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(Nuclear Thermal-hydraulics and Reactor Safety)

The Conceptual Heat Exchanger Design for Heat Pipe Cooled Micro Reactor

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I. Introduction

[1] K.C. Wagner et al., “MELCOR Integrated Severe Accident Code Application to Safety Assessment of Heat Pipe Reactors”, SAND2021, 2021.
[2] M. M. Swartz et al., “Westinghouse eVinci Heat Pipe Micro Reactor Technology Development”, ICONE28, August 4-6, 2021.

➢ Heat pipe cooled micro reactors;

- The micro reactors have been developed for space applications, military bases and transportable solutions (by Westinghouse, LANL, INL, MIT, Oklo power etc.).
- Typically cooled by liquid metal heat pipes (HPs).
- The primary heat exchanger condense the vapor in the condenser region of HPs.

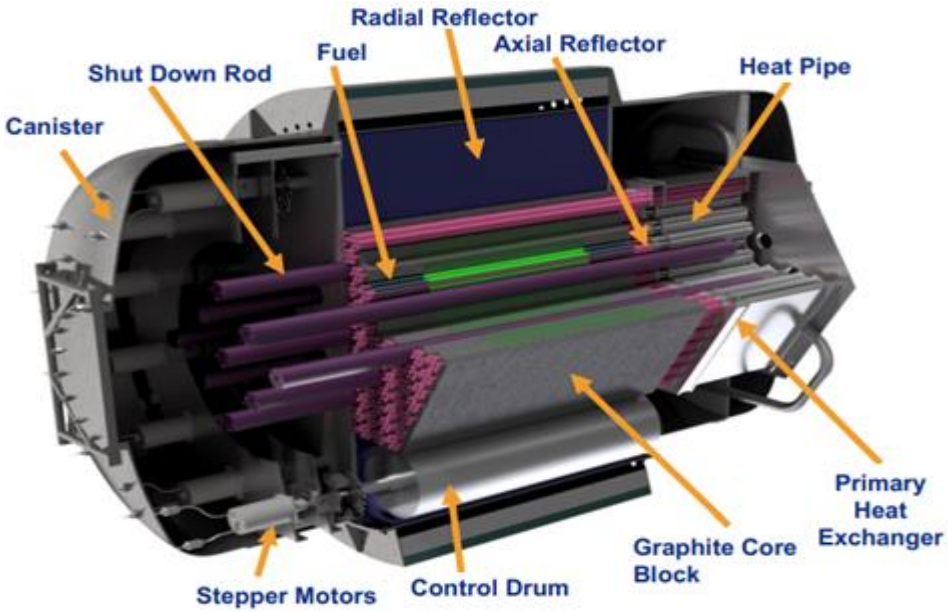


Fig. eVinci micro reactor overview.

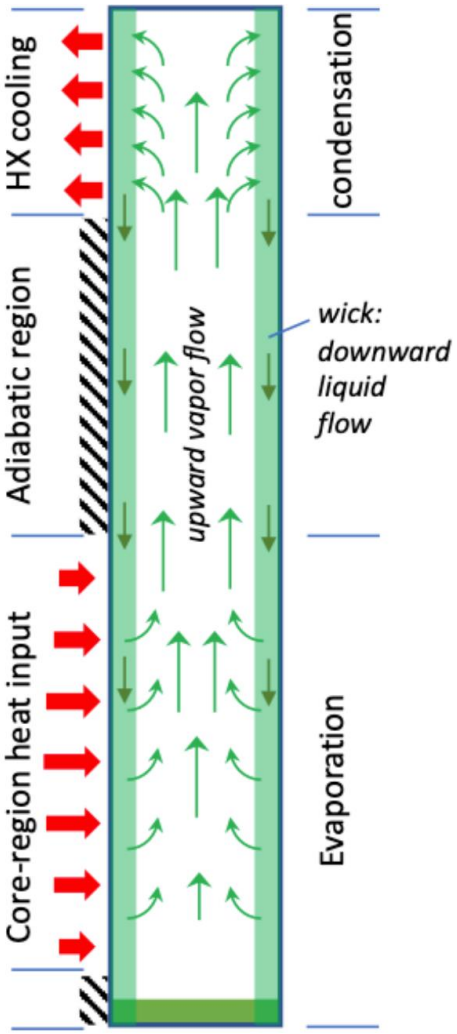


Fig. Illustration of a vertically oriented heat pipe.

I. Introduction

[3] W. Zhang et al., “Conceptual design and analysis of a megawatt power level heat pipe cooled space reactor power system”, Annals of Nuclear Energy, Vol. 144, pp. 107576, 2020.

➢ Heat exchanger flow type;

- The heat exchanger (HE) typically has cross flow in some designs.
- Because of the nonuniform velocity and temperature distribution, the cross flow can become less efficient than the axial flow (parallel or counter flow).
- The fluctuant temperature distribution causes local deformation (because of the local temperature peaks).

