Preliminary Study of Conceptual Design of Passive Residual Heat Removal System for PMFR Safety

Speaker: **Jihun Lim** (jihunlim@hanyang.ac.kr)

Advisor: Prof. Sung Joong Kim

Advanced Thermal-Hydraulic Engineering for Nuclear Application Lab.

Department of Nuclear Engineering, Hanyang University

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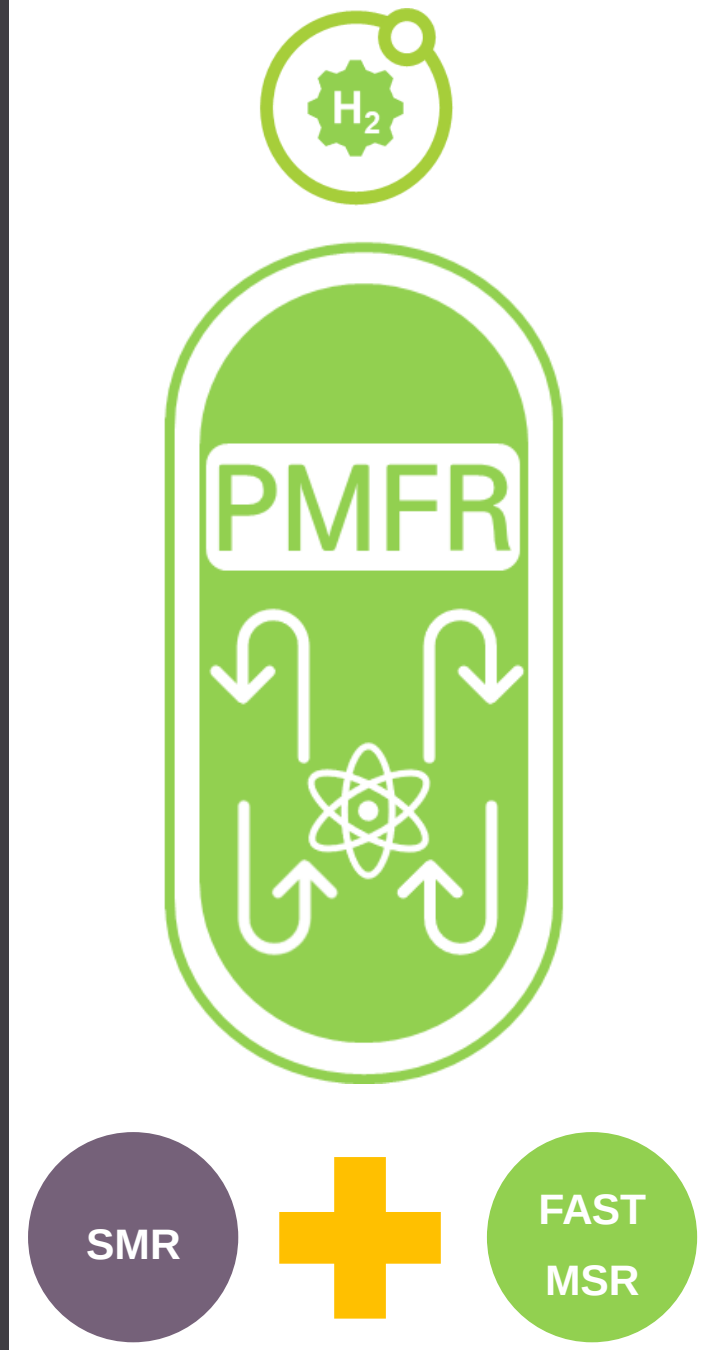
2022 KNS Meeting



Contents

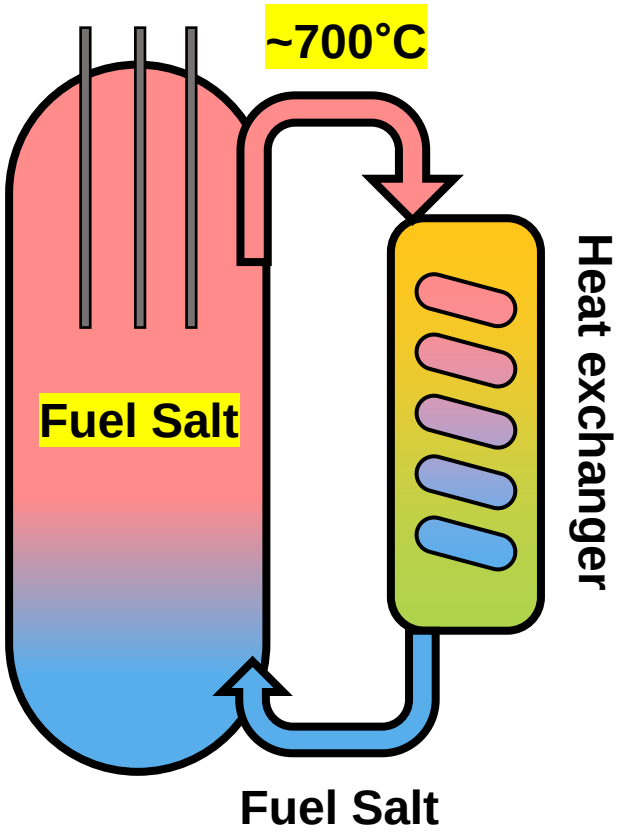
- Background
- Reviews of draining system
- Overview & Objectives
- Conceptual design of PMFR safety system
- Methodology
- Results & Discussion
- Conclusion

