

Advanced Cooling Technologies for High-Power Accelerator Targets

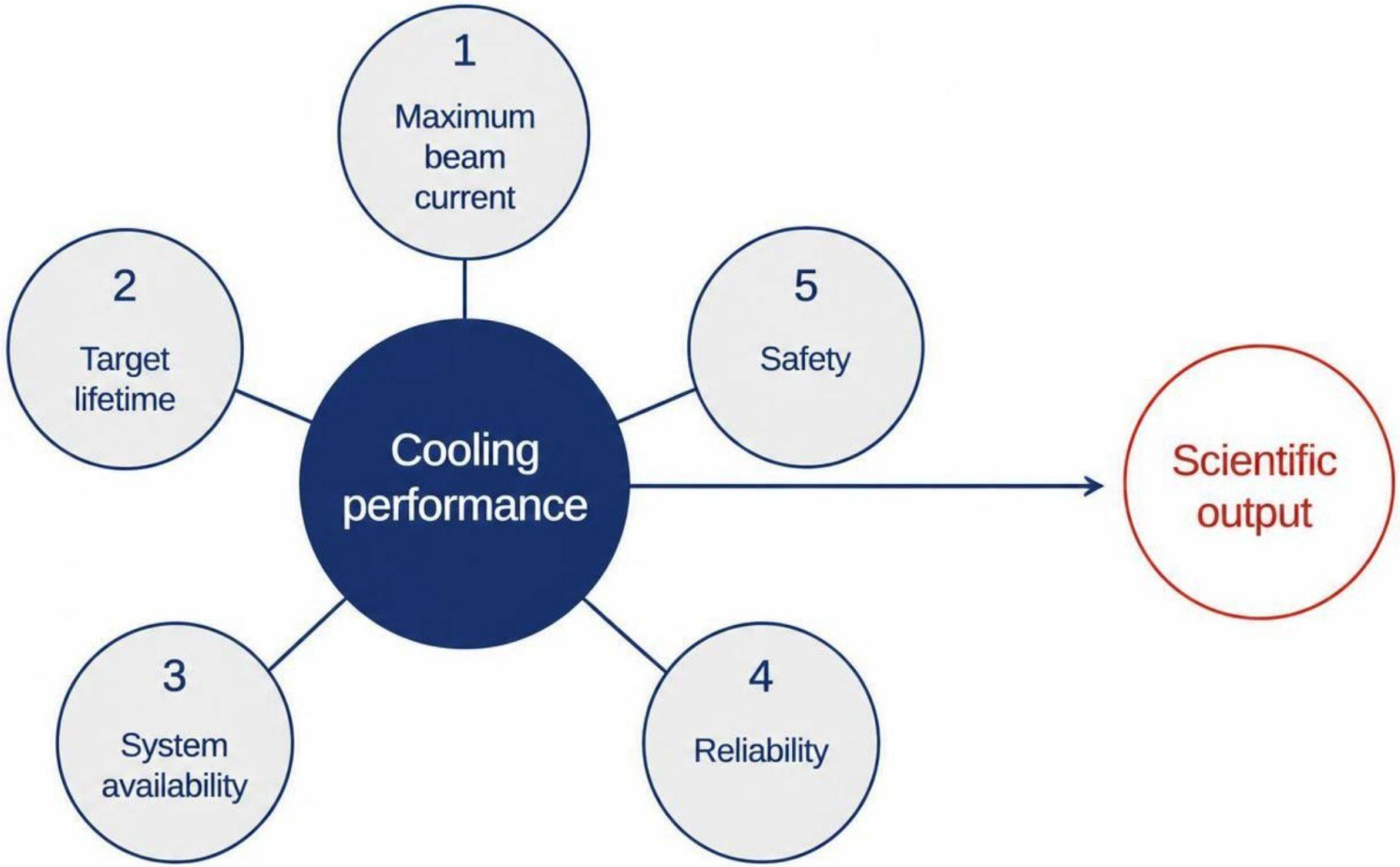
Lessons Learned from Radioisotope Production, CERN Detectors and Fusion Diagnostics