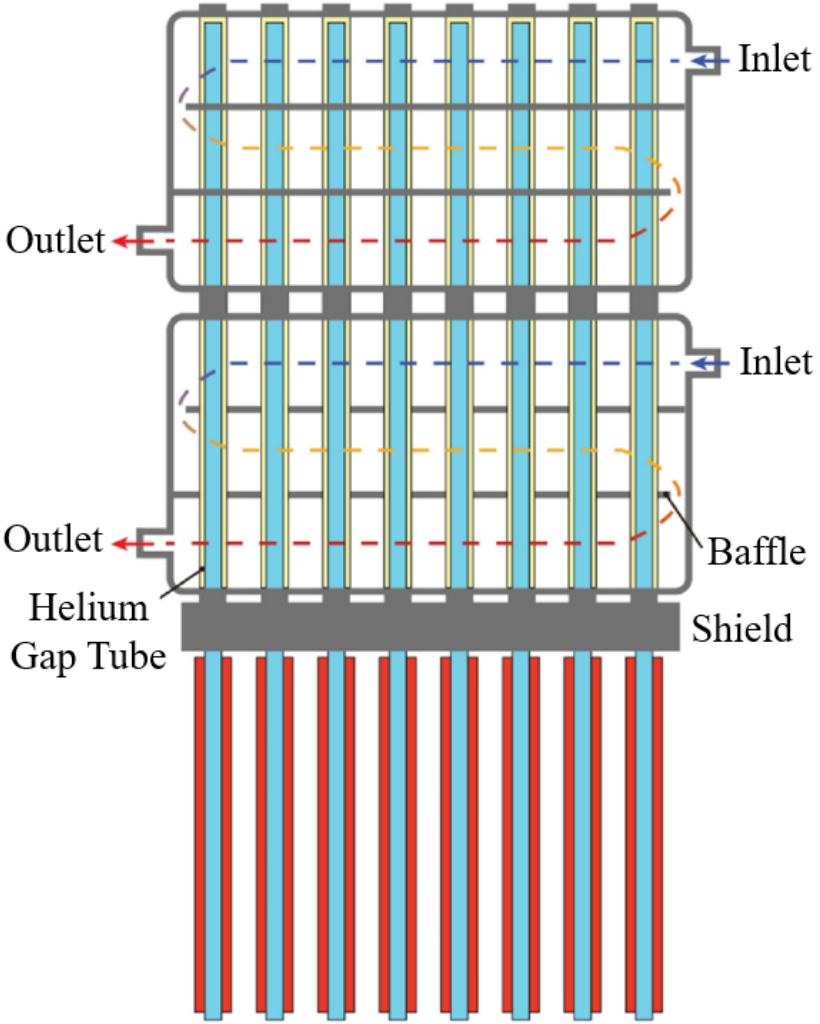


Fig. Schematic of the cross-flow HP-Gas heat exchanger concept.

I. Introduction

[1] K.C. Wagneret al., “MELCOR Integrated Severe Accident Code Application to Safety Assessment of Heat Pipe Reactors”, SAND2021, 2021.

➢ Heat pipe failure conditions;

- At the high power conditions, as the temperature increases, the pressure increases in HP.

- At high pressures and temperatures;
  - If the **creep rupture** exceeded, the HP wall will strain and fail.
  - Fuel cladding and HP wall fail simultaneously near the **melting** temperature of stainless steel (~1400 °C).

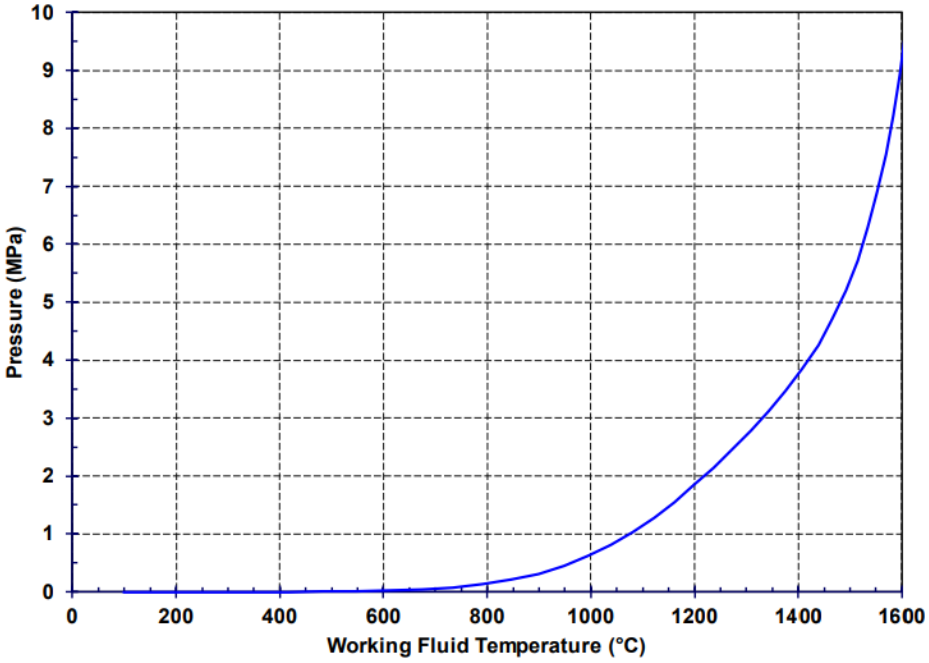


Fig. Potassium Equilibrium Pressure Temperature Curve.

I. Introduction

[1] K.C. Wagneret al., “MELCOR Integrated Severe Accident Code Application to Safety Assessment of Heat Pipe Reactors”, SAND2021, 2021.

➢ Fission product release;

- The fuel cladding failure begins the fission product release from the fuel.
- Since the fluid in the HP is approximately isothermal, a creep failure can occur anywhere along the HP wall.
- If the HP wall fails;
  - The high pressure fluid exits from the HP and it ceases to operate.
  - The fission product release to the atmosphere by secondary system.