Background

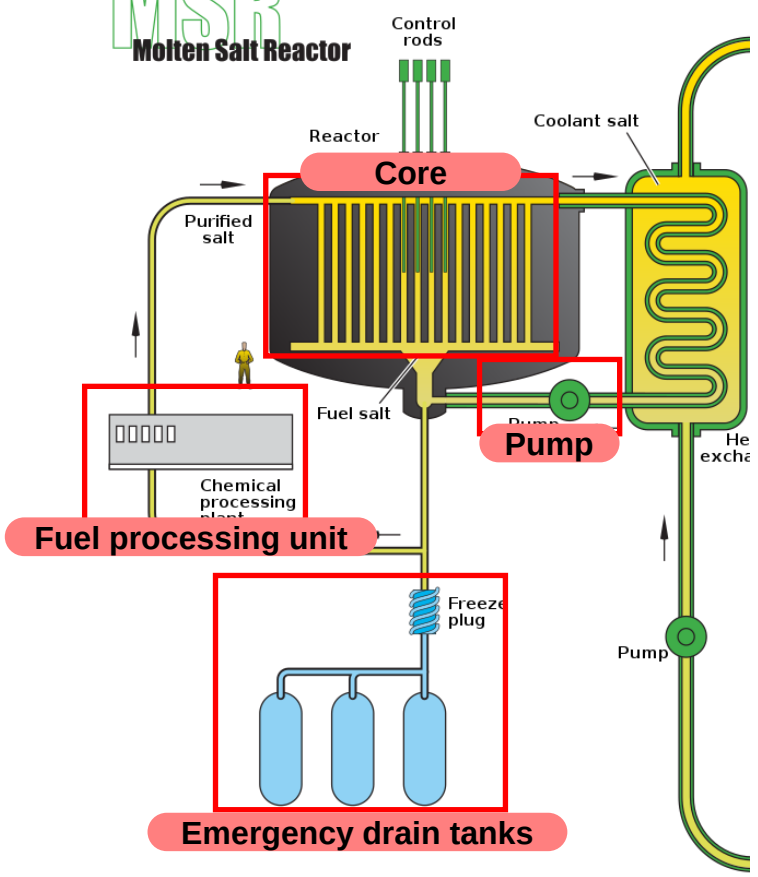
Molten Salt Reactor

- In MSR, Coolant = Fuel = **Molten Salt**

MSR



System of LFTR-type MSR



Characteristics of Molten Salt

Liquid fuel salt

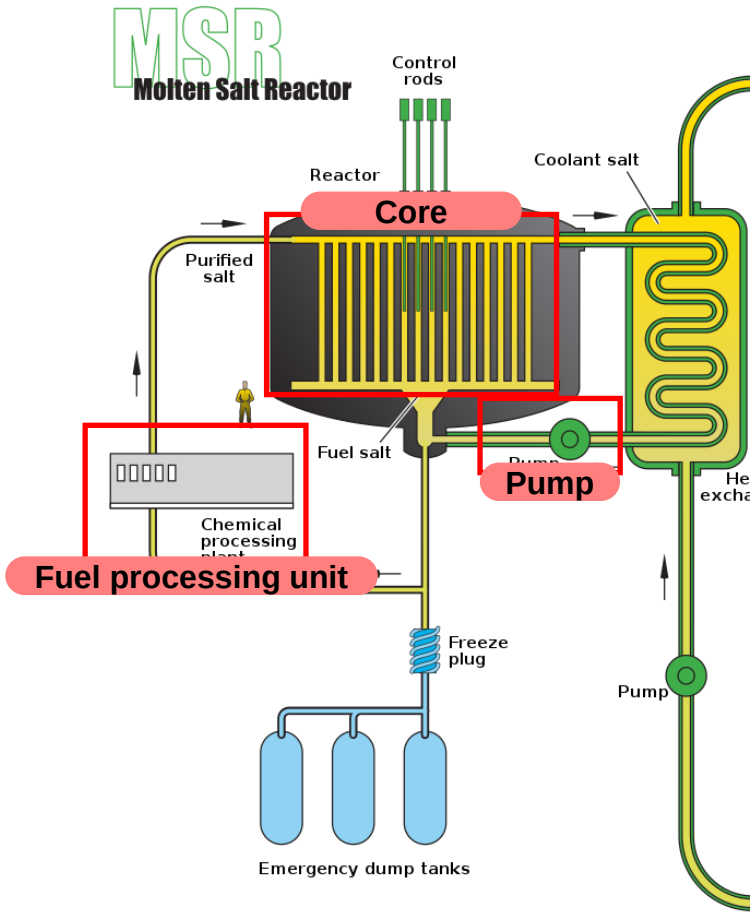
w/ High Melting / Boiling Temp.

- Flexible use (Hydrogen production)
- High burnup
- **ECCS/ADS is not required**
- **Emergency drain system**

Background

I-SAFE-MSR Project & PMFR

System of LFTR-type MSR



Issues of LFTR-type MSR

Fuel processing

- Salt purifying
- U^{234} Proliferation resistance issues

Thermal spectrum Fluoride core

- Li^{7} enrichment
- Graphite disposal

Pump

- Reliability issues
- System complexity

Passive Molten Salt Reactor (i-SAFE-MSR)

i-SAFE-MSR

Innovative original technology of
Severe **A**ccident **Fre****E**
Multi-purpose & long-lifetime
Small modular molten salt reactor
Research center

Long-lifetime Core design

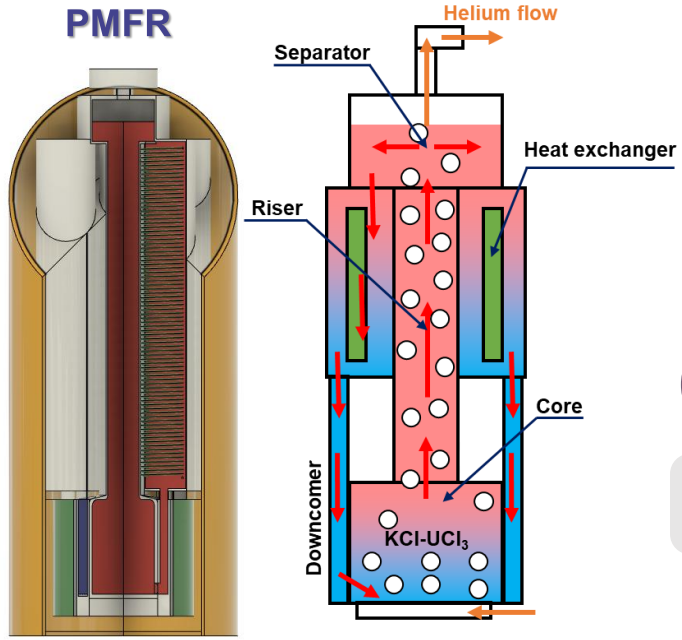
- Fast spectrum chloride core
- No reprocessing

Operation w/o pump

Severe accident free

Passive safety system

PMFR



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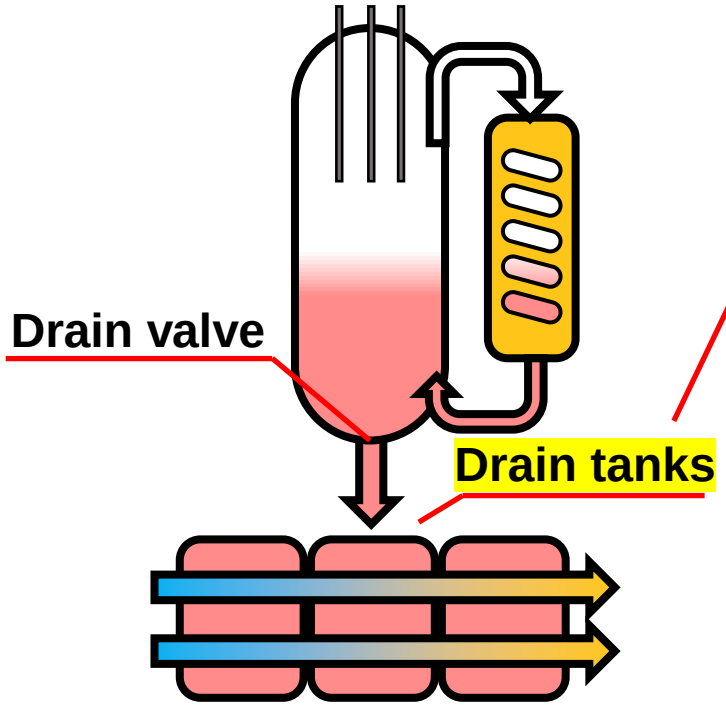
Reviews of draining system