Ryszard Kantor
Krakow University of Technology
Ryszard.Kantor@pk.edu.pl

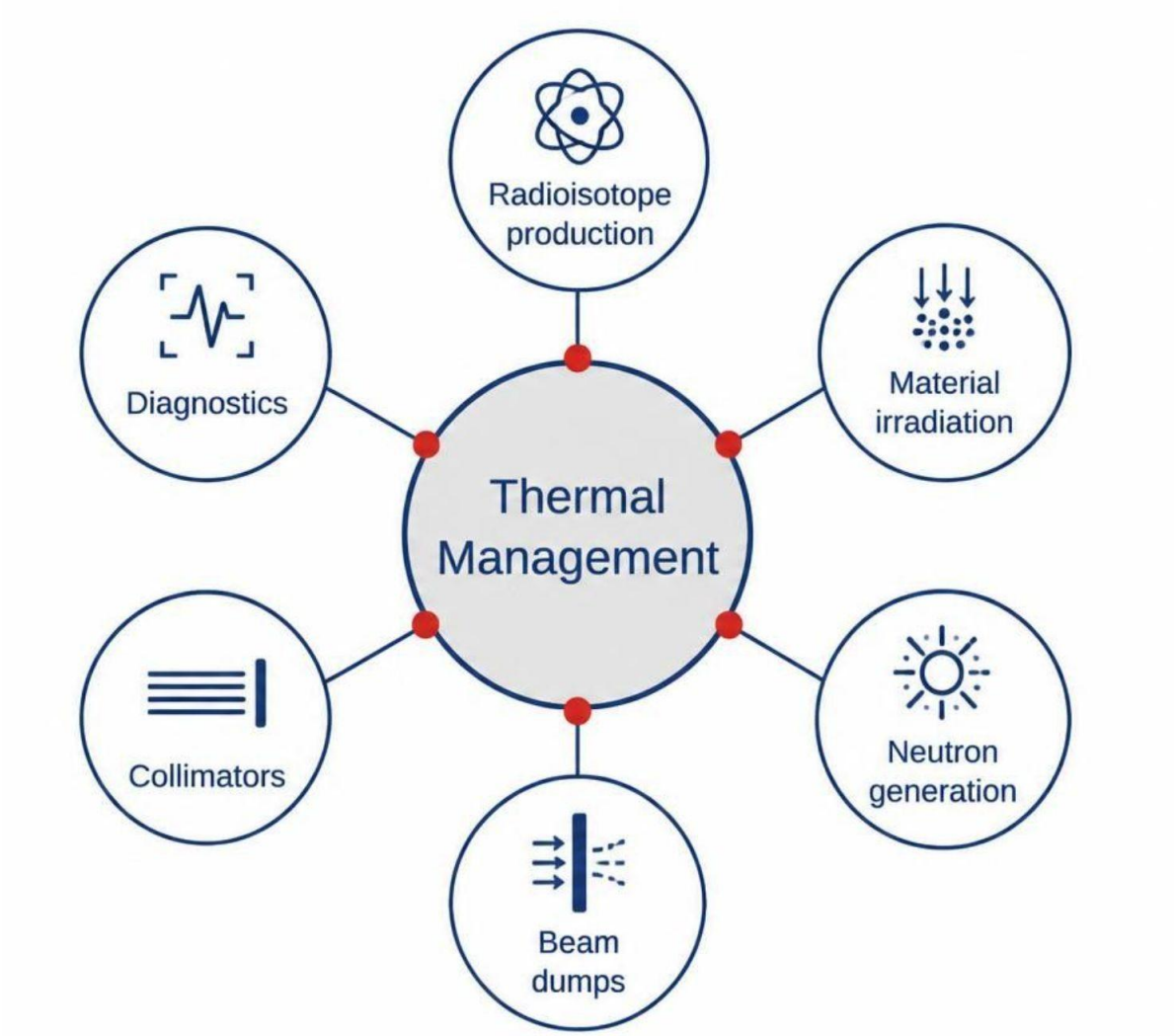
3rd Workshop on Research & Innovation in Poland,
“Research Programme for a Linear Accelerator,”
22–23 October 2026, Kraków.

Advanced cooling enables advanced science

Cooling often determines facility performance.



Many applications, one problem



Radioisotope production,
Material irradiation,
Neutron generation,
Beam dumps,
Collimators,
Diagnostics,
… look quite different, yet they share one challenge:
High heat loads concentrated in small volumes.

