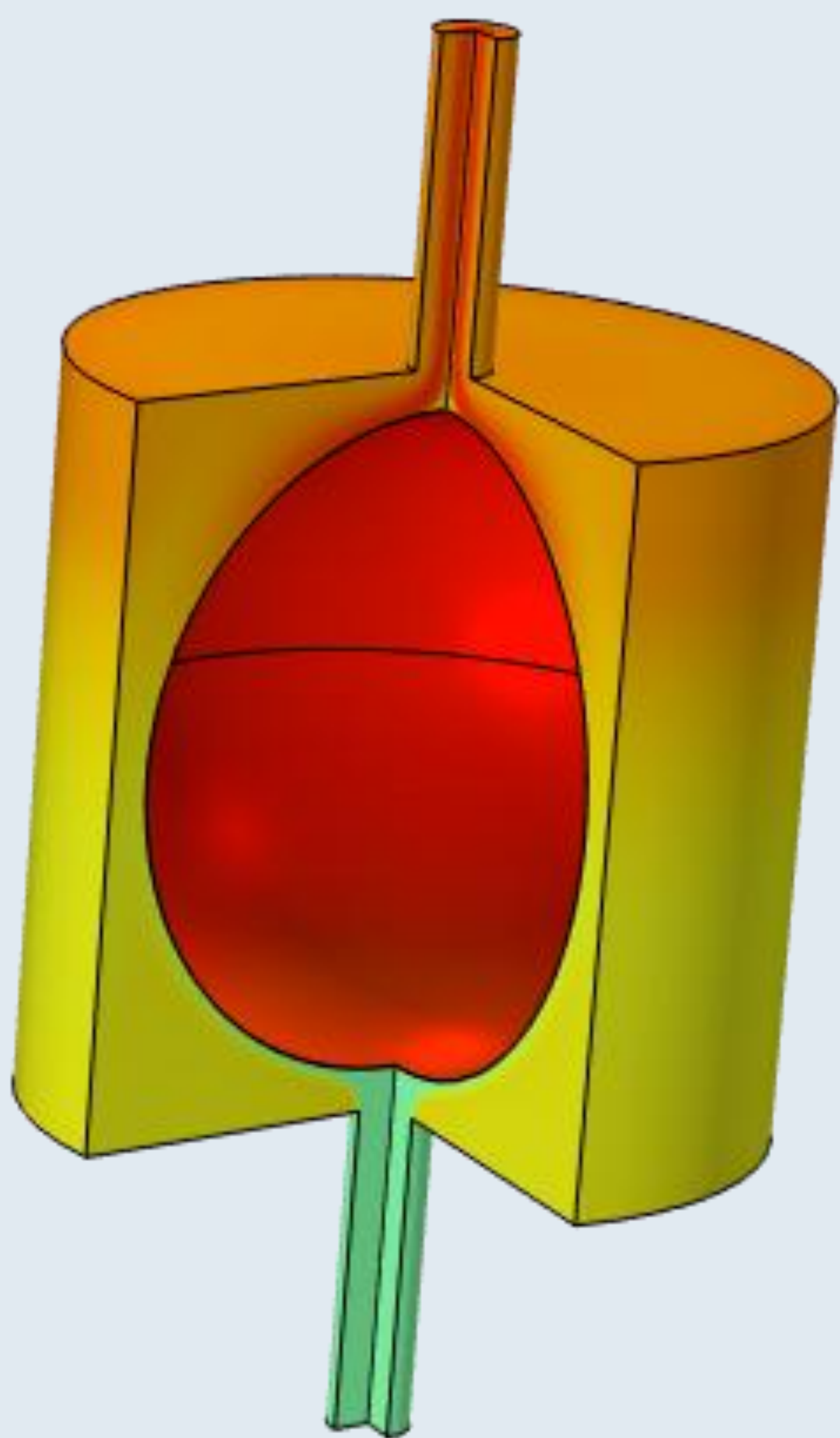




Thermal-hydraulic design exploration of a liquid lithium breeding blanket for an inertial fusion reactor

Investigating heat removal capabilities and lithium flow behaviour under high fusion power loads to support the preliminary design of a liquid breeder blanket.