Passive cooling mechanism

- **Passive cooling mechanism of draining system**

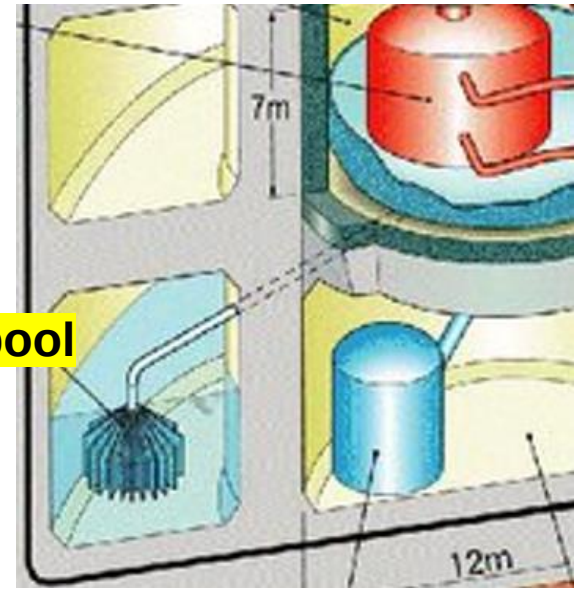
Fuel drain safety system

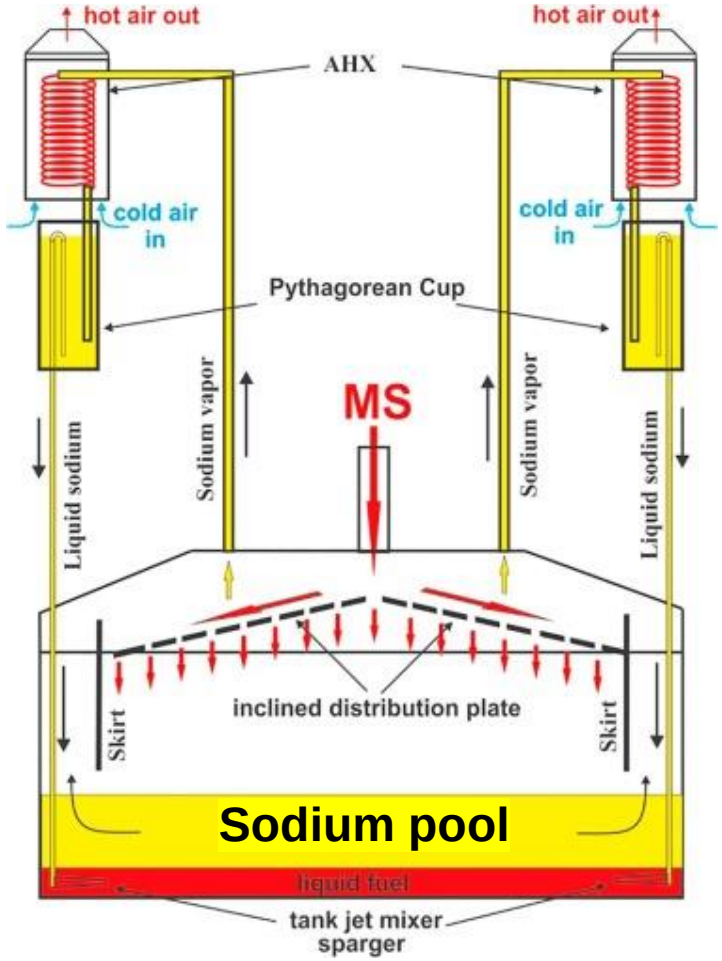


Passive Residual Heat Removal System

Passive Cooling

Phase-changing latent heat
& passive air-cooling





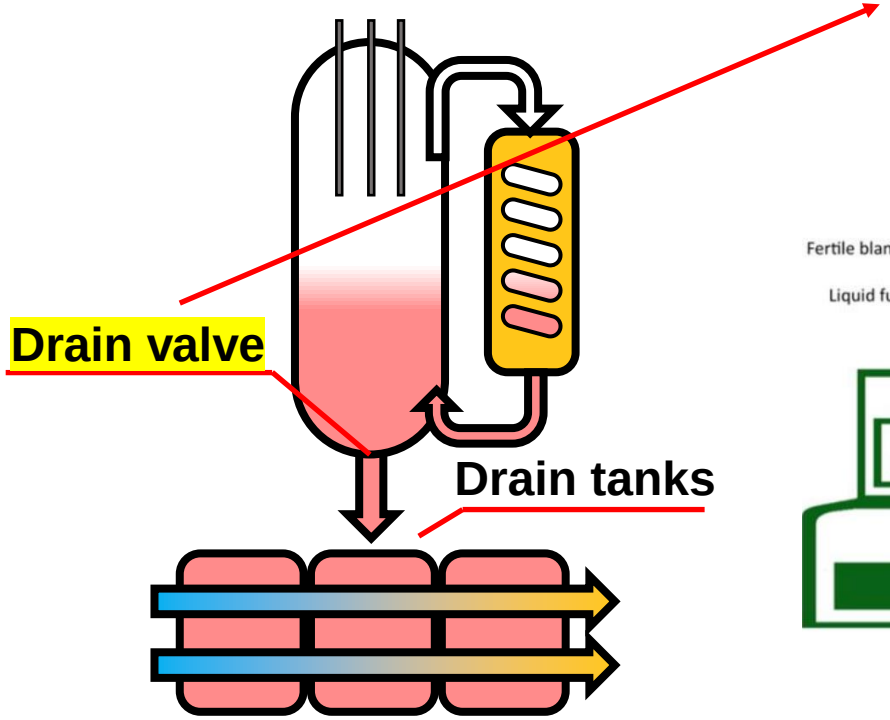
Emergency Draining tank & cooling system (Fuji, MSFR)

Reviews of draining system

Passive Draining mechanism

- **Passive Draining mechanism of draining system**

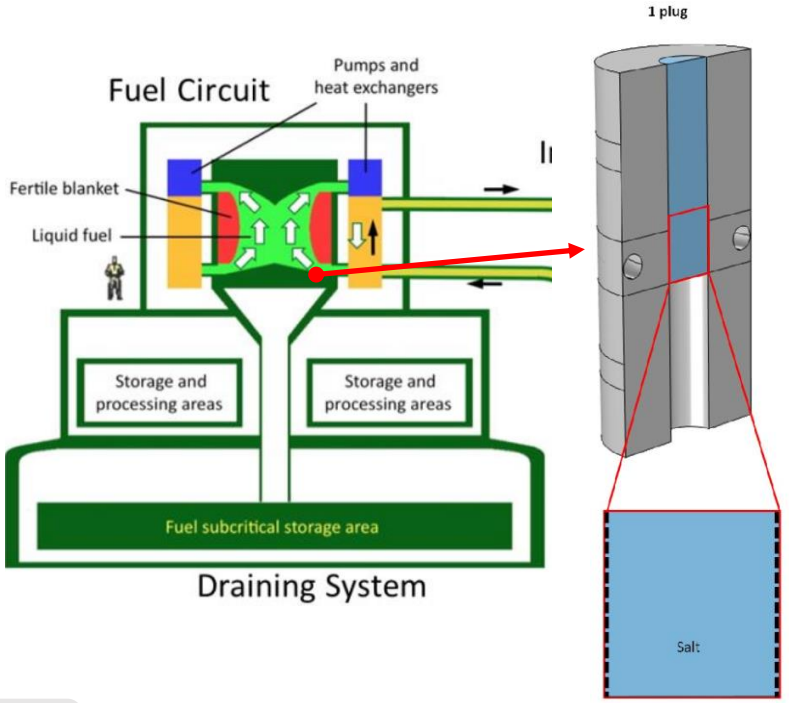
Fuel drain safety system



Passive Residual Heat Removal System

Passive Draining: Freeze plug

Gravity



Open line where a frozen salt is blocking the flow

Actively cooled solidified salt

Melts when the core overheated or active power shutdown

Freeze plug design of MSFR (SAMOFAR, 2018)

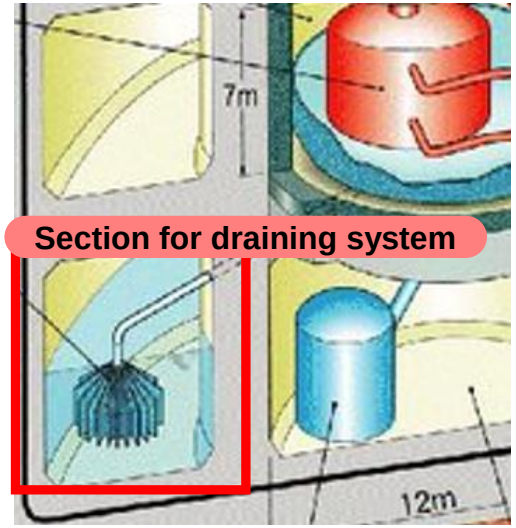
Reviews of draining system

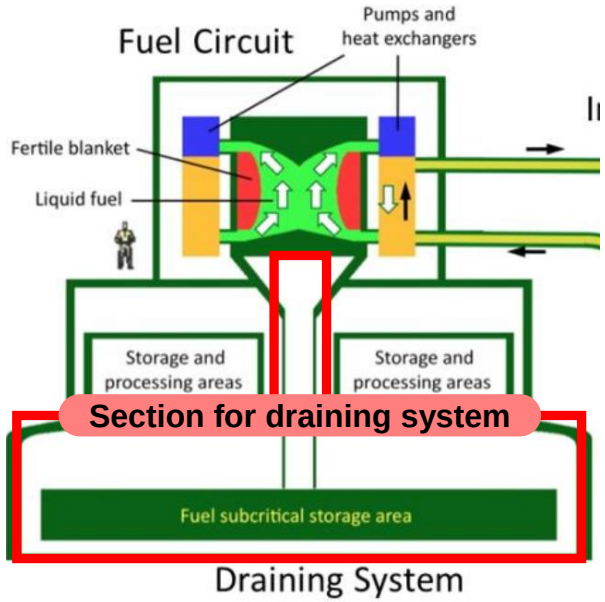
Sizing issue of draining system

- **Issue of fuel drain system in terms of the sizing**

Sizing issue

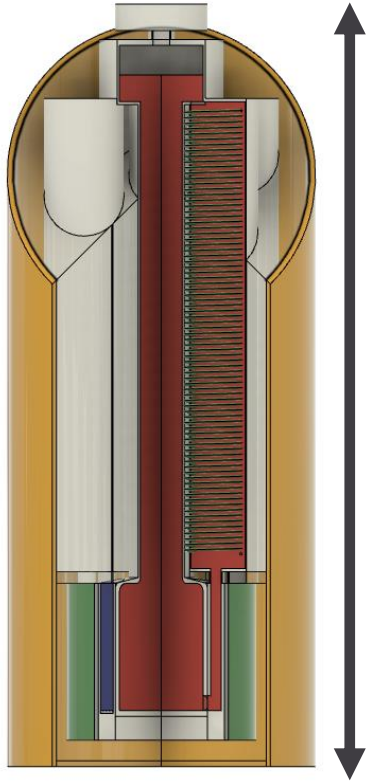
Drain tanks require huge volume in containment





Emergency Draining tank (Fuji, MSFR)

PMFR : Natural circulation, Long-lifetime core



Reactor height : 20m

Fuel salt volume : 32m³

(cf. 3000MWt MSFR : only 18m³)

Required volume for draining

At least 32m³

Required height ???