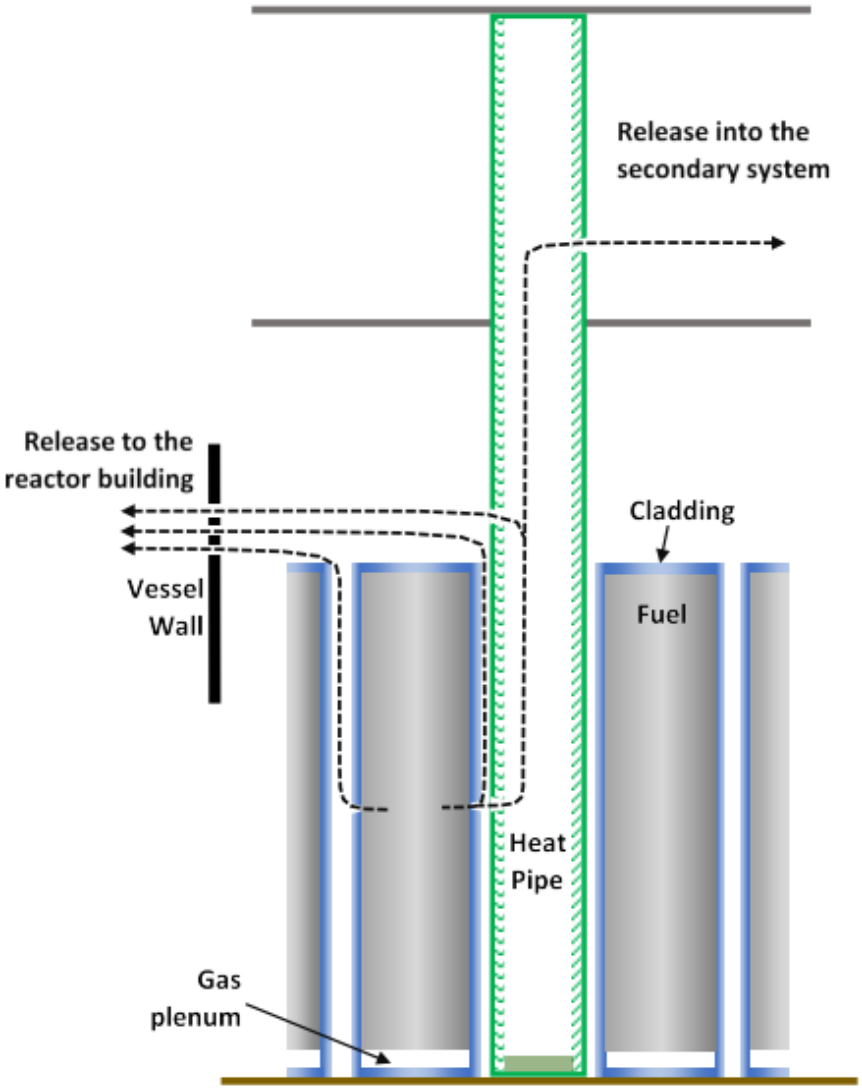
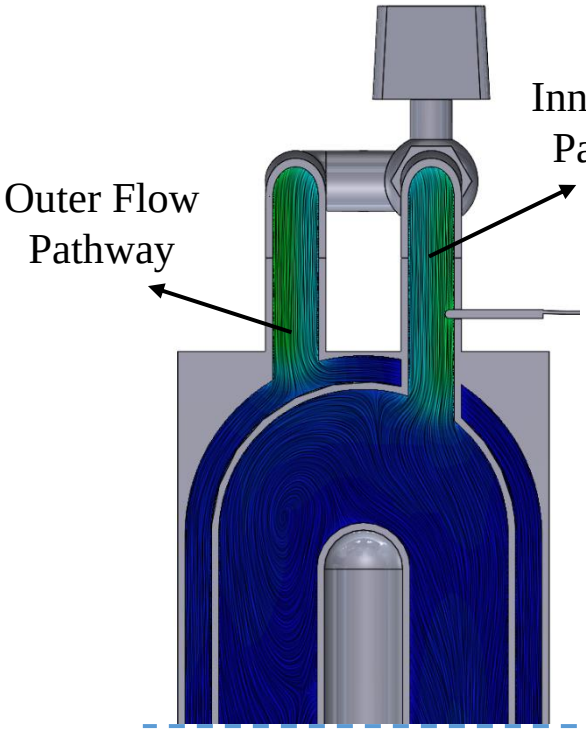


Fig. HP failure pathways.

II. Conceptual Heat Exchanger Design

- To provide uniform velocity and temperature distribution, the flow type was chosen as axial flow.
- Each heat pipe has one channel and two coolant flow path.
- In the normal operation;
  - The coolant flows in both flow pathways to remove heat.
  - The Electric Actuated Ball Valves (EABVs) are in open position.



