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## Motivation

- Passive decay heat removal is a key safety function in molten salt reactors (MSRs).
- During shutdown or accident scenarios, fuel salt may be drained into a drain tank, where decay heat must be removed passively.
- For compact reactor systems, understanding the heat-transfer mechanisms around the drain tank is essential for safety assessment and design.

## Objective

- Develop a 3D CFD-based conjugate heat transfer model for an MSR drain tank.
- Confirm mesh independence.
- Evaluate sensitivity to key heat-transfer parameters.
- Identify dominant passive cooling mechanisms.

## Methodology

- A three-dimensional conjugate heat transfer model was developed using ANSYS Fluent. The model includes the drain tank, containment, internal support structures, and the surrounding air region.
- Geometry and Computational Domain**
  - The computational domain consists of the drain tank, containment, internal support structures (including H-beams), and the surrounding air region. The full conjugate domain was modeled to capture coupled conduction, natural convection, and surface radiation.

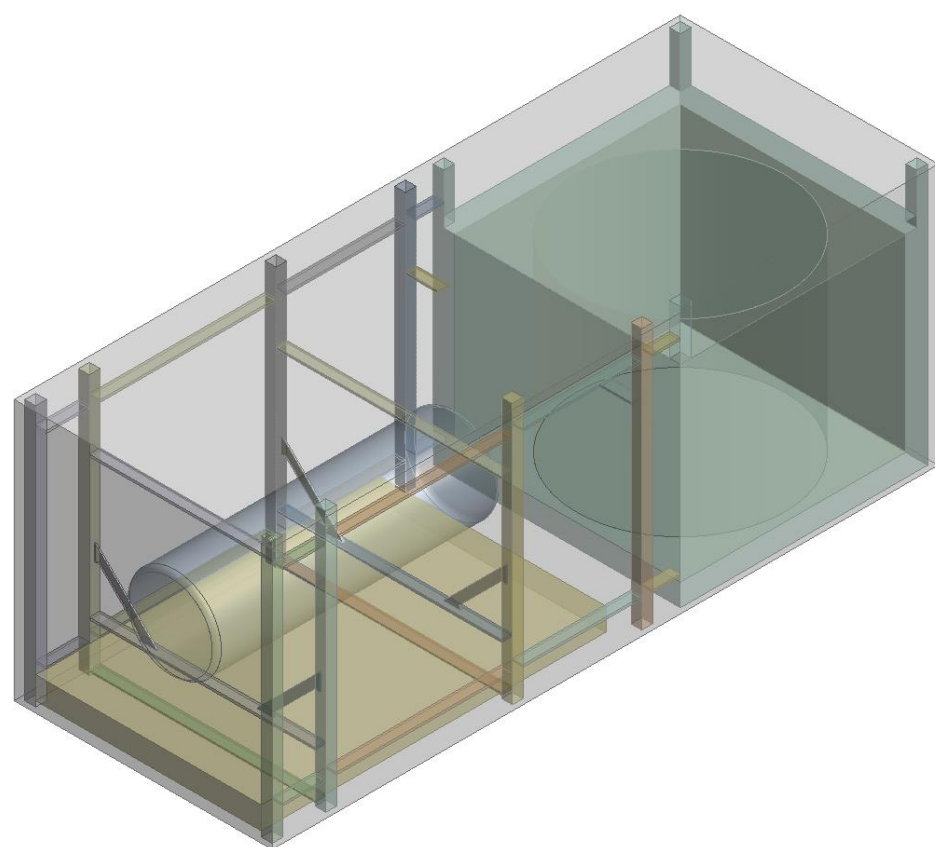


Fig. 1. Geometry and computational domain of the MSR drain-tank passive cooling system.

