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Numerical study of conjugated heat transfer for DONES high flux test module

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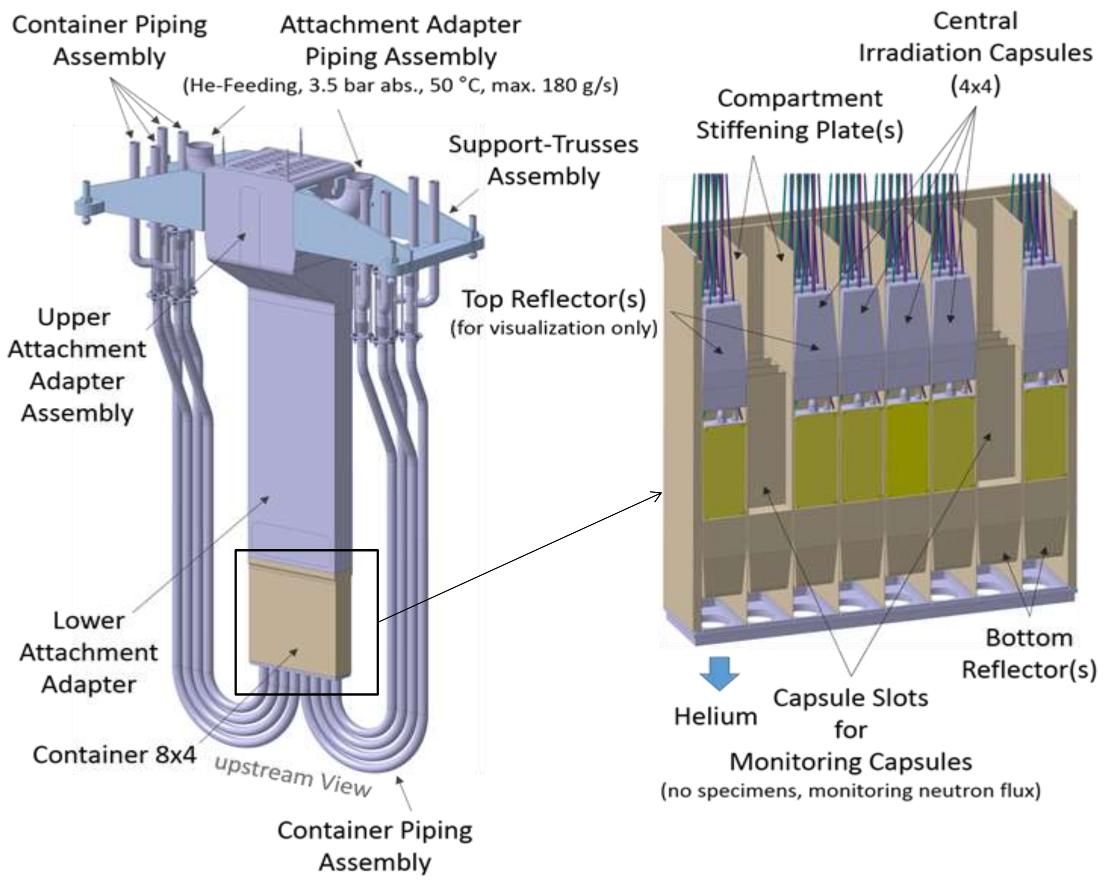