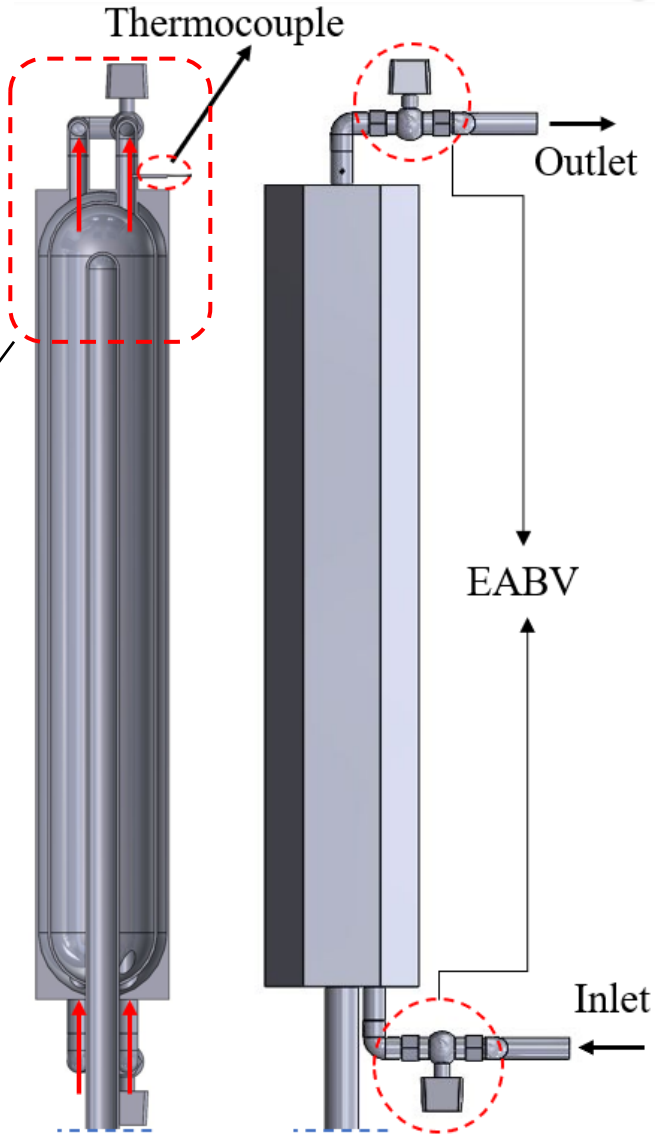
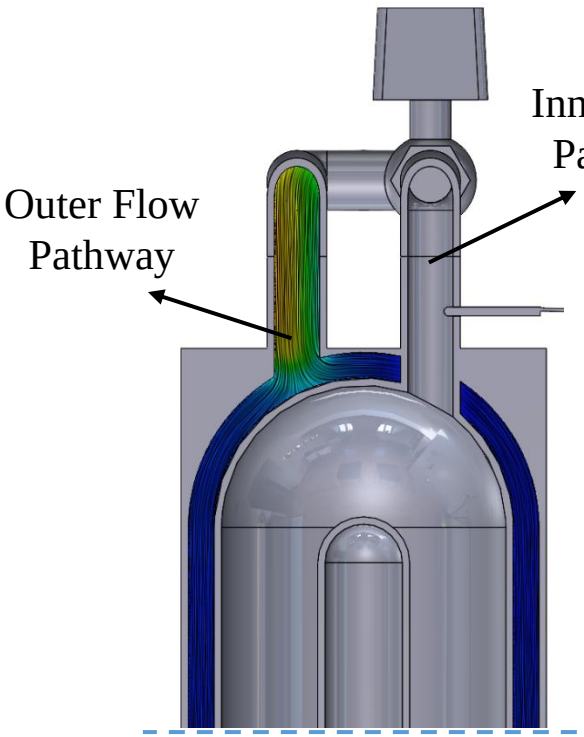


Fig. The flow direction of coolant in new heat exchanger design

II. Conceptual Heat Exchanger Design

- In the HP failure condition;
  - The thermocouple detects the temperature increase, and the EABVs are switched to closed position to seal inner flow path.
  - The coolant inside inner flow pathway stays stationary.
  - The main line continues to flow in the outer flow pathway to remove heat.



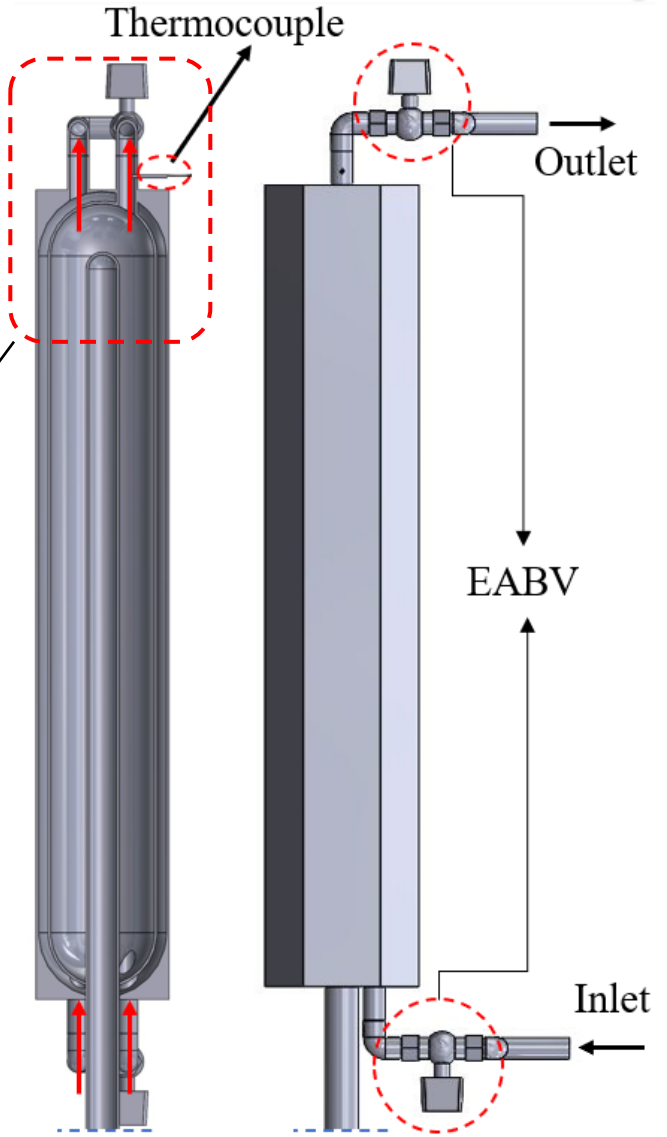


Fig. The flow direction of coolant in new heat exchanger design

II. Conceptual Heat Exchanger Design

- Each heat pipe has one flow channel with two flow path.
- Each flow path has its own flow line.