Containment size ???

Should be avoided for **small modular design**

Passive draining & cooling w/o **sizing issue**

Overview & Objectives

Contents of this study

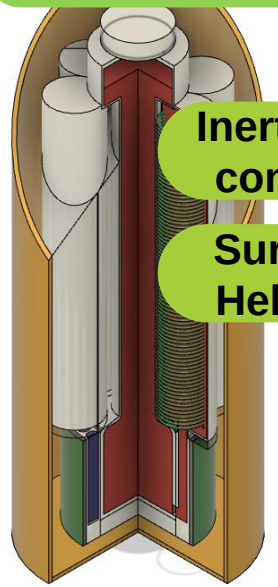
- **Main objective of this study : Conceptual design of PRHRS for PMFR**

Suggest the conceptual design of passive residual heat removal system for PMFR

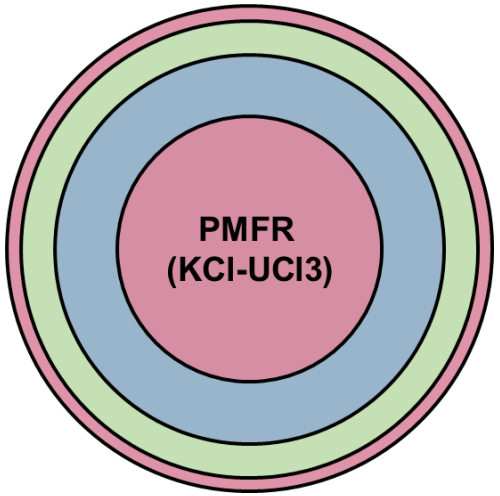
Model the PMFR passive residual heat removal system

Investigate the cooling capability of the PMFR PRHRS

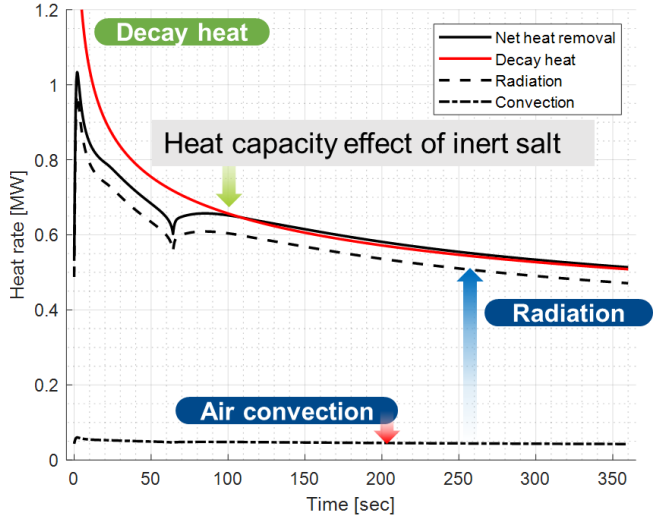
PMFR PRHRS



Modeling



Cooling capability



Cooling capability of the system

Conceptual design of PMFR safety system

He bubbling system of PMFR

- **Preliminary design & T/H characteristics of the PMFR**

Characteristics of PMFR T/H systems

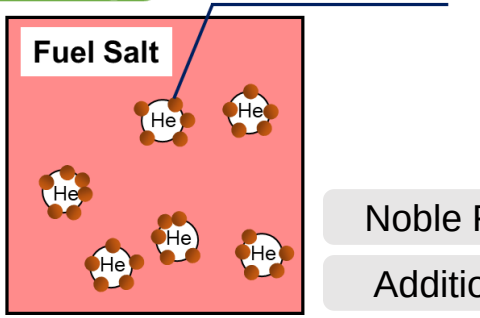
No pump & long-lifetime

Tall height to promote natural circulation

Helium injection from the bottom of the core

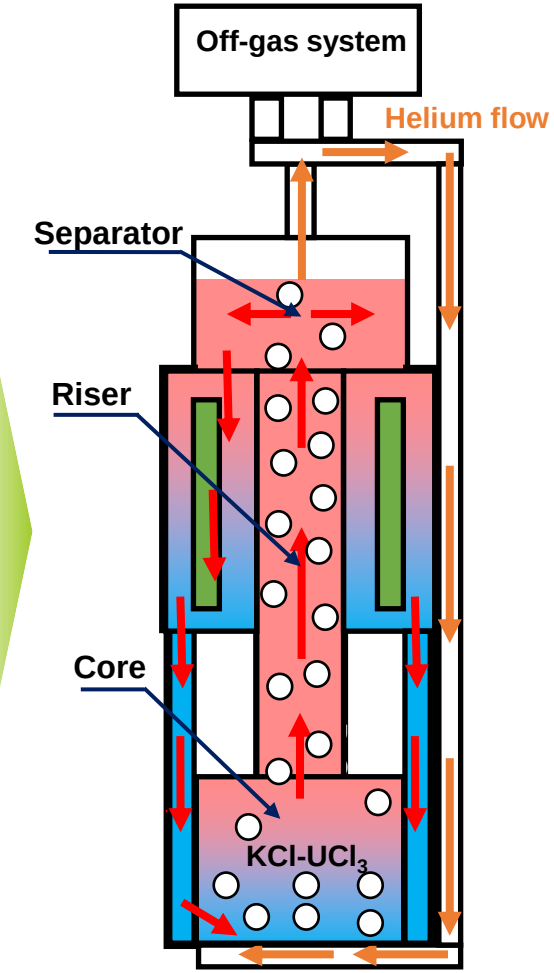
Filtering & separation tank for insoluble fission products removal