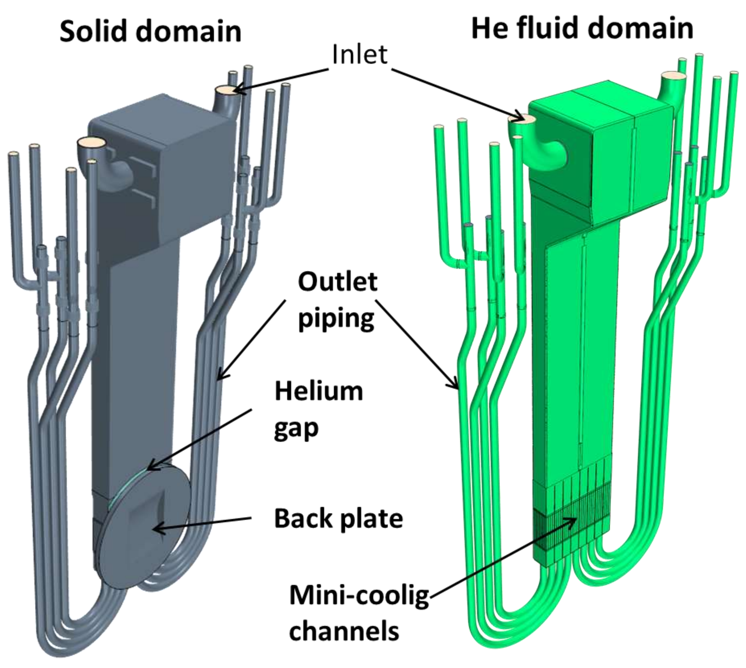
IFMIF-DONES HFTM

IFMIF-DONES (International Fusion Materials Irradiation Facility- DEMO Oriented NEutron Source) is a IFMIF-based neutron irradiation facility which aims at providing the irradiation data required for the construction of a DEMOnstration fusion power plant (DEMO). DONES consists of only one of the IFMIF accelerators (40 MeV and 125 mA), and utilizes only the High Flux Test Module (HFTM) for the irradiation of material specimens. The HFTM is the key component to provide the material irradiation data which fulfil the mission of DONES. The irradiation is planned at several blanket-relevant irradiation temperatures and shall accumulate structural damage of up to 50 displacements per atom (dpa) per campaign

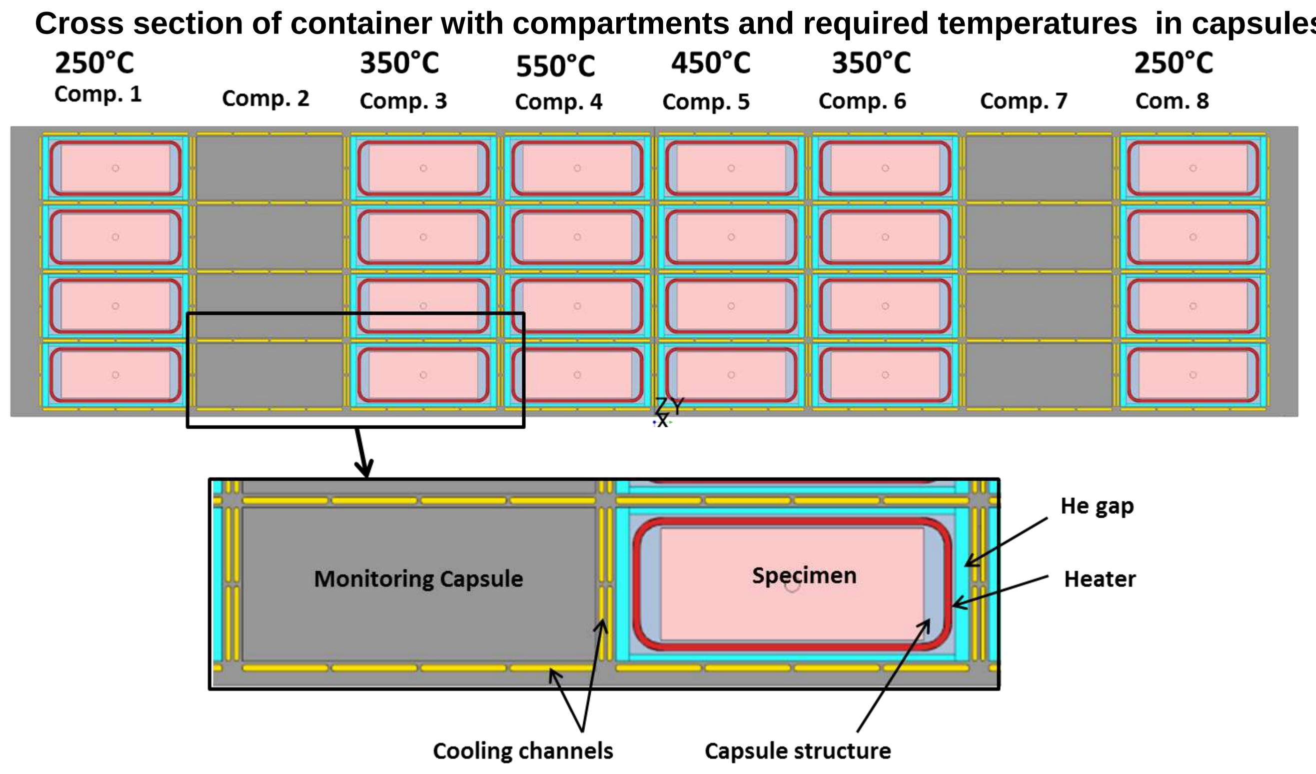
Requirements (rooting in irradiation objectives and facility boundary conditions) to the HFTM operation considered in the study:

- ❑ Control the specimen temperature at defined levels between 250 and 550 °C. The temperature spread within the specimen stack of one irradiation capsule shall be limited to ±3% relative to the absolute (Kelvin) temperature (in 80% of the available volume – cold corners without specimen loading can be accepted);
- ❑ The maximal possible mass flow rate of helium should be less or equal t o180 g/s for all compartments;
- ❑ The maximal allowed electrical heating is 1000 W (180V) per heater coil;
- ❑ The temperature of the container structure is limited by 150°C (maintain strength and reduce swelling).

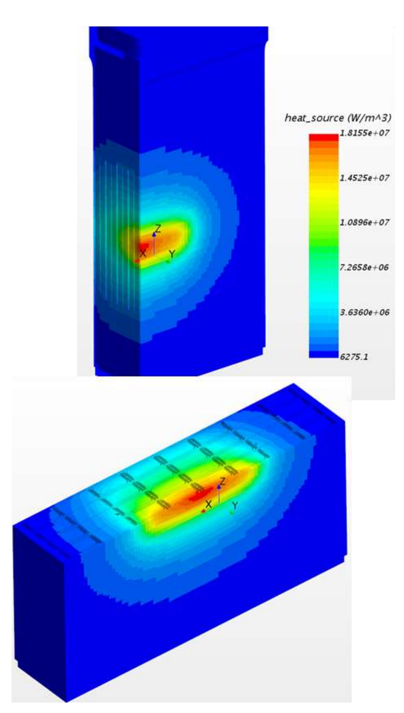
Geometry and boundary conditions of HFTM CFD model



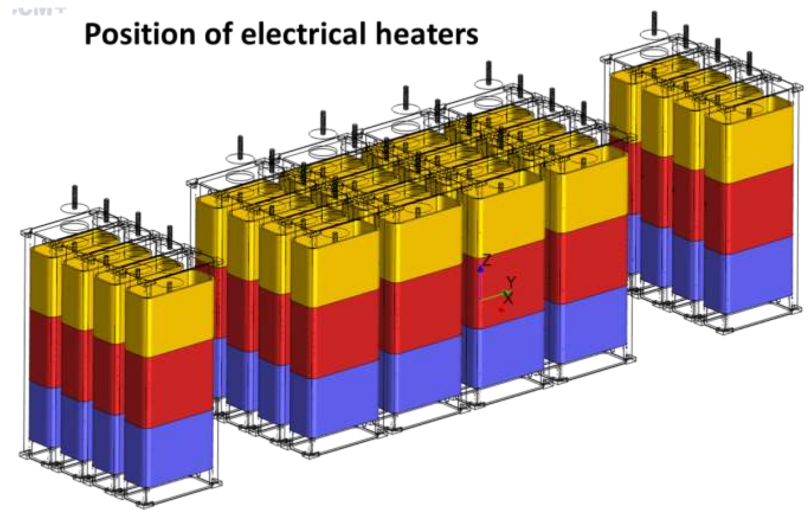
Cross section of container with compartments and required temperatures in capsules