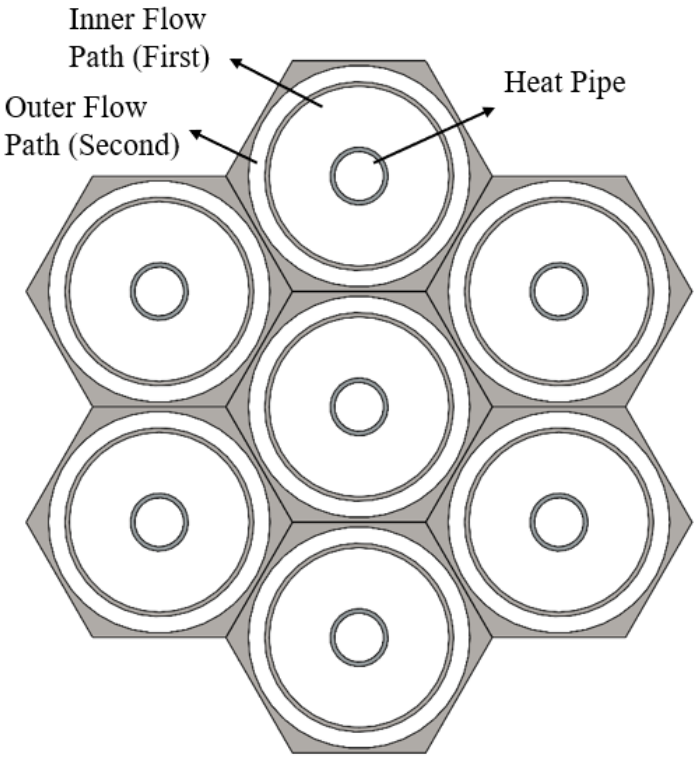


Fig. Midplane view of conceptual 7 channels design.

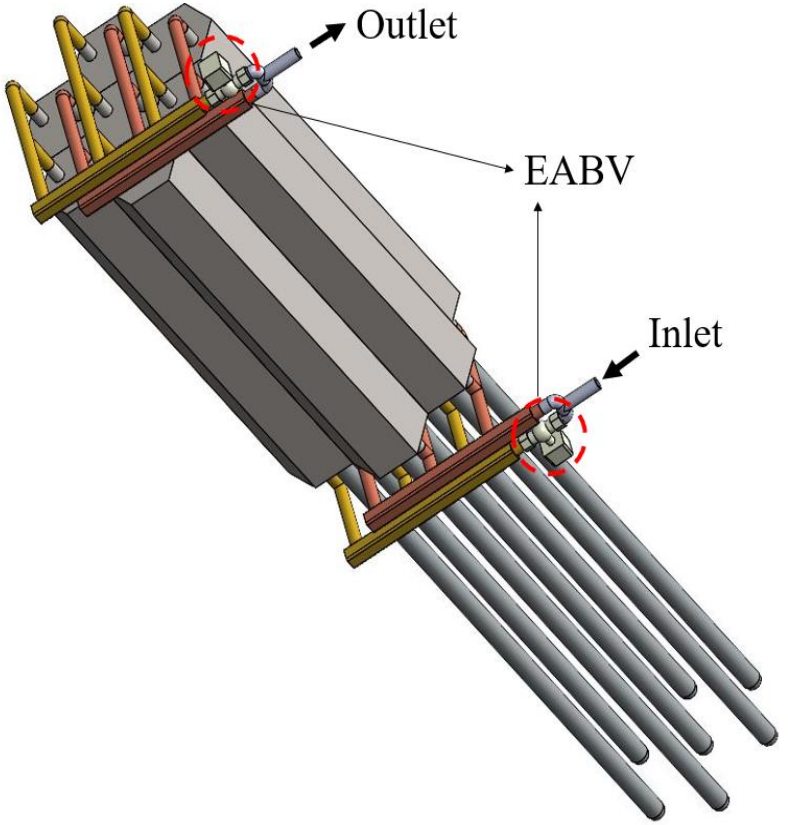


Fig. The conceptual heat exchanger design which consist 7 heat pipes channels.

- EABV was inserted the only inner flow line.
- Depending on the temperature rise, EABVs seal the inner flow line.

III. Thermal and Flow Analysis

[4] J.W. Sterbentz et al., "Special Purpose Nuclear Reactor (5 MW) for Reliable Power at Remote Sites Assessment Report", Idaho National Laboratory, April 2017.

➢ Design parameters;

- LANL design was chosen as a reference design.
- Inlet temperature into the turbine is 675 ℃.
- Heat exchanger of this reactor operates between 486.1 ℃ and 675 ℃.