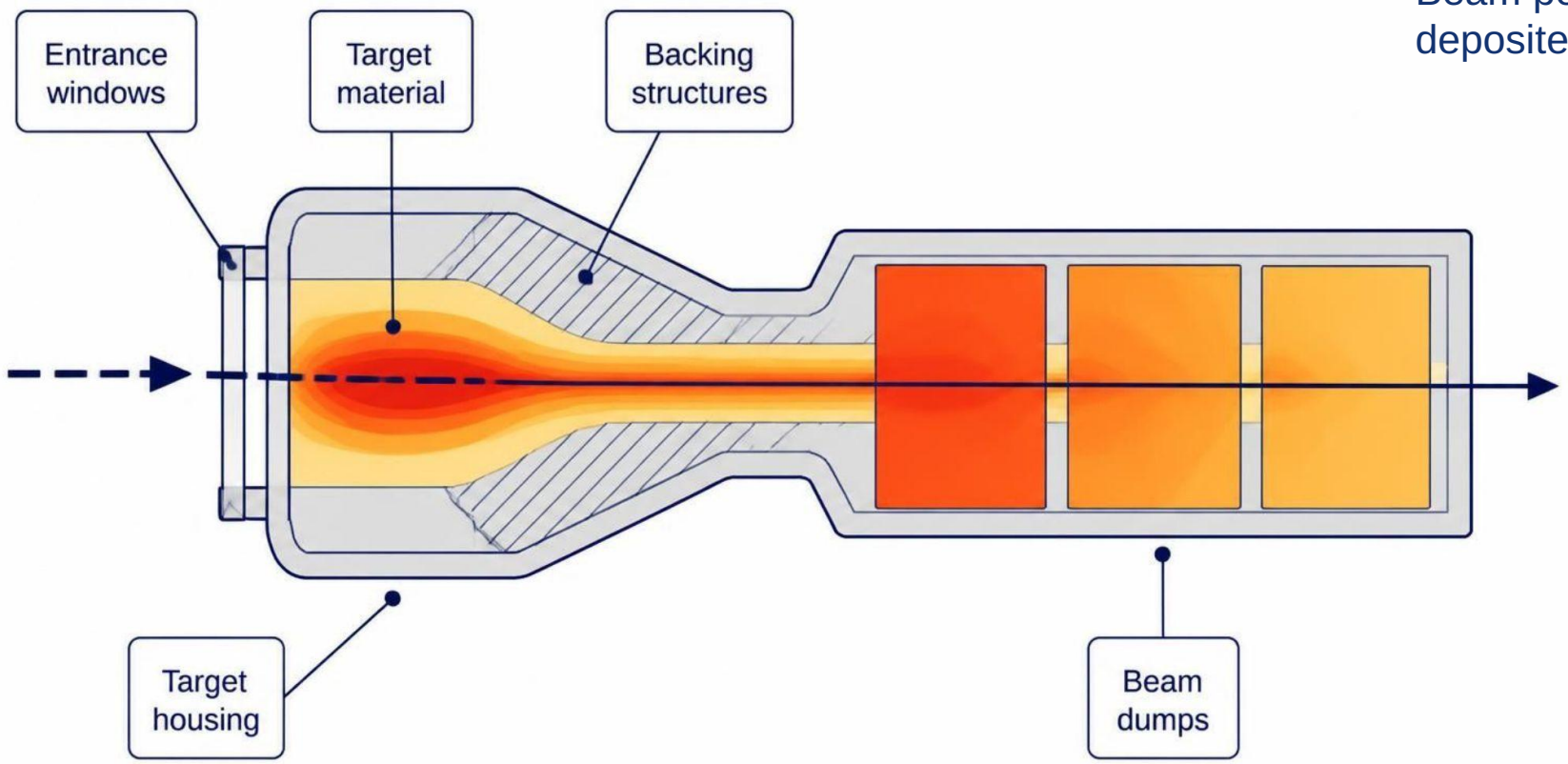
Common denominator: high heat loads concentrated in small volumes.

Beam power and thermal load

$$P = I \times \Delta E$$

I = beam current, ΔE = deposited energy.