Nuclear heating distribution



Position of electrical heaters



- The 3D-CAD geometry model of HFTM developed in KIT was used for the meshing.
- Structural material for capsules: reflectors and specimen - EUROFER-97, for compartment walls and heaters SS316 (AISI 316 LN).
- The insulation gap is modelled as solid medium with helium thermal properties.
- The nuclear heating data for the simulation is obtained from neutronic calculations Y. Qiu et al.(KIT)
- The helium inlet pressure i- 3.3 bar, temperature of 50°C.
- Initial helium mass flow rates : compartments 1, 2, 7, 8, - 10g/s,

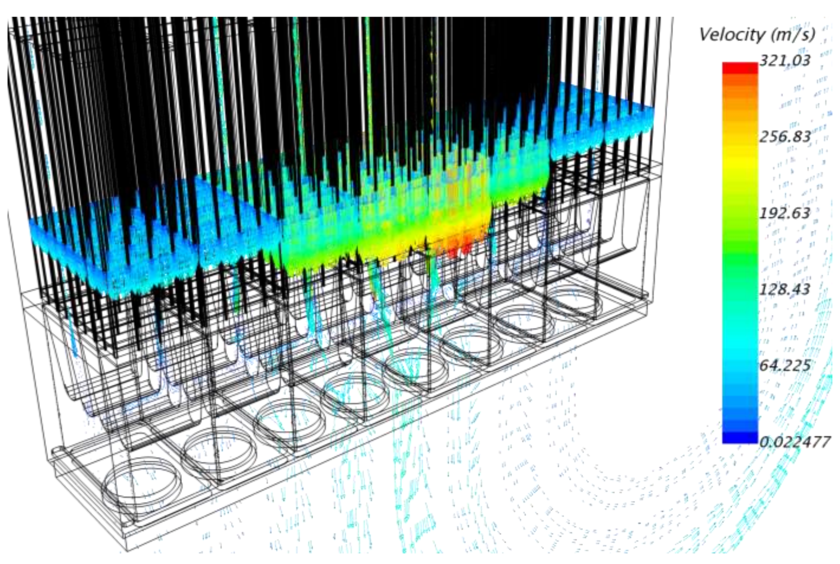
compartments 3 and 6 - 16g/s, compartment 5 - 24 g/s, compartment 4 - 32 g/s.
The heat transfer interaction between HFTM and the target was taken into account. Temperature of the target back is obtained from thermal-structural calculations (University of Palermo).

- The heat transfer within the gap is simulated using solid material with helium thermal properties.
- Thermal radiation across the insulation gaps is considered.
- The heat loss from the HFTM to the test cell: natural convection with HTC of 5 W/m²/K, ambient atmosphere temperature of 50°C.
- The near wall y^+ value within the mini-cooling channels ranges from 0.8 to 3. The total cell number is about 30 million for the fluid domain and 20 million for the solid structure. The CFD simulations were performed with the SST turbulence model. The ability of the SST model to predict the heat transfer in mini-channel flow for Re number range between 4500 and 10000 was tested and confirmed by comparing simulations with ITHEX experiments

Simulation results, thermal design optimization

Thermal-hydraulic characteristics of helium flow

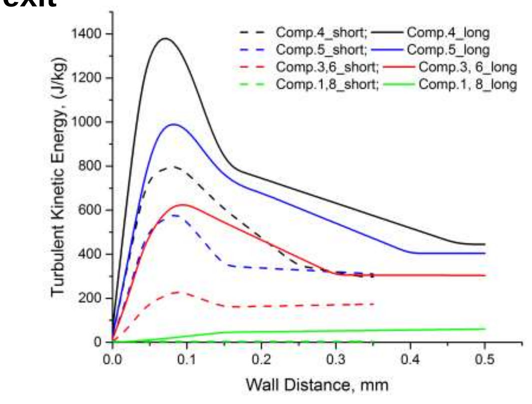
Axial velocity (vector presentation) distribution on the cut-plane near the exit of mini channels (z=-90 mm)



