CFD-Aided Design of a Small Modular SFR

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Purposes and Ultimate Goal

Purposes : To analyze conjugate heat transfer phenomena over the SALUS PHTS (Primary Heat Transfer System) being directly contact with HAA(Head Access Area) and RVCS (Reactor Vault Cooling System) by using CFD(Computational Fluid Dynamics) technology

Ultimate Goal : Validation and Improvement of the proposed SALUS design

SALUS Reactor System

SALUS (Small, Advanced, Long-cycled and Ultimate Safe SFR) reactor:

- A pool-type sodium-cooled SFR (Sodium-cooled Fast Reactor) generating 100MWe with a long refueling period of ~20 years.
- Under design-development in KAERI

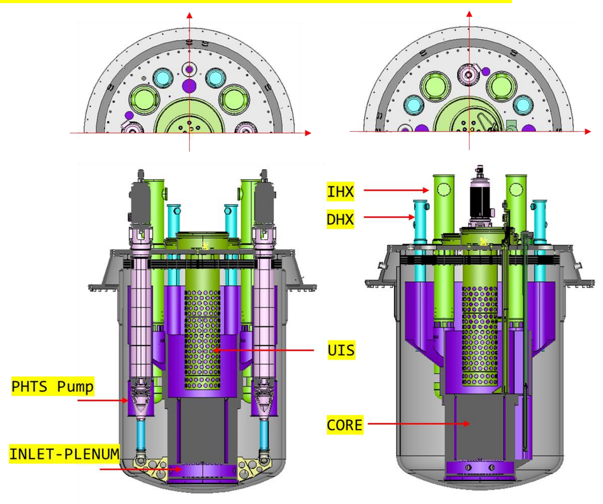


Fig. SALUS PHTS

HAA (Head Access Area):

- Cylindrical compartment covering Reactor Head
- Diameter = 14.56m, Height = 10.75m
- 4 air inlets on upper side wall & 4 outlets on lower side wall

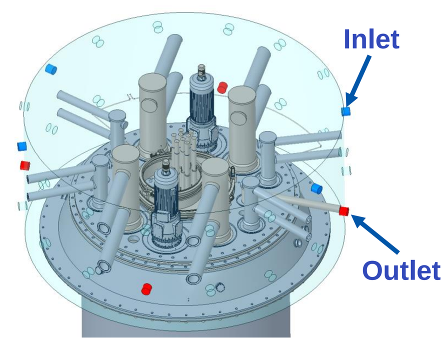


Fig. SALUS HAA

RVCS (Reactor Vault Cooling System):

- ~2m-thick concrete container
- Top surface of RVCS supports Containment Vessel and Reactor Support System
- Atmospheric air circulates and cools the outer surface of containment vessel