Heat is generated in…

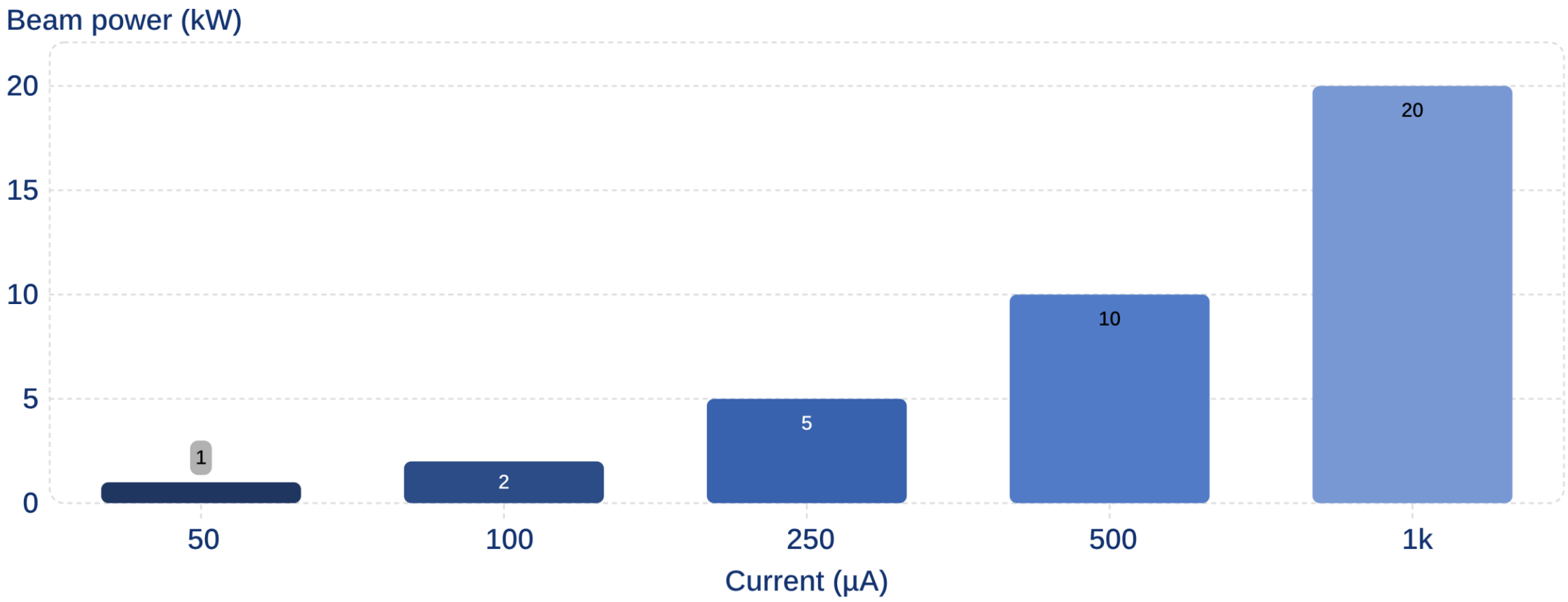


Beam power is the product of beam current and deposited energy, as the formula shows.

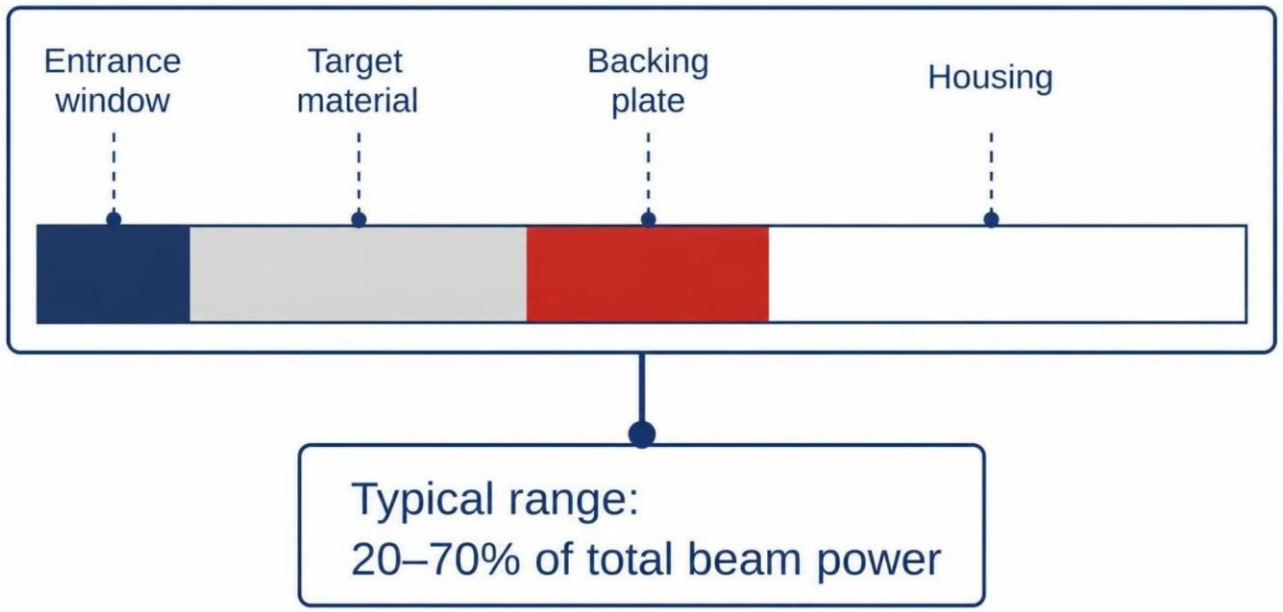
Even moderate currents mean multi-kilowatt loads