### Physics Models & Boundary Conditions

- Buoyancy-driven flow** was modeled with gravity enabled, and air-density variation was treated using the Boussinesq approximation.
- Natural convection & turbulent air flow:** SST k- $\omega$  turbulence model.
- Surface radiation:** Surface-to-Surface(S2S) radiation model

### Boundary Conditions & Parameters

Parameter	Range	Baseline
Ambient temperature, $T_{\infty}$	-40 to 38 °C	25 °C
Normalized external heat-transfer coefficient, $h^*$	1-4	1
Containment emissivity, $\epsilon_{\text{container}}$	0.2-0.8	0.2
Drain-tank emissivity, $\epsilon_{\text{drain tank}}$	0.2-0.8	0.3

### Normalization and Post-processing

- Temperature results were normalized based on the temperature rise relative to ambient condition.

$$\Delta T = T - T_{\infty}, \Delta T^* = \frac{\Delta T}{\Delta T_{\text{ref}}}$$

- Heat removal was decomposed into radiation, convection, and conduction fractions.

$$f_{\text{rad}} = \frac{Q_{\text{rad}}}{Q_{\text{total}}}, f_{\text{conv}} = \frac{Q_{\text{conv}}}{Q_{\text{total}}}, f_{\text{cond}} = \frac{Q_{\text{cond}}}{Q_{\text{total}}}$$

## Result and Discussion

### Grid Independence

- A mesh-independence test was conducted using coarse, normal, and fine meshes. Since the difference between normal and fine meshes was negligible, the normal mesh was selected.

### Mesh Table

Mesh Level	Number of cells	Max cell size	Mesh type
Coarse	2,527,826	0.10m	Tetrahedral
Normal	3,680,768	0.05m	Tetrahedral
Fine	10,250,828	0.03m	Tetrahedral

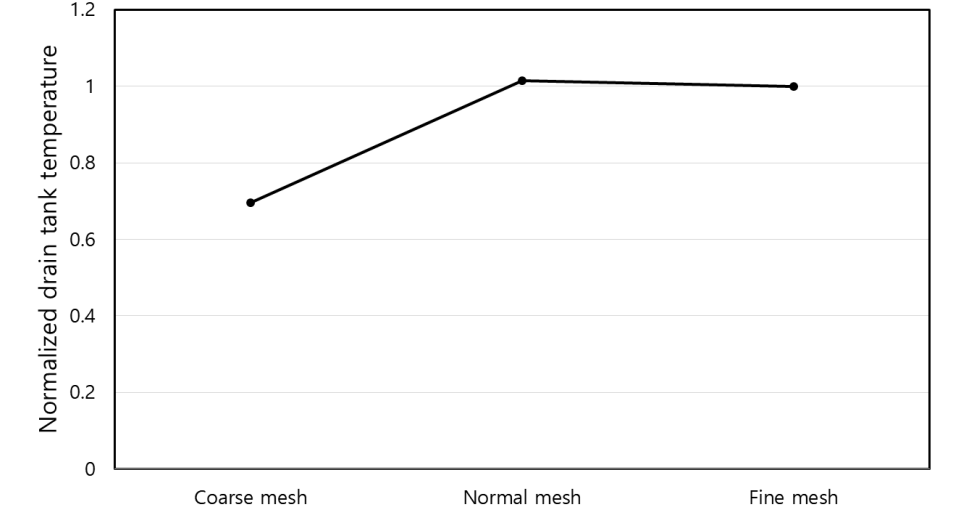


Fig. 2. Grid-independence test based on the normalized peak temperature of the drain tank

### Sensitivity to Heat-transfer Parameters

- The results indicate that the drain-tank peak temperature is primarily governed by the drain-tank emissivity, while the containment peak temperature is mainly controlled by the external heat-transfer coefficient and containment emissivity.