Re numbers of the channel flow near the exit

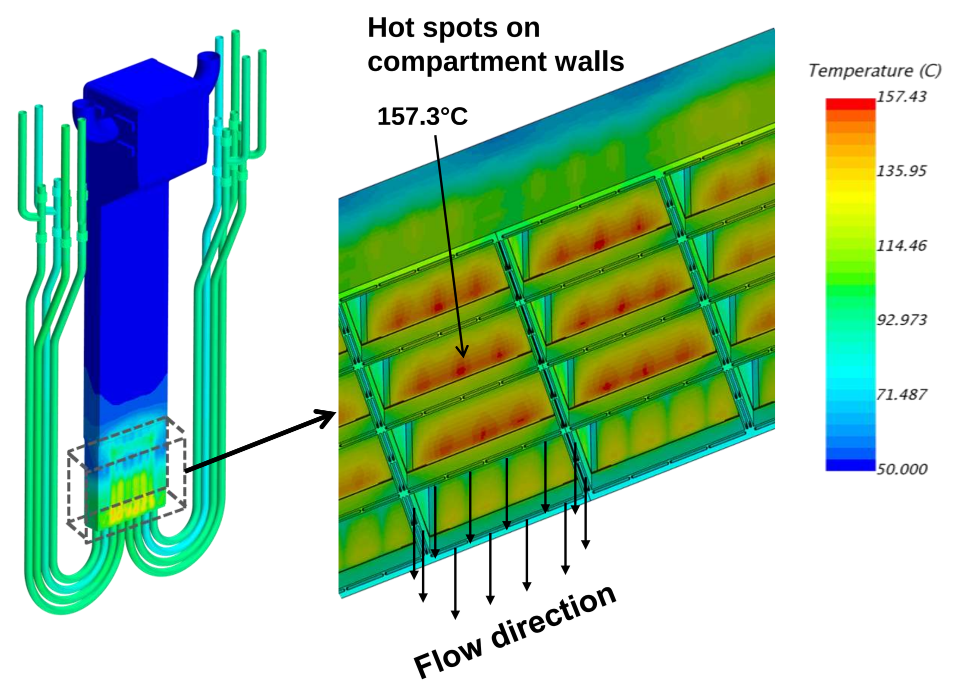
Comp. No.	1, 8	3, 6	4	5
Re, Long-side	2300	6000	10200	8200
Re, Short side	1500	3800	6450	5200

Wall normal distribution of the turbulent kinetic energy in channel flow near the exit