Example:

Using a 20 MeV proton beam as an example, the chart shows beam power rising from 1 kW at 50 µA to 20 kW at 1000 µA.



Not all beam power is absorbed in the target station

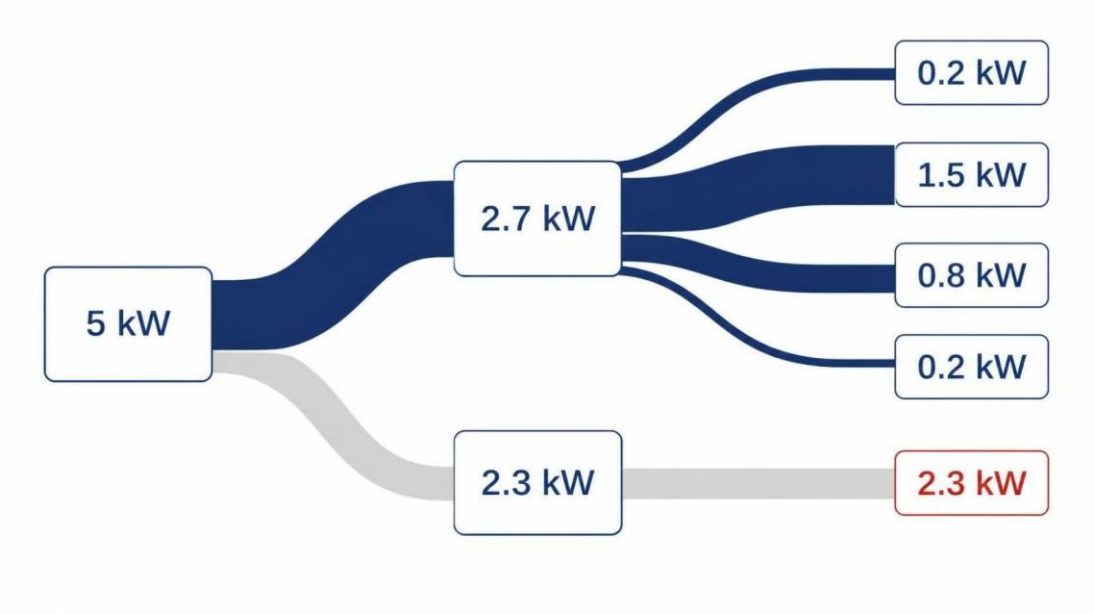


20–70%

Typical range of total beam power absorbed in the target station.