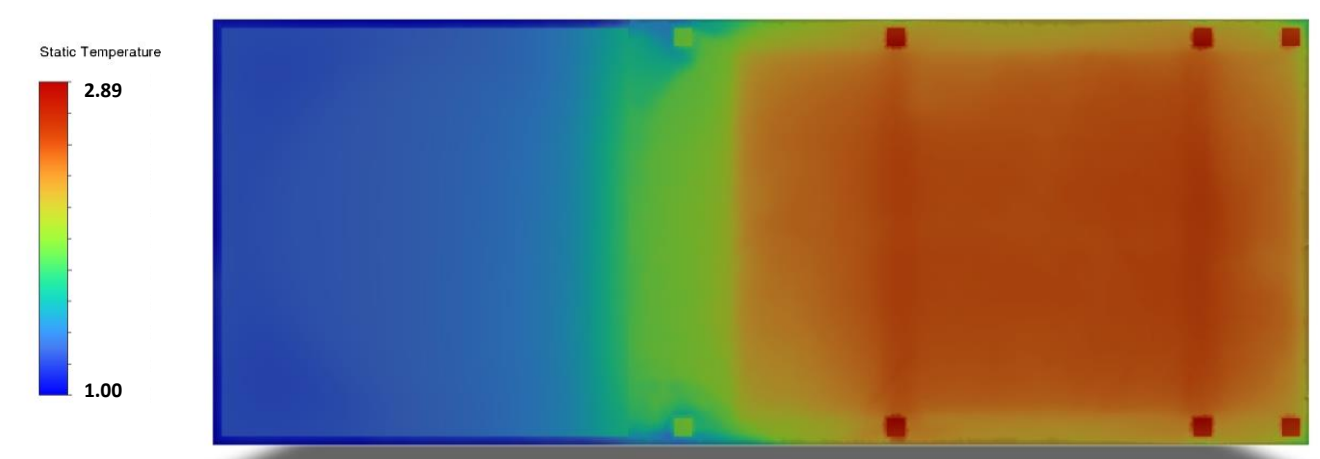


Fig. 3. Normalized temperature contour for the reference case

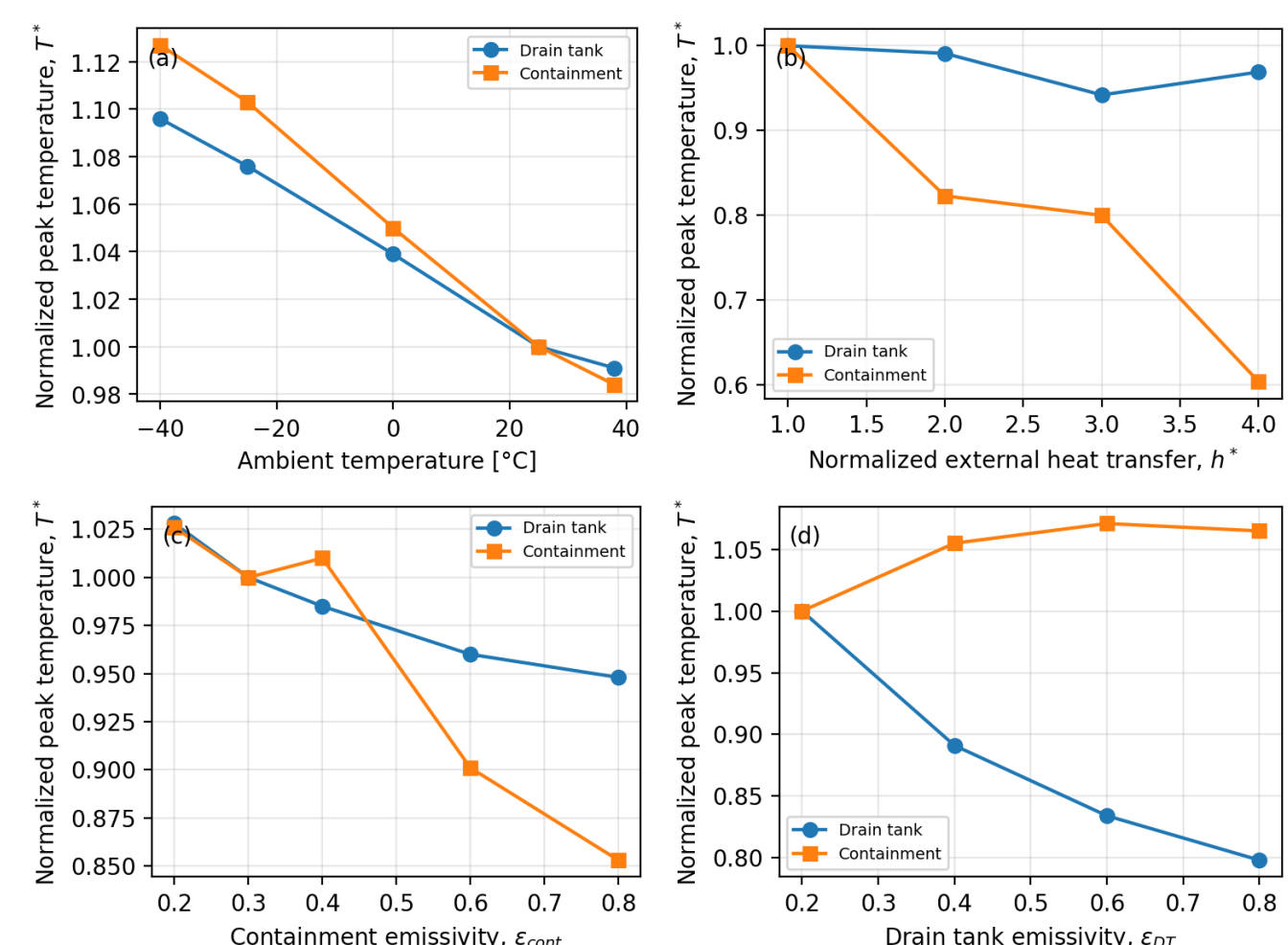


Fig. 4. Sensitivity of normalized peak temperatures to key heat-transfer parameters: ambient temperature, external heat-transfer coefficient, containment emissivity, and drain-tank emissivity.

### Heat-transfer Partitioning

- Radiation is the dominant passive heat-removal mechanism at elevated decay-heat levels.

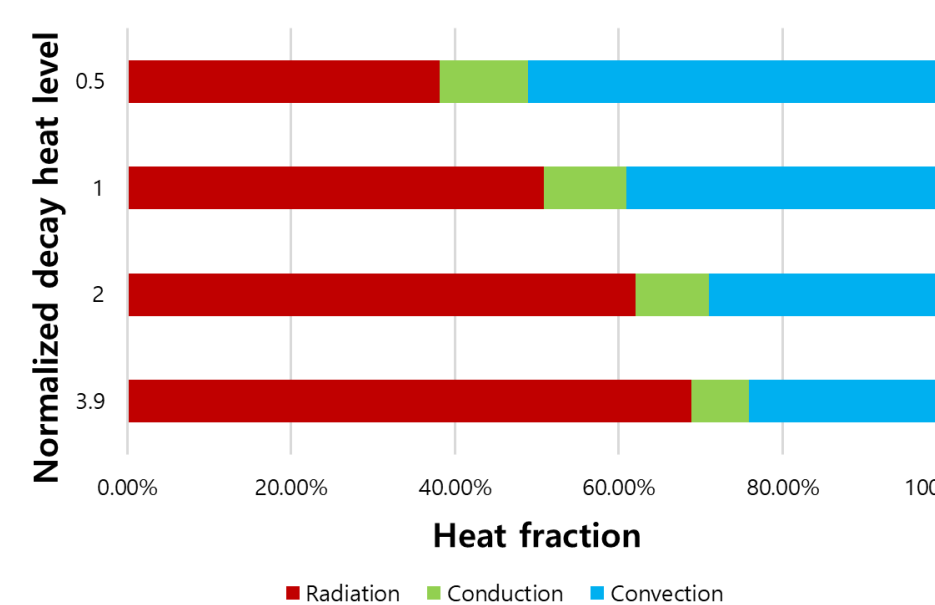


Fig. 5. Heat-transfer partitioning into radiation, convection, and conduction fractions.

- As the decay-heat level increases, the system reaches higher absolute temperatures, and the radiative heat-transfer fraction becomes dominant.

- Conversely, at lower decay-heat levels, the relative contributions of natural convection and conduction through support structures increase.

## Conclusion

- A 3D conjugate heat transfer model was developed for passive cooling of an MSR drain tank.
- The drain-tank peak temperature is most sensitive to drain-tank emissivity.
- The containment peak temperature is mainly governed by external heat-transfer coefficient and containment emissivity.
- Radiation becomes the dominant heat-removal mechanism at elevated decay-heat levels.

## Acknowledgement

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