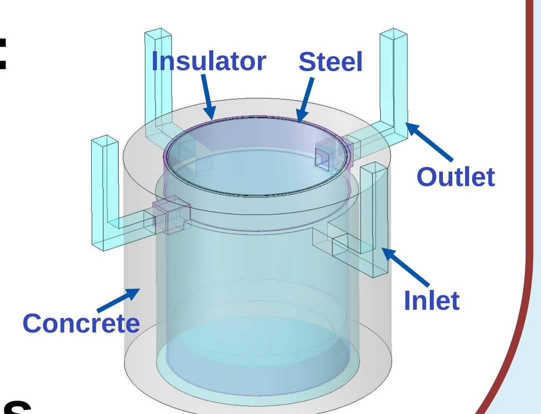


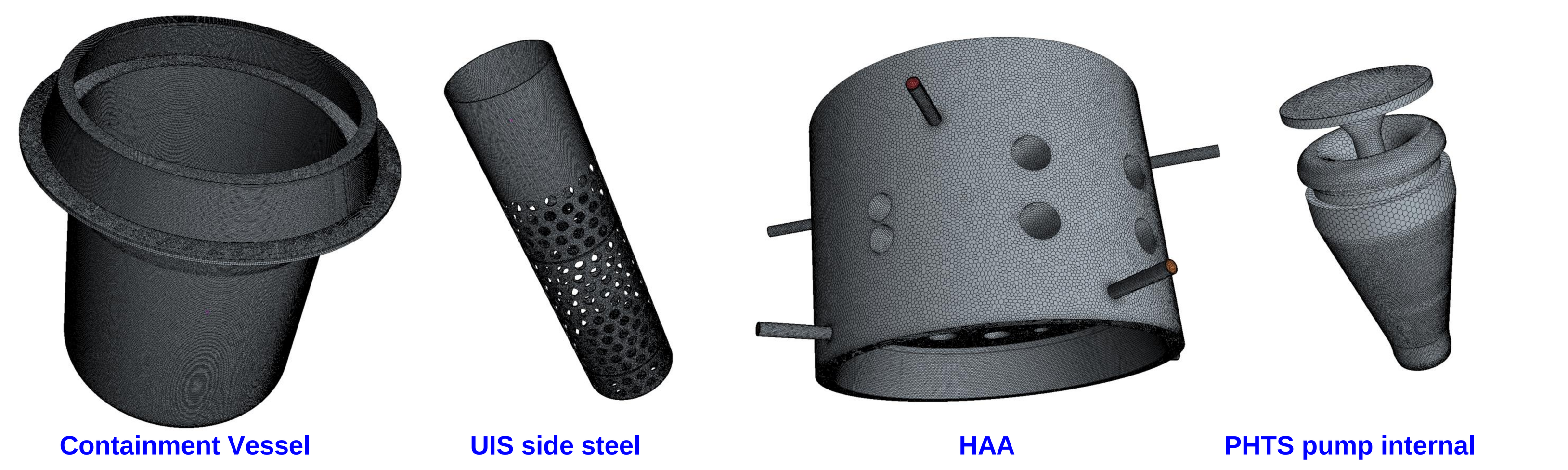
Fig. SALUS RVCS

CFD Analysis Methodology

Part Geometry: generated by SALOME

Mesh: Unstructured polyhedral meshes with prism layers in fluid regions

- Total cell number = ~ 32,000,000



Physics Models: Shear Stress Transport (SST) turbulence model and S2S Gray Thermal radiation model were applied in every gas regions.

Table. Outermost boundary conditions

Location	Boundary	Content	Value
HAA Air	Top wall	Temp. [°C]	40
	Side wall	Adiabatic	
RVCS concrete	Side wall	Temp. [°C]	20
	Bottom wall	Adiabatic	
RVCS air	Bottom wall	Adiabatic	

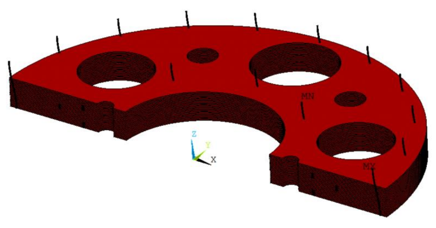
Table. Major analytic conditions

Location	Content	Value
HAA Air	Total volumetric flow rate [m^3/s]	5.72
	Temperature [°C]	20
RVCS Air	Total mass flow rate [kg/s]	9.92
	Temperature [°C]	40
PHTS Pump Sodium	Total mass flow rate [kg/s]	1365.63
	Temperature [°C]	357.8

Simplification of Upper Shielding (Heat) Structure

Upper Shielding Structure (USHS):

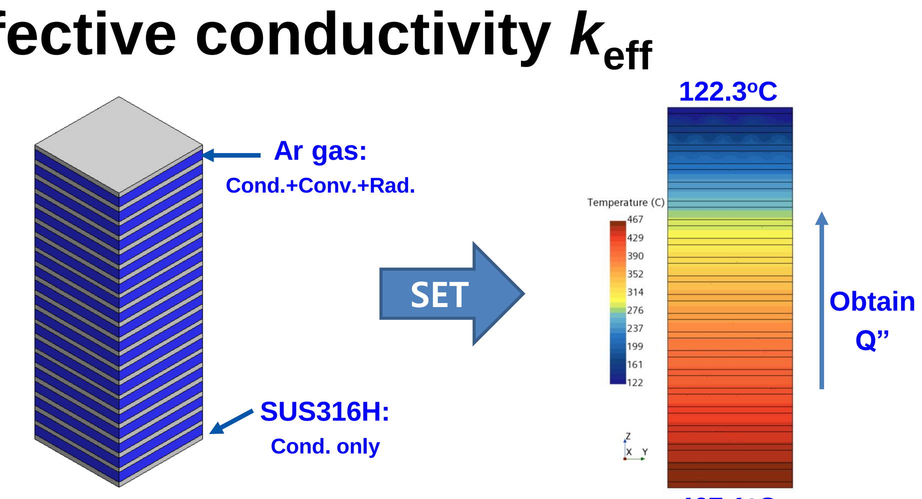
- To shield direct heating from sodium pool to Reactor Head bottom surface
- Layers of 21 1cm-thick SUS316H plates spacing 2cm apart from each others