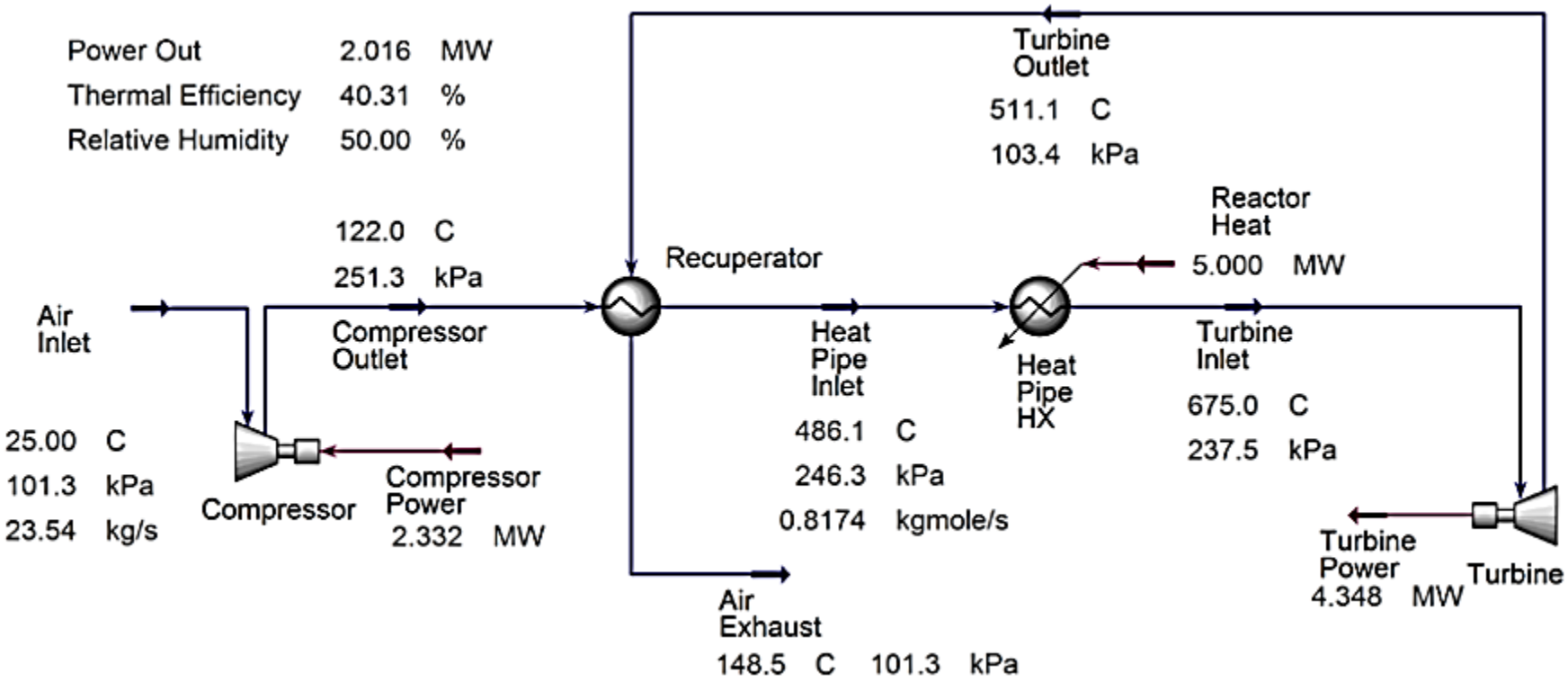


Fig. Aspen HYSYS model of heat recuperated air Brayton cycle.

III. Thermal and Flow Analysis

[4] J.W. Sterbentz et al., “Special Purpose Nuclear Reactor (5 MW) for Reliable Power at Remote Sites Assessment Report”, Idaho National Laboratory, April 2017.

➢ Design parameters;

- The thermal analysis were just performed on one flow channel.
- Representative cross-flow HE design (which achieves 675 °C outlet temperature) were used to make comparison between flow types.
- Same input and analysis parameters were used to analyze the new conceptual HE design.
- Ansys CFX was used to simulate all conditions.

Parameter	Unit	Value
HP Inner Diameter	cm	1.575
HP Outer Diameter	cm	1.757
HP Average Temperature	°C	627-727
HP Operating Pressure	MPa	0.1
HP Working Fluid		Potassium
HE Inlet Temperature	°C	486.1
HE Inlet Pressure	kPa	246.3
HE Inlet Flow Rate	kg/s	0.020
Condenser Length	cm	210
Material		SS 316
Coolant		Air
HP-to-HP Pitch	cm	2.771

Tab. Design and flow analysis parameters.

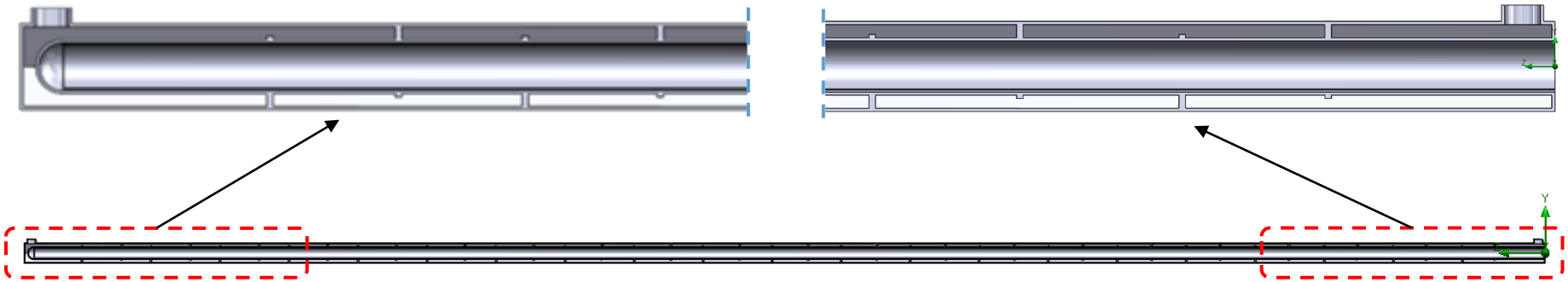


Fig. Representative cross flow heat exchanger.