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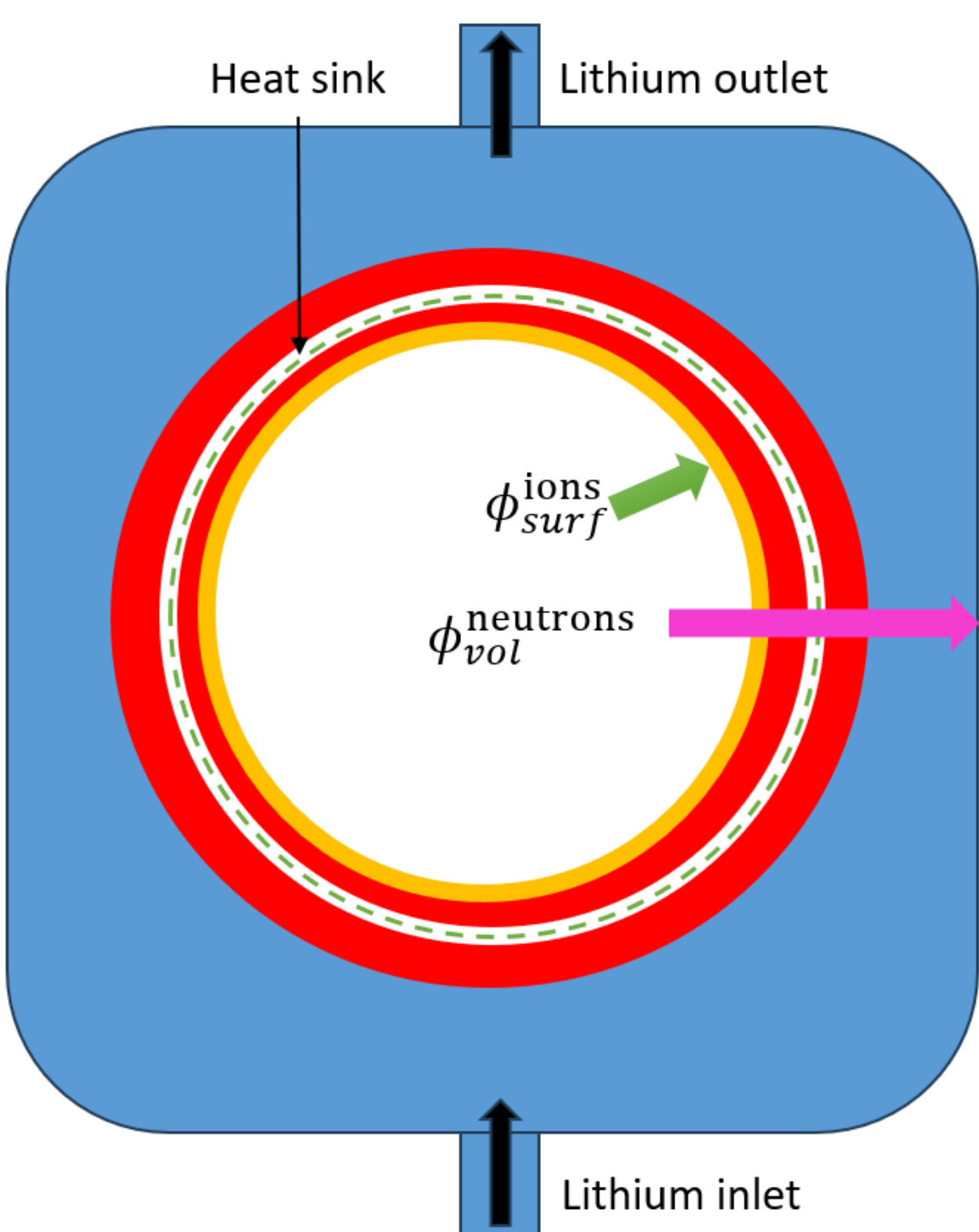
Abstract

Inertial Confinement Fusion (ICF) aims to provide a carbon-free, high-power, and sustainable energy source by using high-power laser beams to compress and heat a deuterium-tritium fuel capsule until thermonuclear ignition occurs. Fusion reactions release a large amount of energy carried by energetic neutrons, charged particles and X-rays. (1)

To produce electricity, an ICF reactor requires a surrounding breeding blanket to absorb and convert fusion energy into usable thermal power while ensuring tritium self-sufficiency (2). GenF, a

spin-off of Thales, in collaboration with CEA, CNRS, and Thales, is investigating a liquid lithium breeding blanket concept. The design of such a system remains a major challenge, requiring efficient heat removal, controlled temperatures, and reliable lithium circulation under high fusion power loads.

Thermo-hydraulic simulations aim to identify thermal hotspots, evaluate natural convection capabilities, and assess different heat extraction strategies to guide the preliminary design of the breeding blanket.