Example energy distribution: target station vs beam dump

20 MeV, 250 µA: total beam power 5 kW.



Target station: 2.7 kW

Window 0.2 kW · Target 1.5 kW · Backing 0.8 kW · Housing 0.2 kW

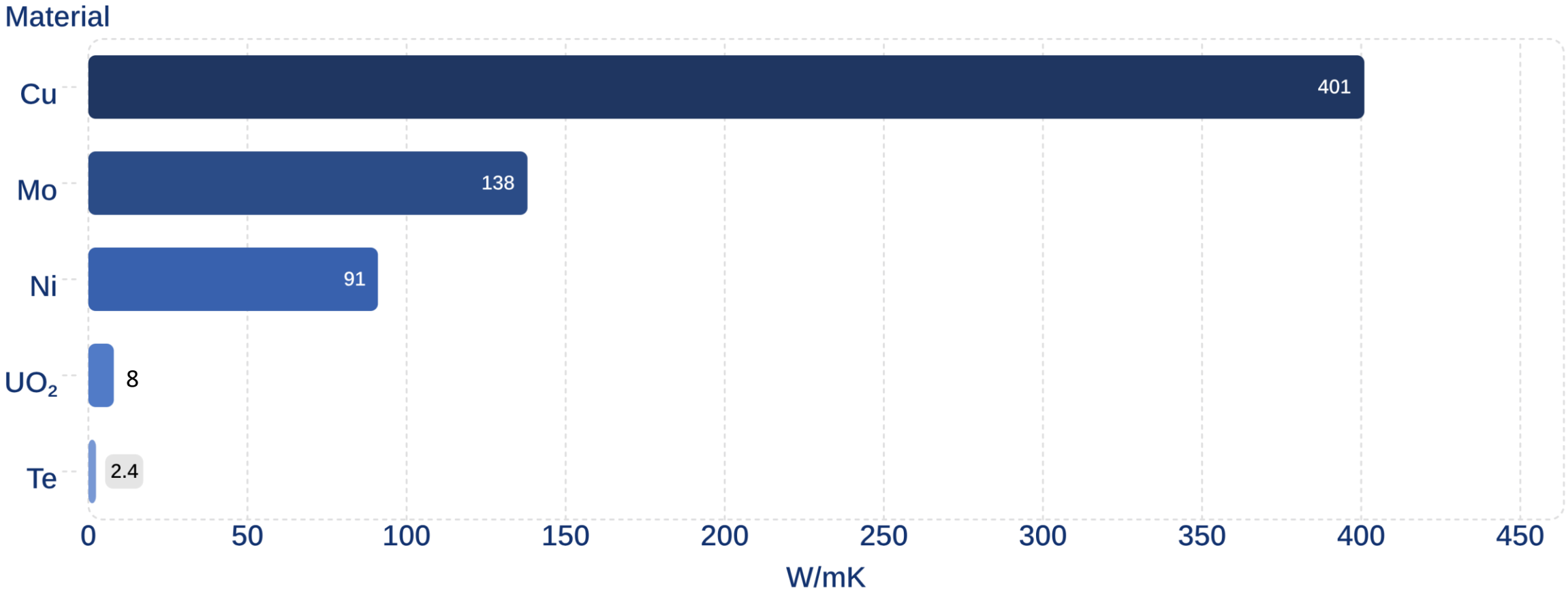
Beam dump: 2.3 kW

Dedicated cooling system