Substitute USHS with a Simple Block Part:

- Advantage: Reduce computing cost & instability
- Disadvantages: Require SET (Separate Effect Test) to get effective conductivity k_{eff}

SET:



$k_{eff} = \frac{Q}{A}\frac{\Delta L}{\Delta T}$ = 0.9571 W/m/°C

Steady-State Simulation Results

At PHTS pump cut:

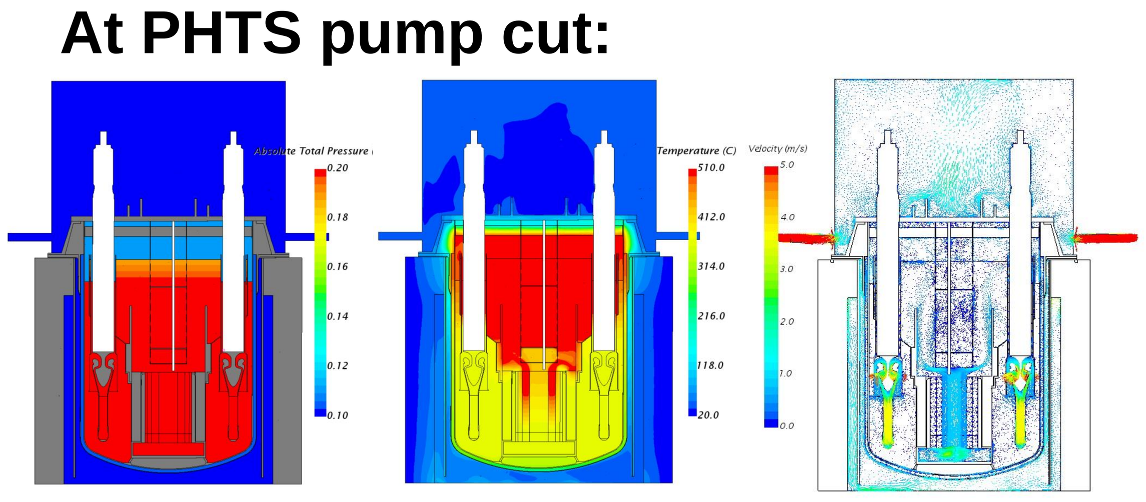


Fig. Pressure   Fig. Temperature   Fig. Velocity Vector

Detailed Views:

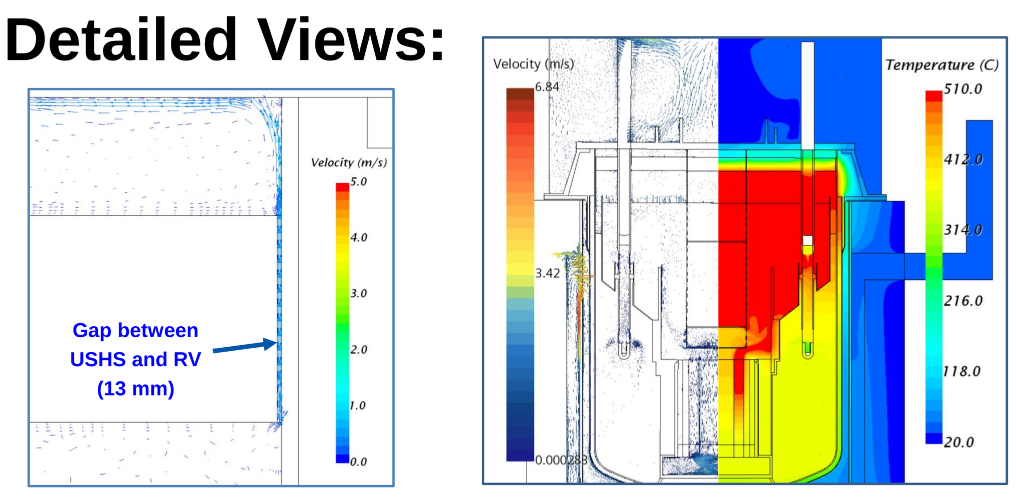


Fig. Flows thru USHS Gap   Fig. Flow vectors & temperature thru IHXs

Air Flows in HAA:

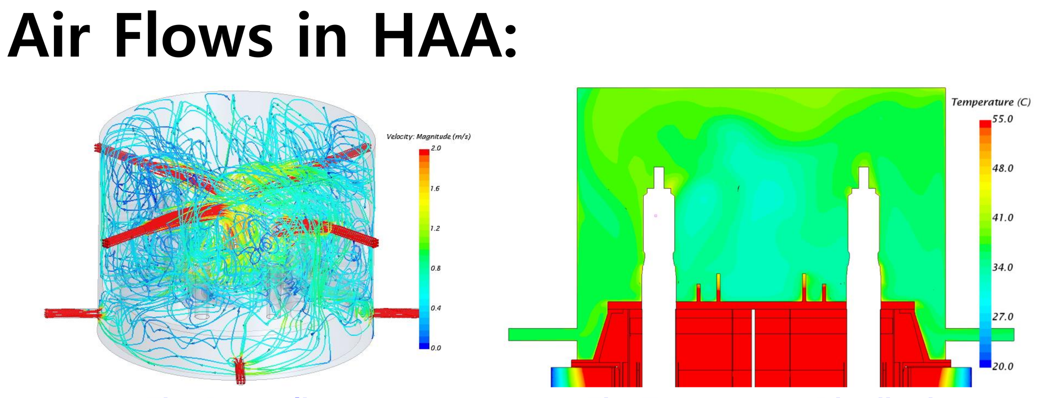


Fig. Streamlines   Fig. Temperature Distribution

Cold inlet air from 4 inlets collide with each others and go down to the reactor head surface.
Regional temperatures above the reactor head center are relatively low than other regions.

Design Parameters & Future Works

Temperature profile on the Containment Vessel outer surface:

- required for RVCS design

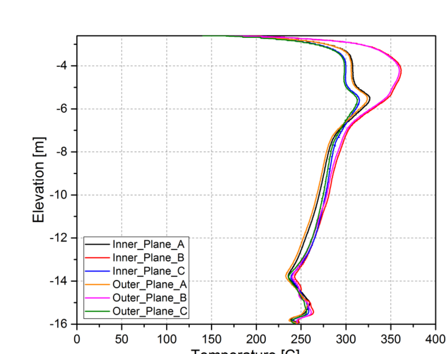


Fig. Temp. Profile of Containment Vessel

Temperature profile of the Reactor Vessel:

- Design requirement for RV temperature limits
- required for MVCS (Main Vessel Cooling System) design

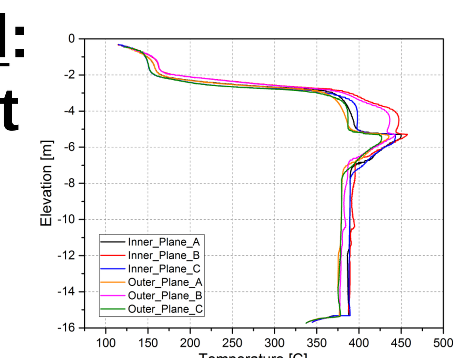


Fig. Temp. Profile of Reactor Vessel

Future Works:

- SALUS PHTS CFD analysis including MVCS design
- Sensitivity study of MVCS flow rates on RV temp. profiles
- Study on IHX shell-side outlet configuration change
- Study on DHX natural circulation flows

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