He bubbling



Noble FP removal

Additional buoyancy



Tall height of reactor vessel

Large surface area

Helium circulation system

Compressed to overcome the system pressure

Separator tank for filtering

Conceptual design of PMFR safety system

Inert salt filled containment & Helium filled drain tanks

- **Passive Residual Heat Removal System of PMFR**

Inert salt filled containment

Passive air cooling

Heat of fusion – initial heat sink of decay heat

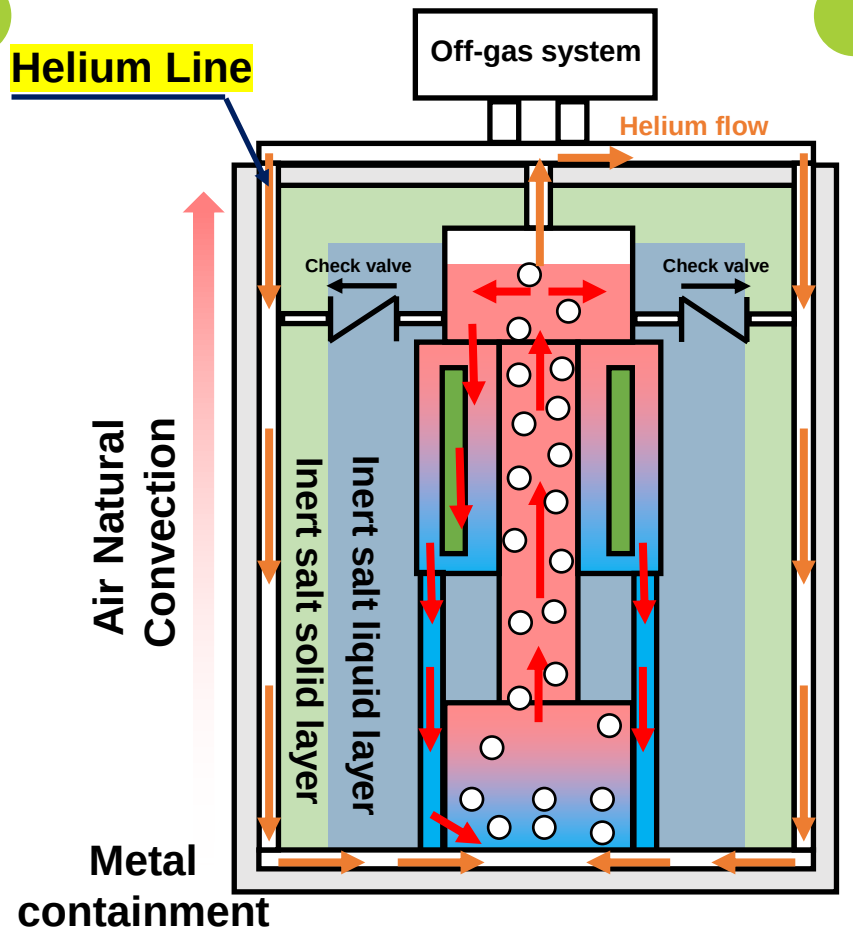
Inert salt solid layer

Excellent heat capacity

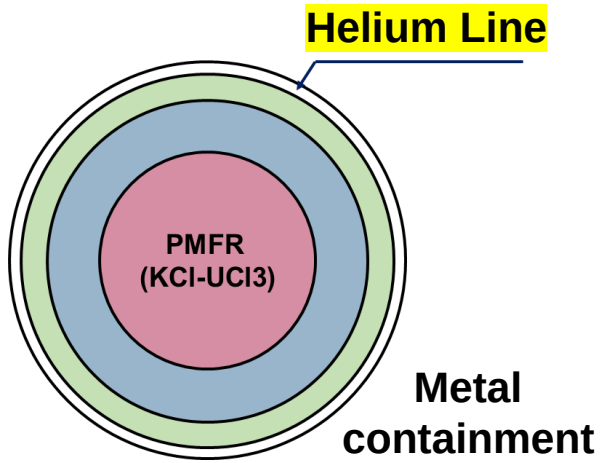
Inert salt liquid layer

+

Additional radioactive material release shielding



With Surrounding Helium lines



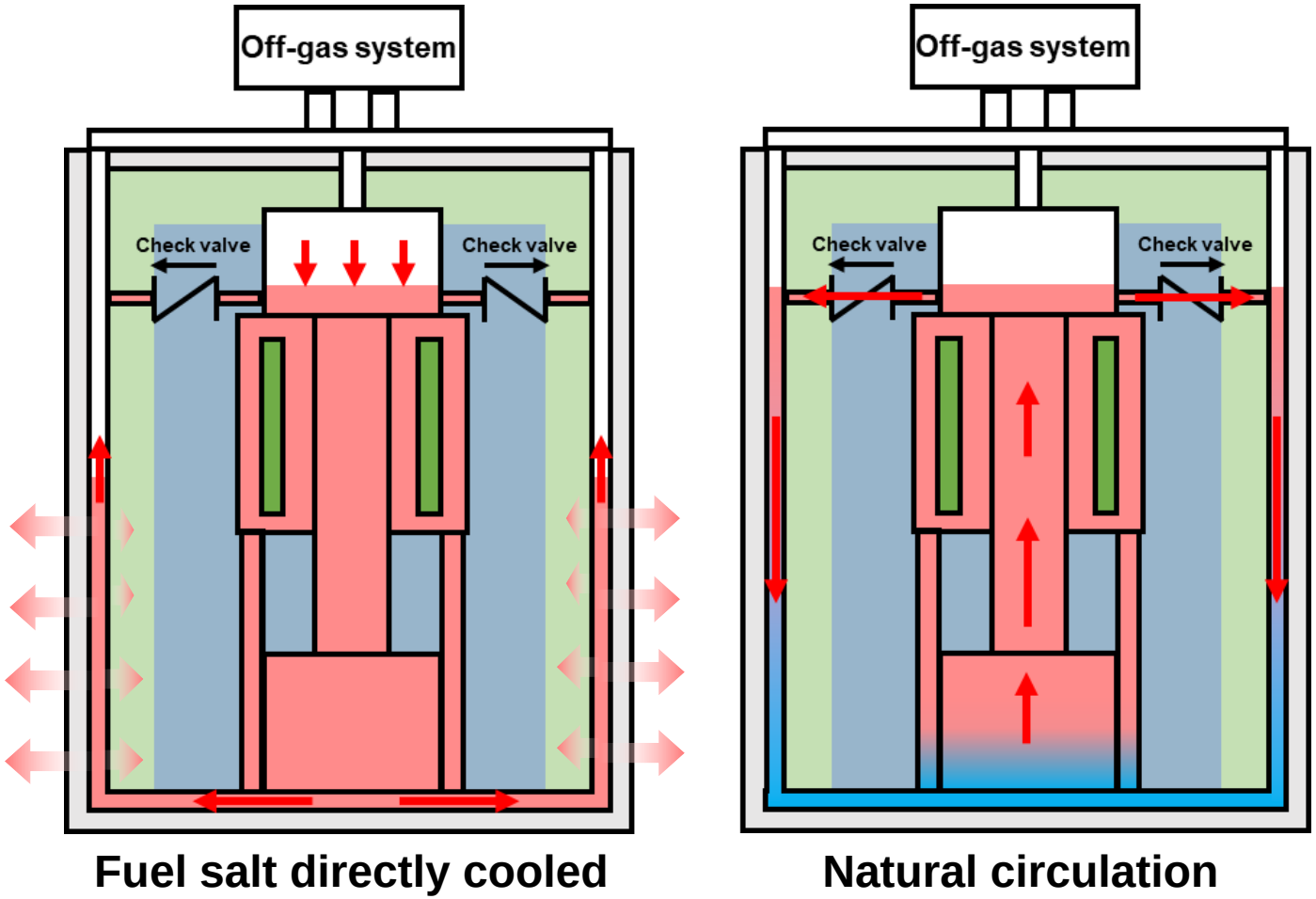
The lines surround the inner wall of containment vessel

The lines of helium circulation system & **fuel salt drain tanks**

Conceptual design of PMFR safety system

Draining & circulation mechanism

- **Draining & circulation mechanism of PMFR**



Fuel salt directly cooled **Natural circulation**

Abnormal situation

Helium line decompression due to helium circulation shutdown

PMFR **fuel salt flow in the lines** due to gravity

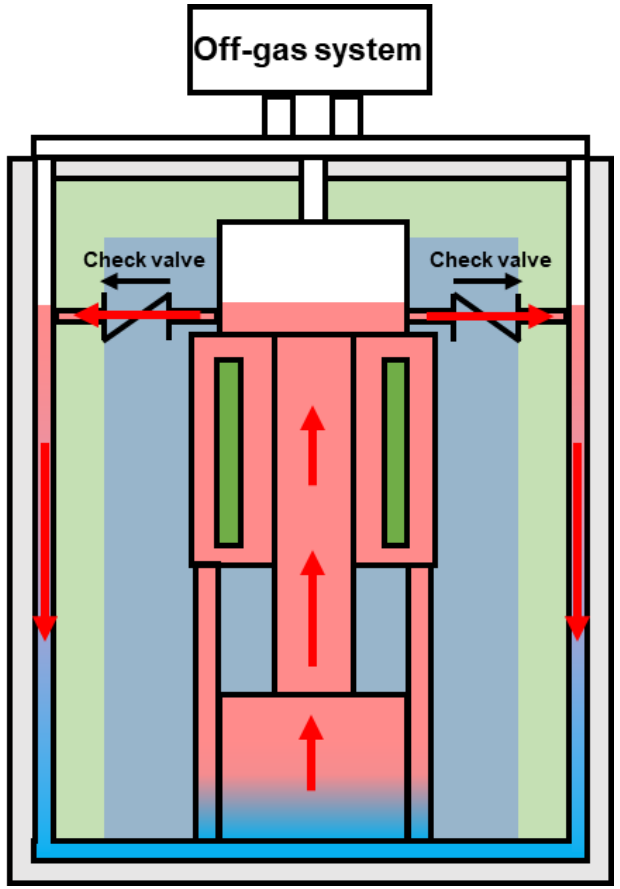
Fuel salt directly cooled and melts the solid layer

Natural circulation occurs due to the temperature gradient

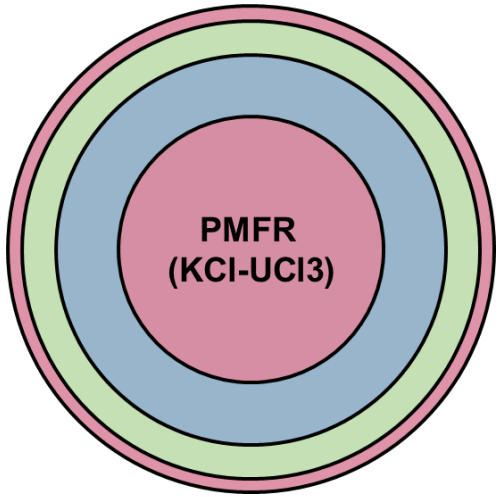
Methodology

Modeling the PMFR system

- **1-D simplification of the PMFR system**



Ambient air



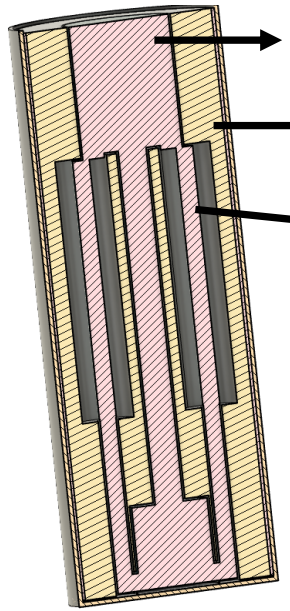
Clean salt liquid layer

Clean salt solid layer

T/H Assumption

- Adiabatic without r-direction
- Neglect thermal resistance of metal layer
- Neglect friction resistance drain lines

