removal transient. This is done deactivating cross-section updating, so that thermal feedback does not contribute. Then, the value for the void coefficient we find in the next section is employed to separate the variation of k_{eff} into a void and a GFP poisoning contribution.

These two strategies provide essentially identical values for the reactivity contribution of GFPs. Numerically, we have, in absolute value, 38 pcm. Performing the same procedure with only ^{135}Xe gives a contribution of only 0.1 pcm.

The value we found, 38 pcm, should be compared with both the circulating delayed fraction β_{circ} and with the reactivity inserted by the change in void fraction. In particular, this reactivity is not negligible in absolute terms, corresponding to roughly 0.3$.

Fission Yields at 400 keV for the Investigated Isotopes

Isotope	Fission Yield	Isotope	Fission Yield
^{80}Kr	4.801×10^{-8}	^{130}Xe	1.614×10^{-7}
^{82}Kr	8.767×10^{-7}	^{131}Xe	2.306×10^{-2}
^{83}Kr	9.919×10^{-3}	^{132}Xe	2.985×10^{-2}
^{84}Kr	4.639×10^{-2}	^{133}Xe	4.116×10^{-2}
^{85}Kr	9.243×10^{-3}	^{134}Xe	5.883×10^{-2}
^{86}Kr	6.912×10^{-2}	^{135}Xe	5.195×10^{-2}
^{128}Xe	1.346×10^{-6}	^{136}Xe	6.686×10^{-2}
^{129}Xe	6.973×10^{-9}		

In MSR where β_{circ} is small, 38 pcm is not negligible