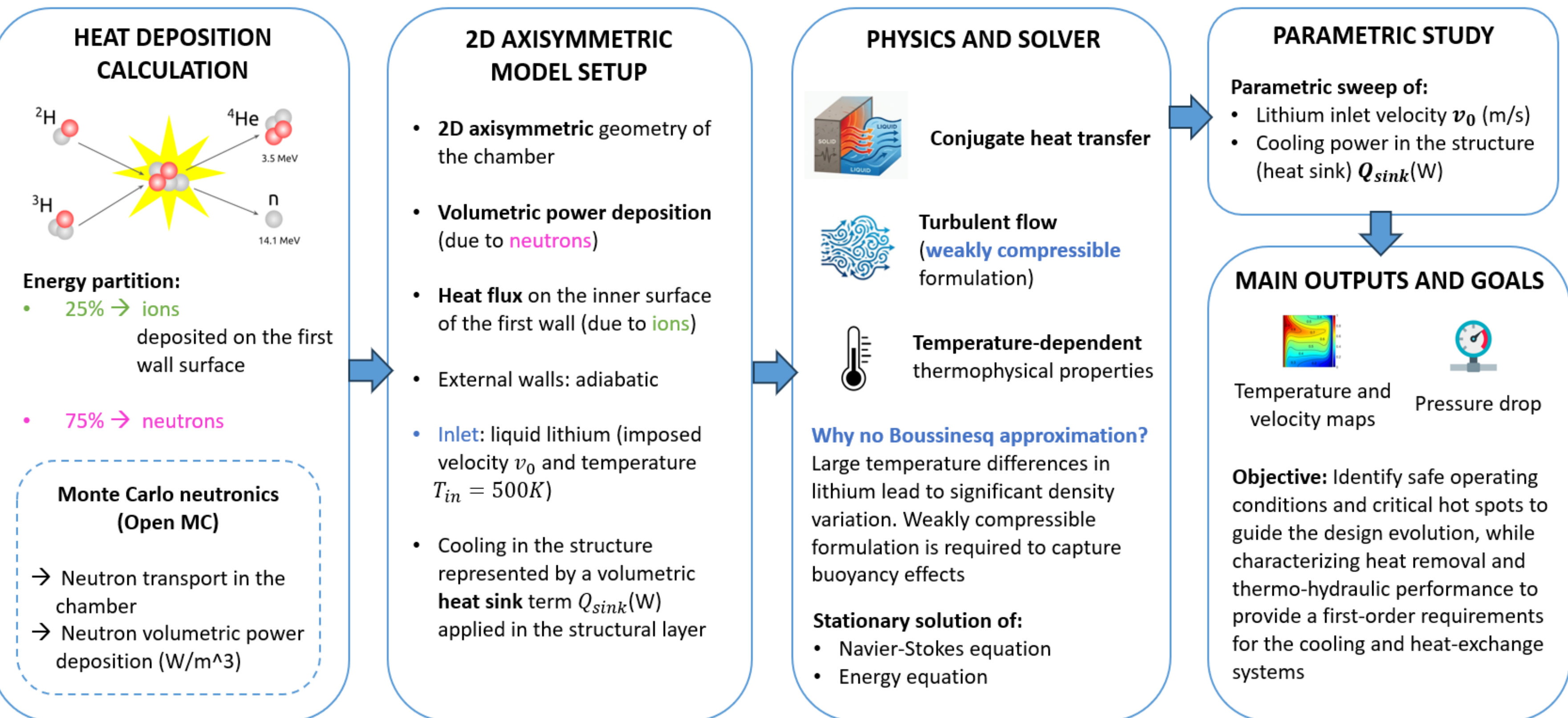


- First wall (FW) – Tungsten
- Main Internal Structure (MIS) – SS316L
- Coolant – He or Lithium
- Breeder – Liquid Lithium

Domain	Phenomena to avoid	Operating criteria	Degradation category
Lithium (breeder)	Solidification	$T > 453K$	Critical
Lithium (breeder)	Boiling	$T < 1615K$	Critical
Li/SS 316L wall	Corrosion	$T < 673K$	Moderate
Tungsten (FW)	Fusion	$T < 3695K$	Critical
Tungsten (FW)	Recrystallisation	$T < 1473K$	High
Tungsten (FW)	DBTT	$T > 573K$	Moderate
SS 316L (MIS)	Melting	$T > 1673K$	Critical
SS 316L (MIS)	Recrystallisation	$T > 1393K$	High
SS 316L (MIS)	Creep	$T > 673K$	High

FIGURE 1. Left: Blanket geometry. Right: Limiting thermal constraints.

Methodology



Results and outlooks

- Lithium flow alone is insufficient for structural cooling:** dedicated cooling of the structure is required
- Increasing the lithium flow rate provides limited thermal benefits at a rapidly increasing hydraulic cost.** Higher lithium flow rates strongly increase pressure drop and pumping power.
- Coolant selection is critical:** He offers high-temperature operation and low corrosion, but its low density requires **~80 bar** and high pumping power for **~1.6 GW** heat removal. **Li and sCO₂** are also considered.
- 316L creep temperature limit is highly restrictive:** a strong structural heat sink is required. **Thermo-mechanical analysis** is needed to assess stresses, thermal expansion and cyclic loading.
- Cooling system design:** channel geometry, flow rate and operating pressure must now be optimized.
- Best operating point: ($v_0=1\text{m/s}$, $Q_{\text{sink}}=1.6\text{GW}$) offers a good thermal-hydraulic compromise while respecting temperature limits
- Dead zone identified:** poor Li circulation in the northern region may lead to **tritium accumulation**. **Next step:** investigate **distributed injectors and split-flow architectures** to improve flow distribution and eliminate dead zones.