Geometry normalization



Volume of the fuel salt

Volume of inert salt

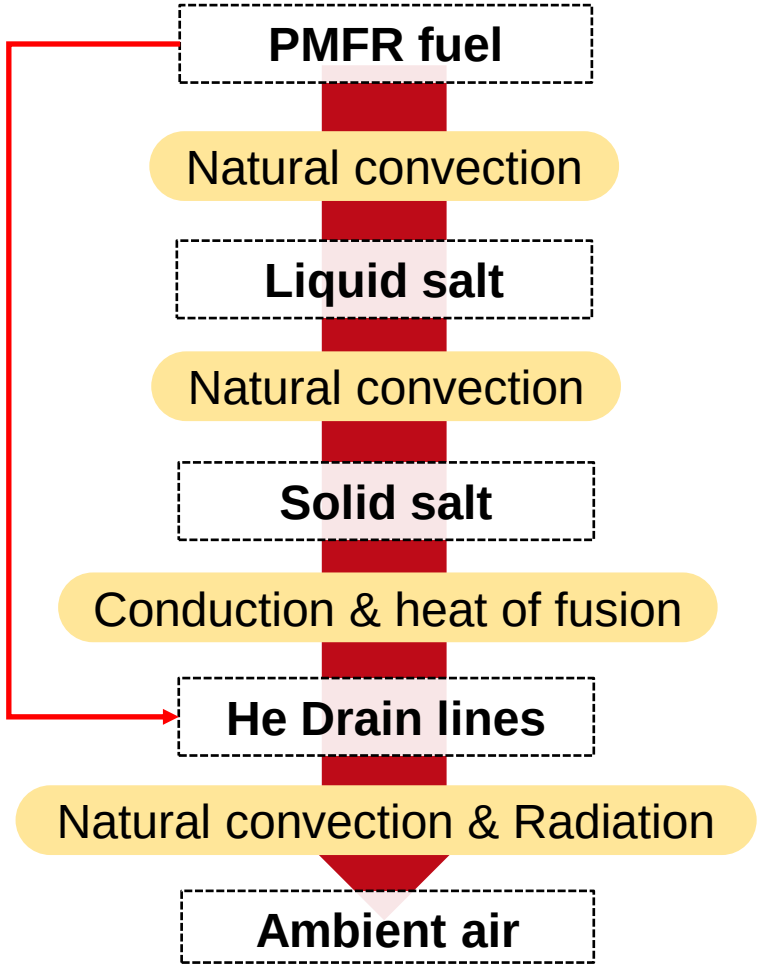
Heat transfer area

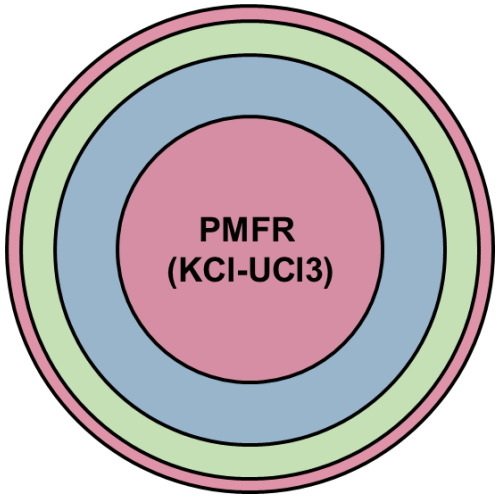
Reactor design parameters	
Desired thermal power	250 MW_t
Normalized surface area	
• PMFR reactor	241.1 m^2
• Liquid-solid interface	155.3 m^2
• Containment	196 m^2
Salt inventory [mass]	
• Fuel salt	95.15 ton
• Liquid layer (assumed)	151 ton
• Solid layer (assumed)	151 ton

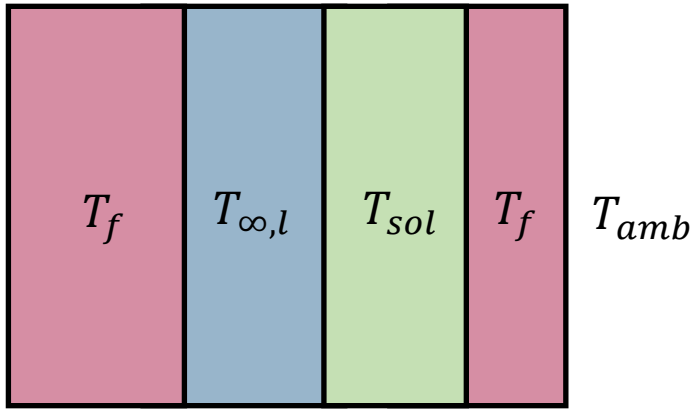
Methodology

Modeling the PMFR system

- **Heat transfer modeling for cooling capability estimation**







Melting Temp. of inert Salt

NaCl-KCl [50:50] = 657 °C

Initial conditions

Inert salt temperature

$$T_{\infty,l} = \frac{1}{2}(T_{f(0)} + T_{melt})$$

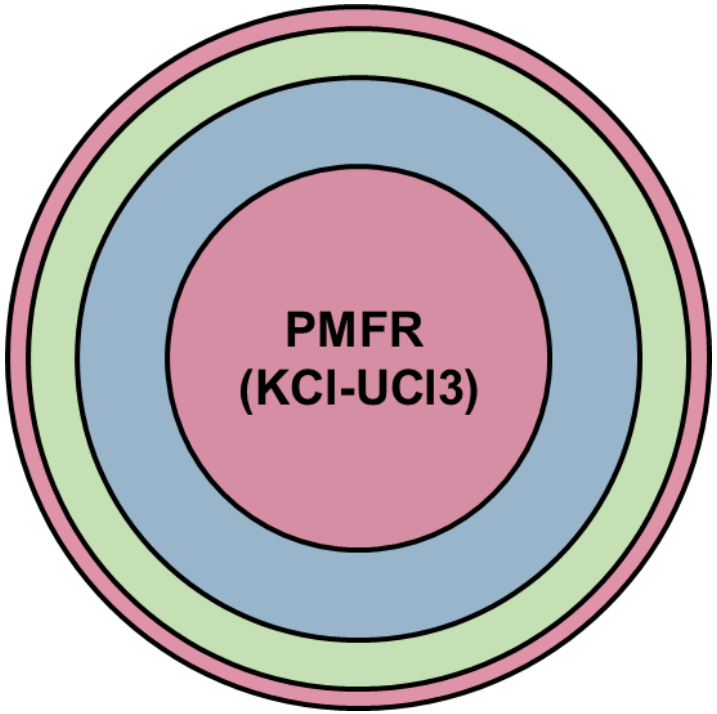
$$T_{sol} = \frac{1}{2}(T_{melt} + T_{amb})$$