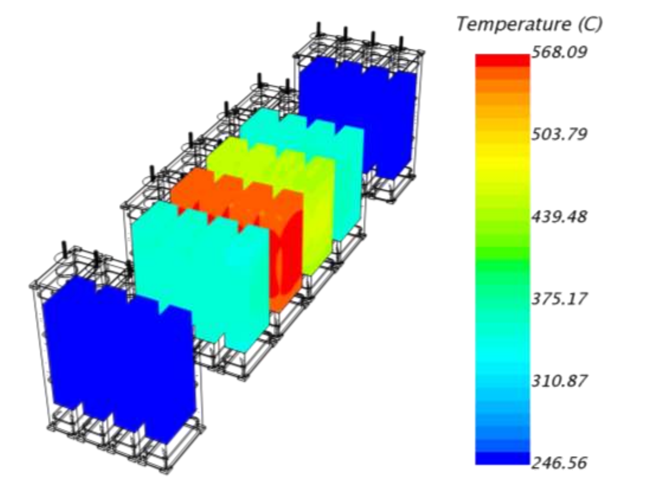


Temperature distribution in the solid part

Temperature of the HFTM structure

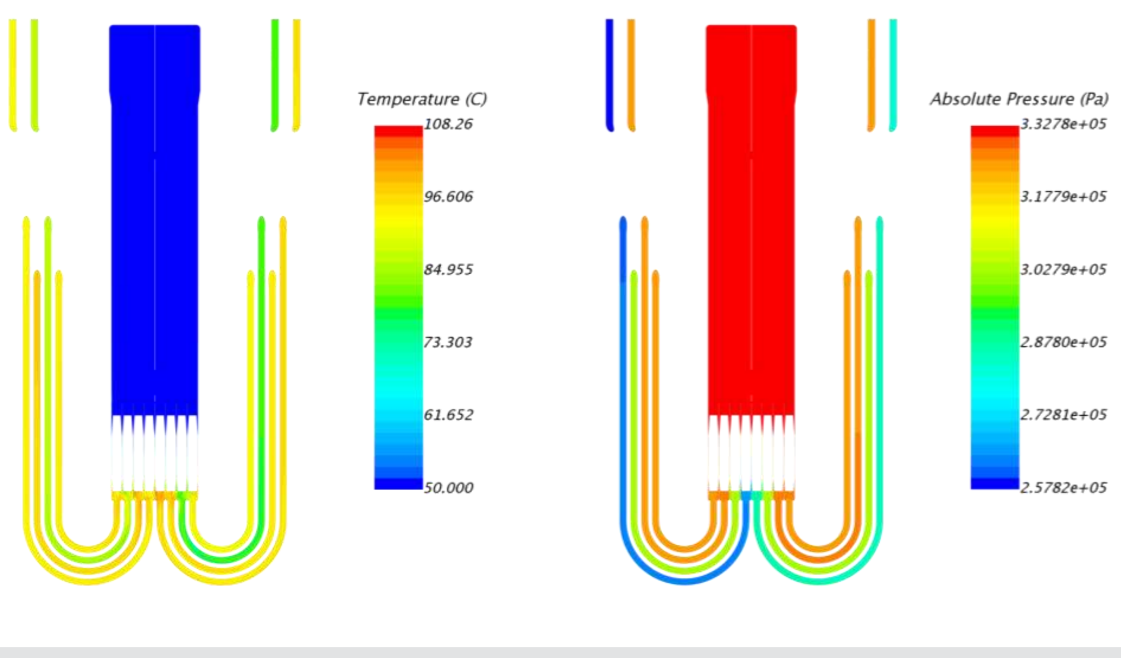


Temperature distribution in specimen



Comp. ($T_{ref.}$)	Tmax., °C	Tmin., °C	ΔT, K	ΔTmax, % $T_{ref.}$ K	ΔTmin, % $T_{ref.}$ K
1 and 8 (250°C)	253	246	7.0	0.5	0.76
3 and 6 (350°C)	369	339	30.0	3.0	1.76
4 (450°C)	465	435	30.0	2.0	2.0
5 (550°C)	568	545	23.3	2.2	0.61

He Temperature (left) and Pressure drop (right) in cooling channels



- The behaviour of the channel flow predicted by SST turbulence model is in agreement with validation results
- Simulations show that in case of 100% nuclear heating conditions the helium mass flow rate in the compartments 1 and 8 with the prescribed temperature of 250°C has to be kept by 10 g/s, in compartments 3 and 6 (350°C) by 24 g/s, in compartment 5 (450°C) by 32 g/s and in compartment 4 by 40 g/s.
- To avoid the overheating of specimen the insulation gap thickness in compartments 3 and 6 was reduced down to 0.6 mm and in the compartment 5 to 0.8 mm. In all capsules the specimen temperatures fit the requirement of the ±3% variation in temperature referred to absolute temperature.
- Small areas with the overshot of about 7°C over the maximal allowed temperature for compartment structure material are detected on the inner surfaces of the compartments 4 and 5. The location of the hot spots corresponds with the position of the division walls between the mini cooling channels.

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