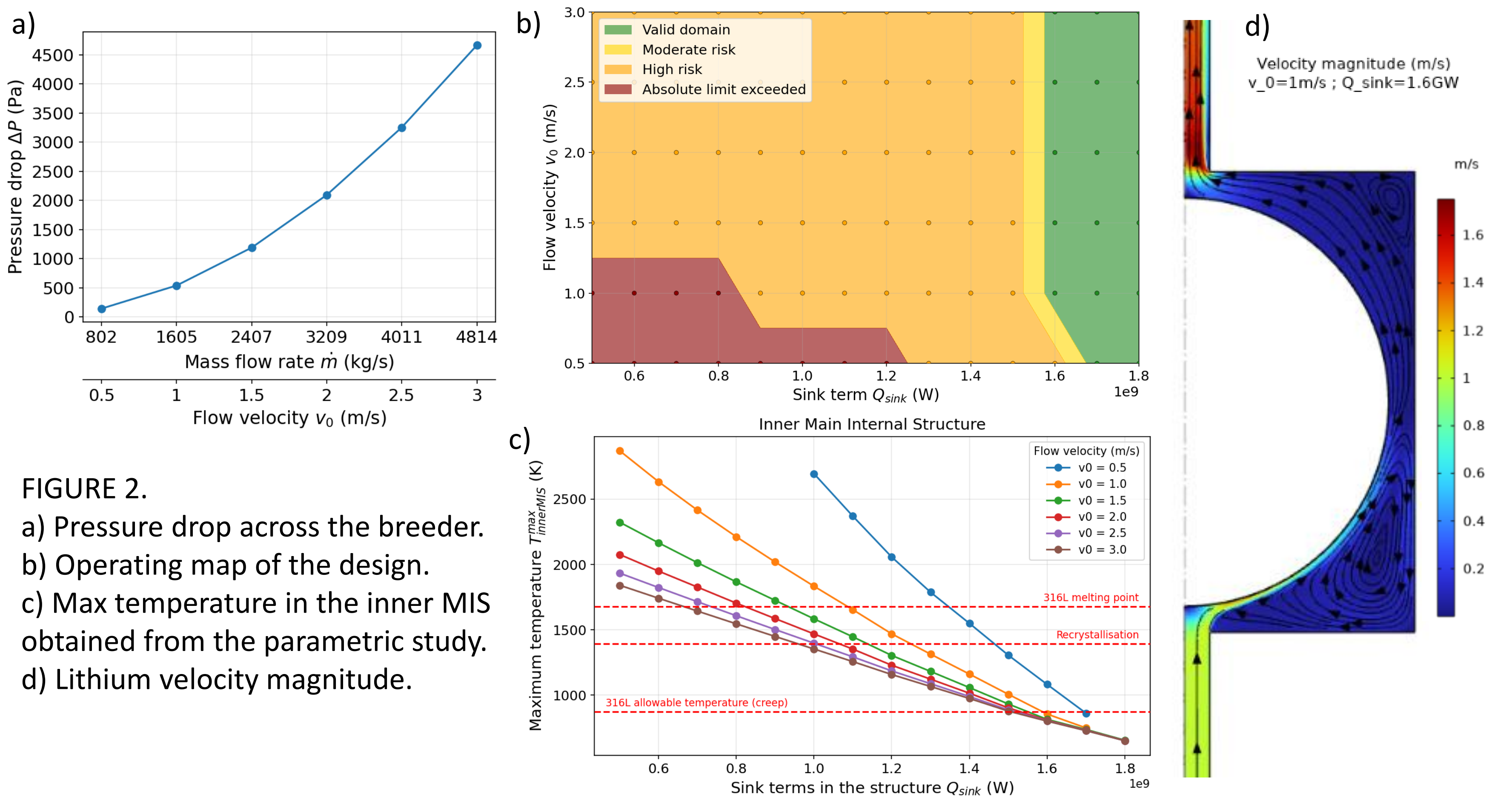


FIGURE 2.
a) Pressure drop across the breeder.
b) Operating map of the design.
c) Max temperature in the inner MIS obtained from the parametric study.
d) Lithium velocity magnitude.

REFERENCES

- R. S. Craxton and all, "Direct-drive inertial confinement fusion: A review", Phys. Plasmas 22, 110501 (2015)
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