Ambient air temperature is assumed as constant of 100°C

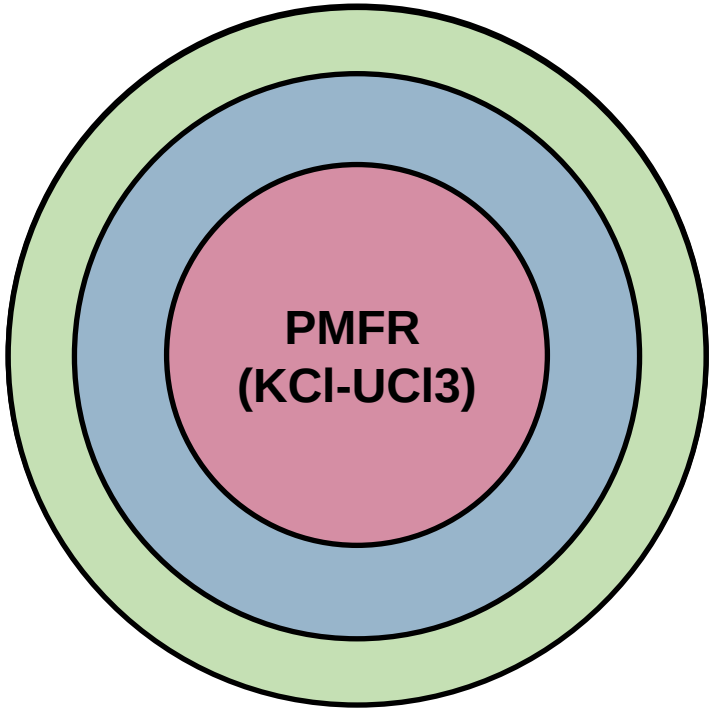
Methodology

Effects of PRHRS for cooling capacity

- **Comparison for the best and worst cases**



Ideal case- initially filled drain line

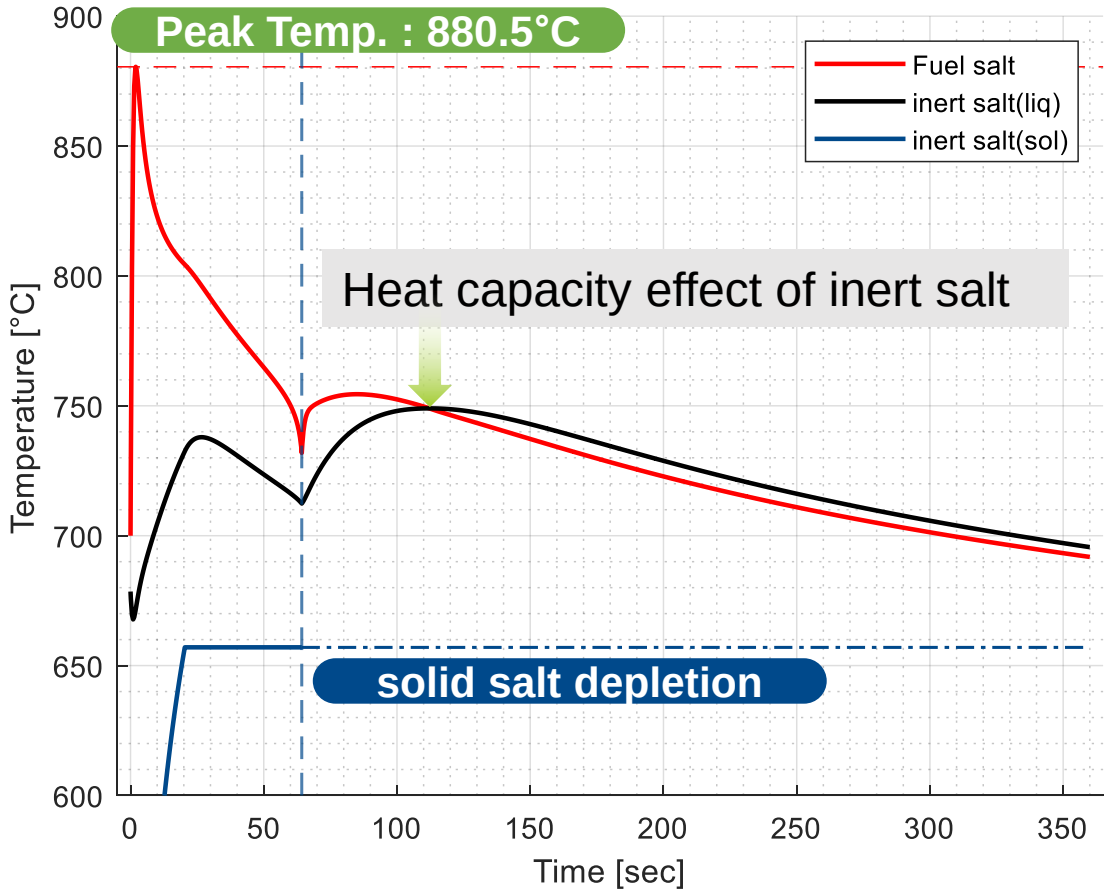


Worst case - no draining

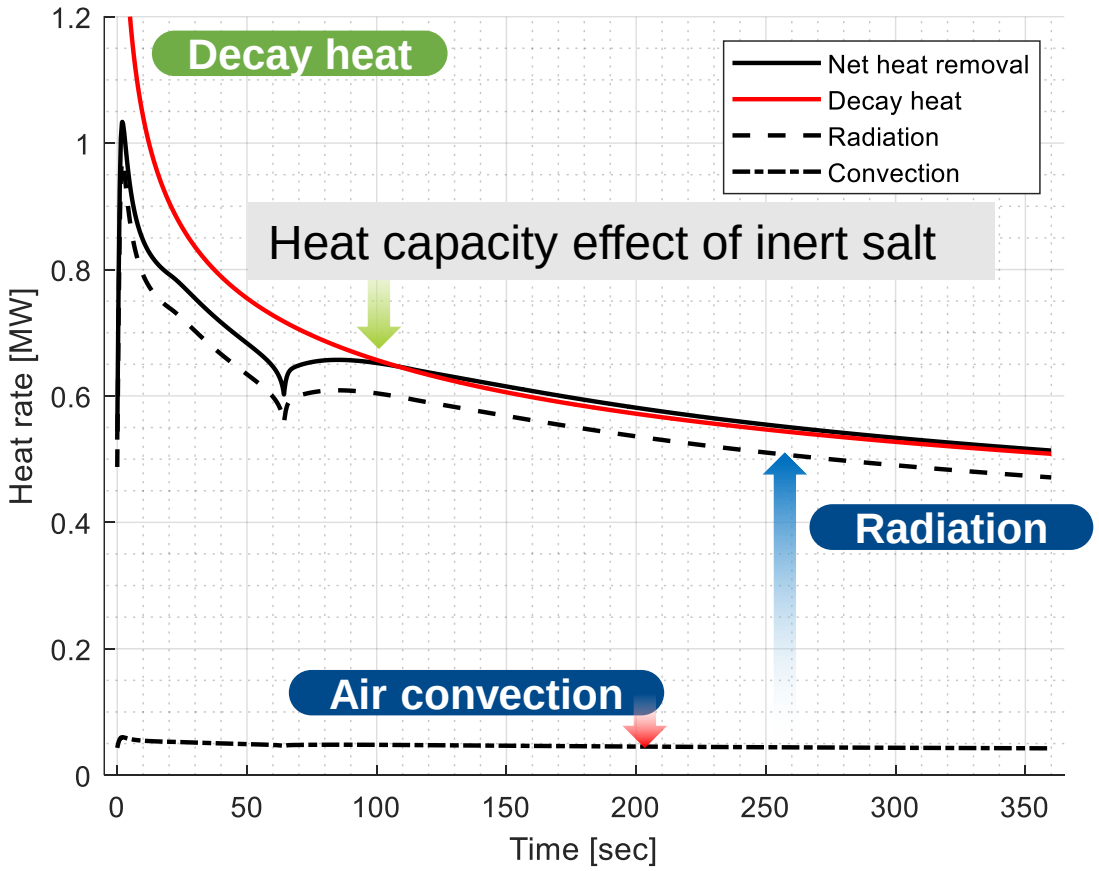
Results & Discussion

Cooling capability analysis results

- **Results of Ideal case**



Temperature profile

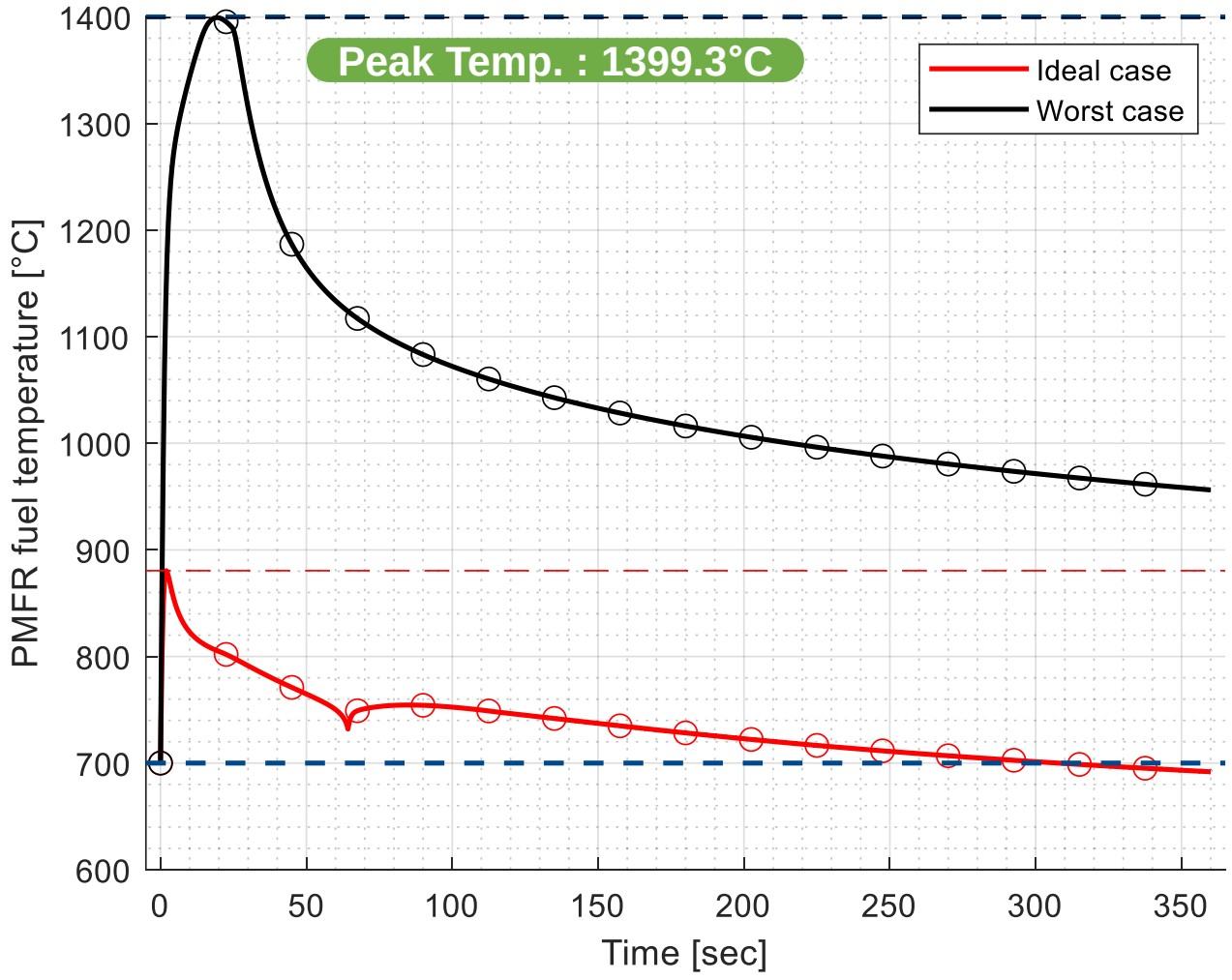


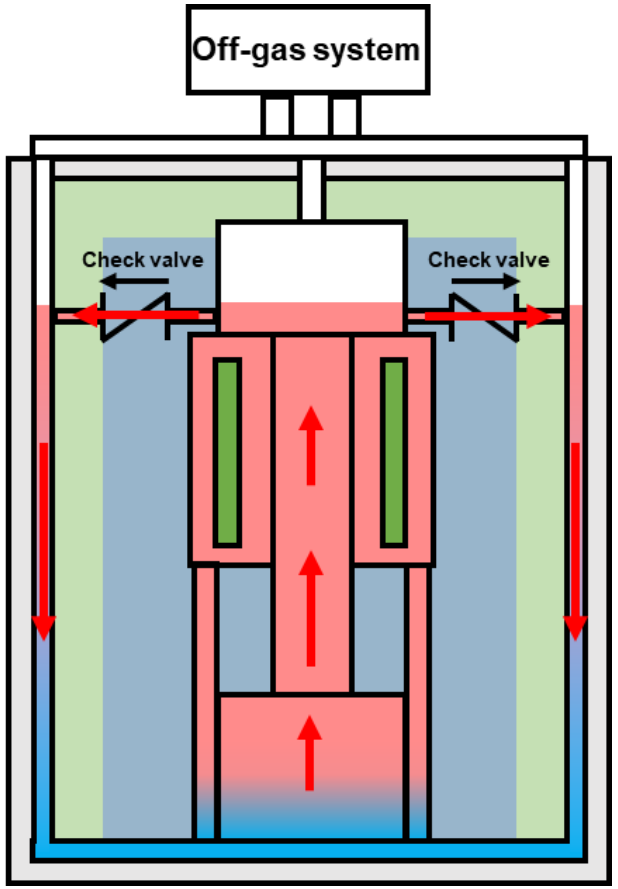
Cooling capability of the system

Results & Discussion

Cooling capability analysis results