III. Thermal and Flow Analysis

- **Results;**

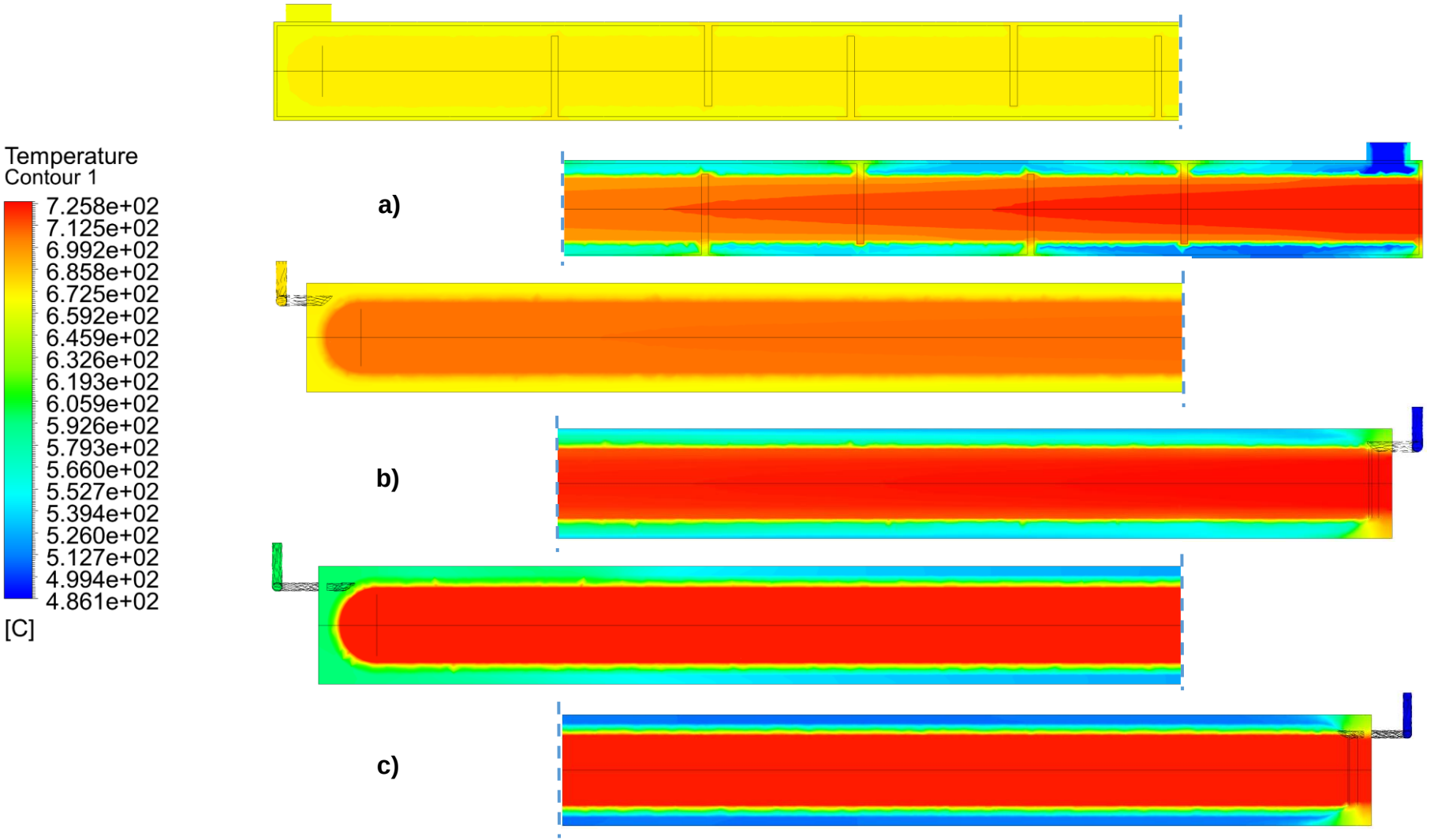


Fig. Temperature distribution of a) representative cross-flow, b) conceptual design in normal operation, and c) conceptual design in HP failure condition.

III. Thermal and Flow Analysis

➢ Results;

- According to simulation results, the outlet temperature of the conceptual HE design matches with the reference temperature (~675 °C).
- The crossflow design has mixed flow because of the structural barriers which cause fluctuation via the channel.
- The conceptual heat exchanger design has uniformly distributed temperature.
- In the accident condition, outer flow continues to remove heat.