- **Worst case results**

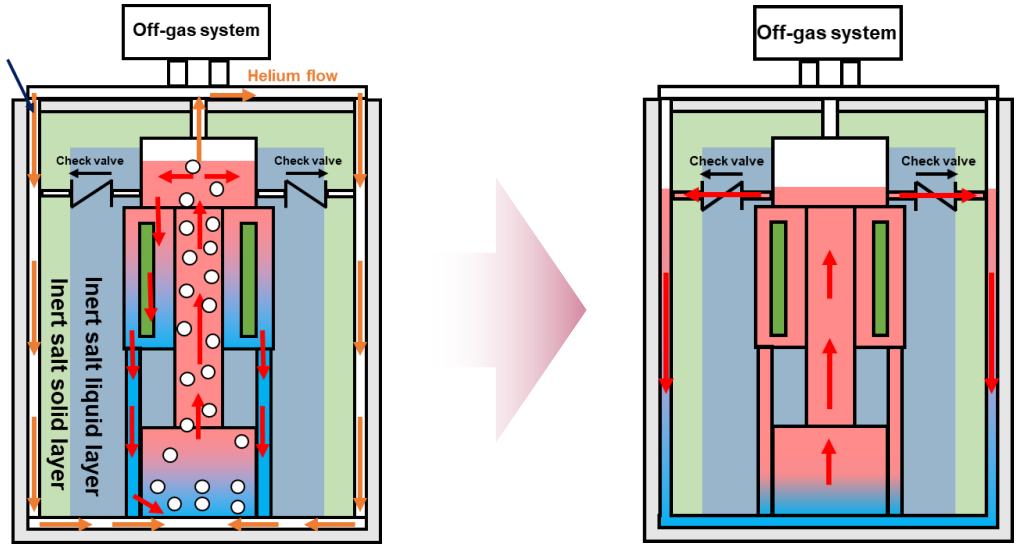


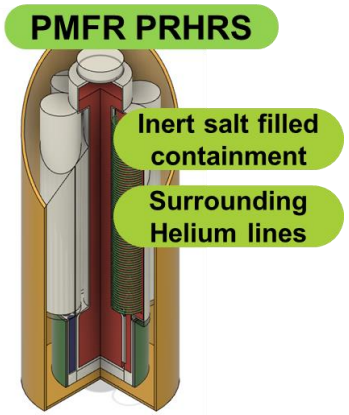


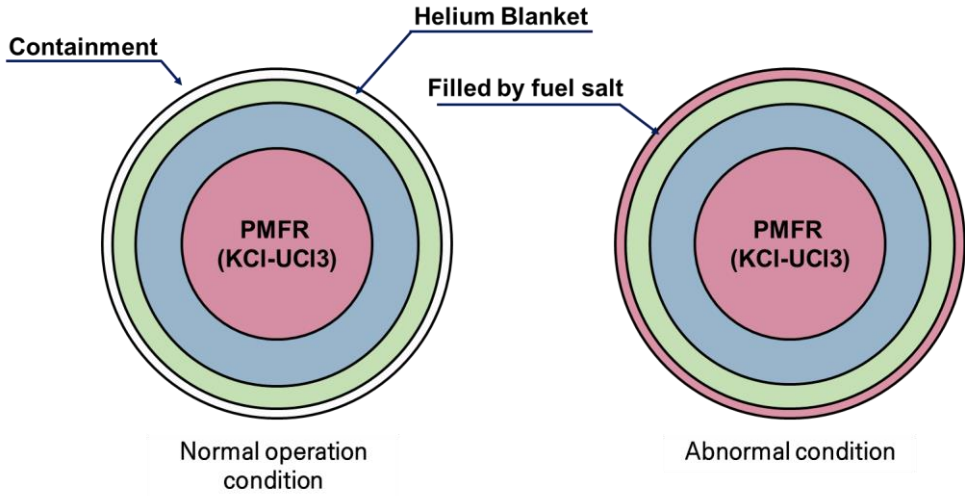
The initial draining process is key to investigate feasibility

Conclusion

- A conceptual design for PMFR PHRRS using a helium circulation system was suggested.
- the cooling capability was estimated, and the result showed the suggested system could present enhanced cooling capacity
- Natural circulation & initial draining behavior will be conducted for future works to investigate the feasibility of the system







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Jihun Lim

jihunlim@hanyang.ac.kr