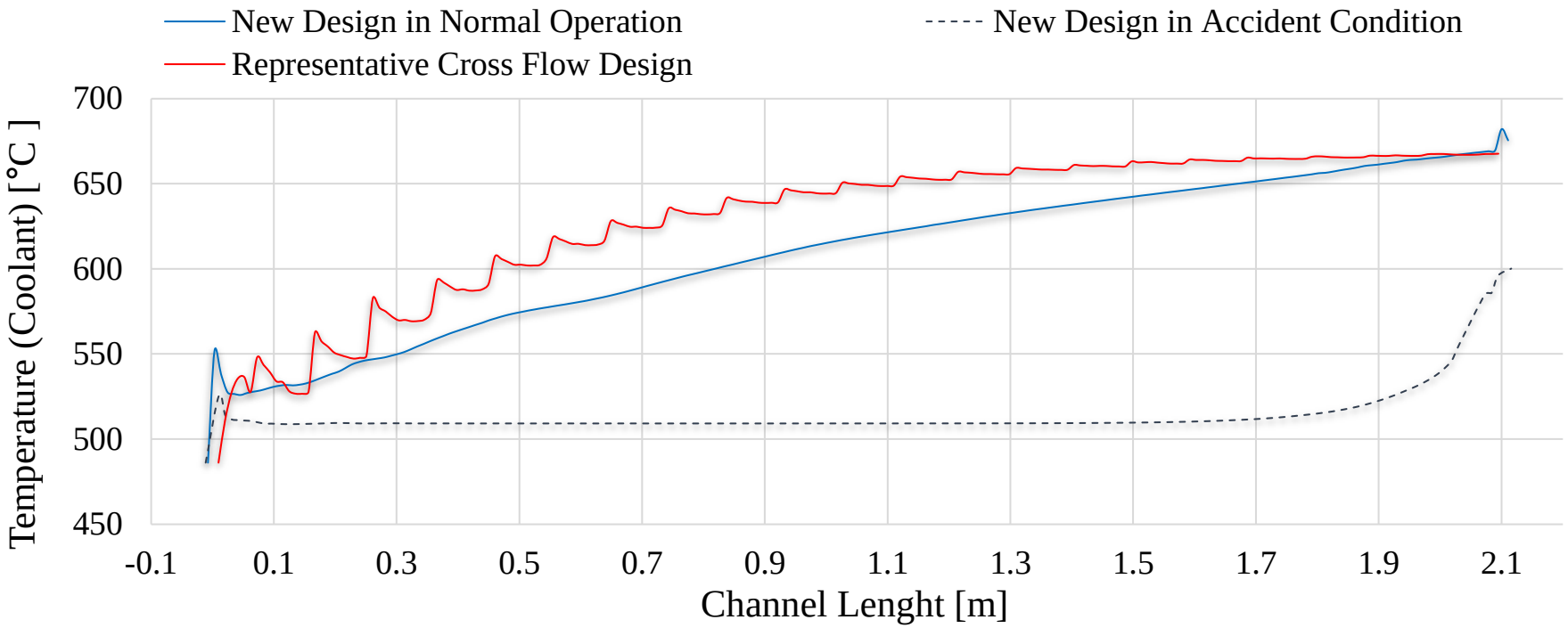


Fig. Coolant temperature change through the channel (Ansys CFX results).

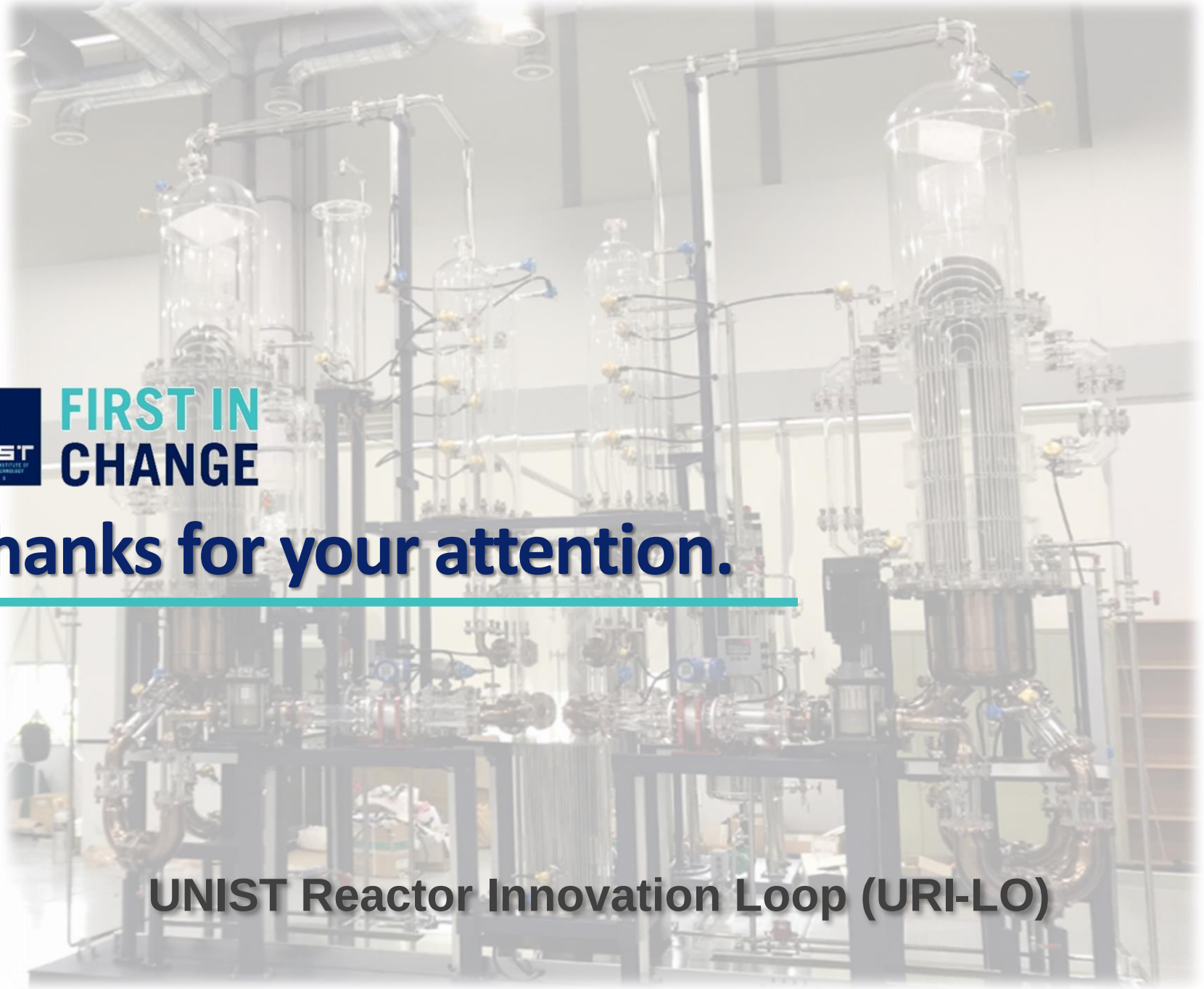
IV. Conclusion and Future Works

➢ Conclusion

- Each heat pipe has its own heat exchanger channel which provides partially separate flow process, and this system prevents the channels from each other.
- In the normal operation, the representative cross flow design has fluctuant temperature profile while the new design has uniform distribution with axial flow.
- In the HP failure conditions, two-stage coolant flow prevents the leakage from channel to the atmosphere.
- According to CFD results, the conceptual heat exchanger design has similar thermal output with original design.(Additionally it has safety system in case of heat pipe failure)

➢ Future works

- The detailed CFD and safety analysis will be performed for related accident conditions and different sizes.
- The thermal stress effect on the heat exchanger wall and heat pipe wall will be investigated.
- The test facility is planned to establish for making real time experiments.



FIRST IN CHANGE

Thanks for your attention.

UNIST Reactor Innovation Loop (URI-LO)