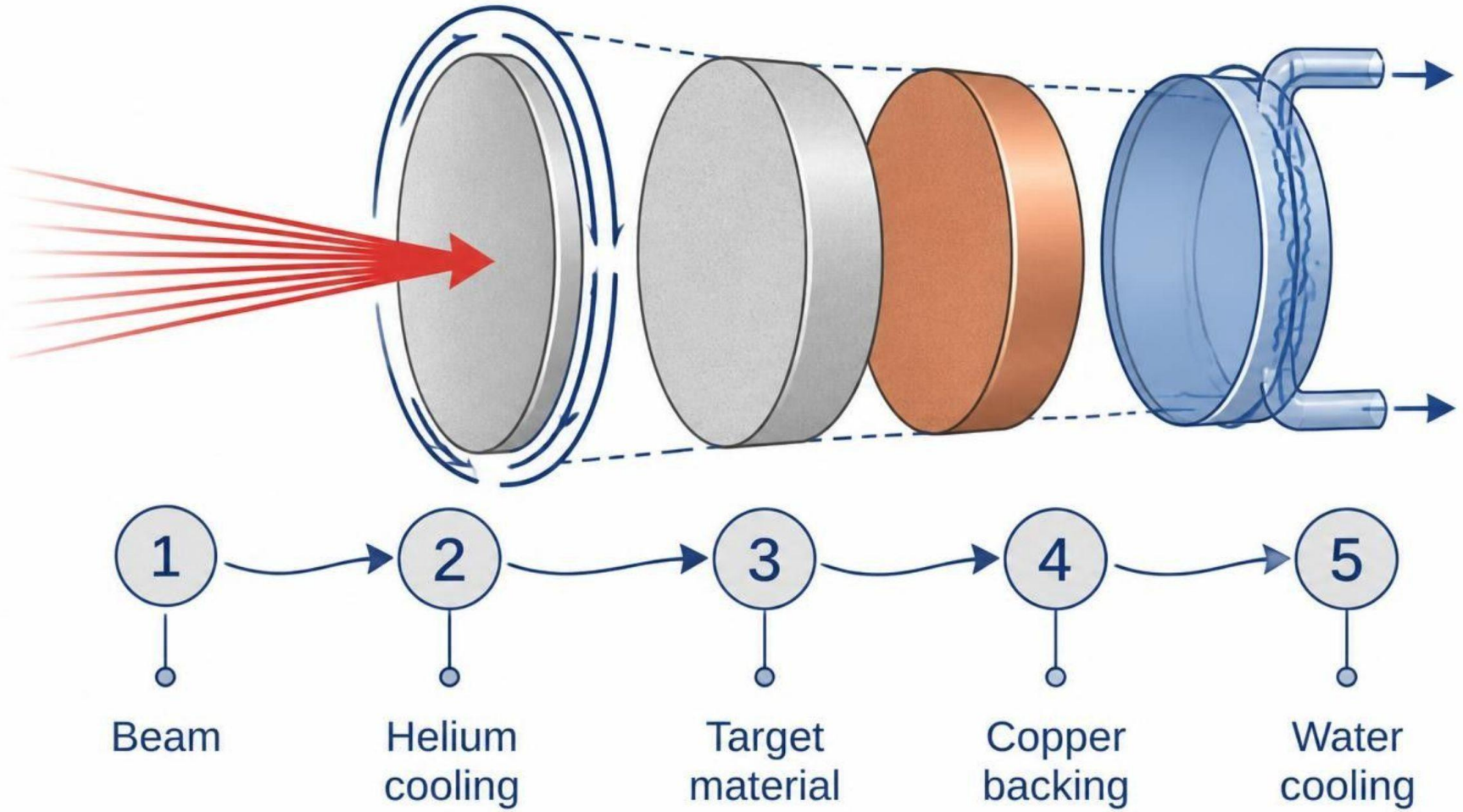
Independent thermal design

The most interesting isotopes need the most challenging materials

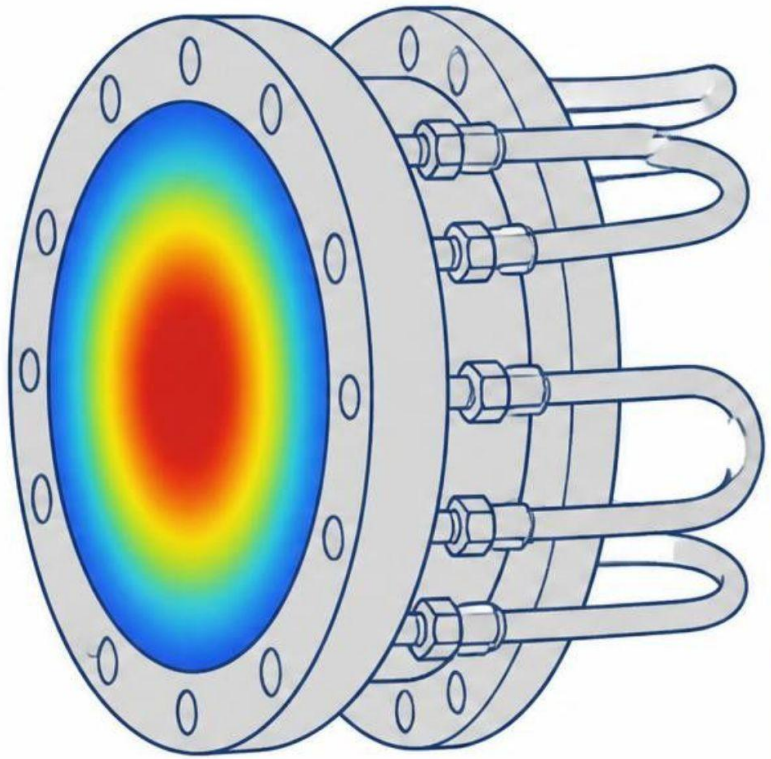
Thermal conductivity, W/mK.



Current standard: typical target architecture



Water cooling



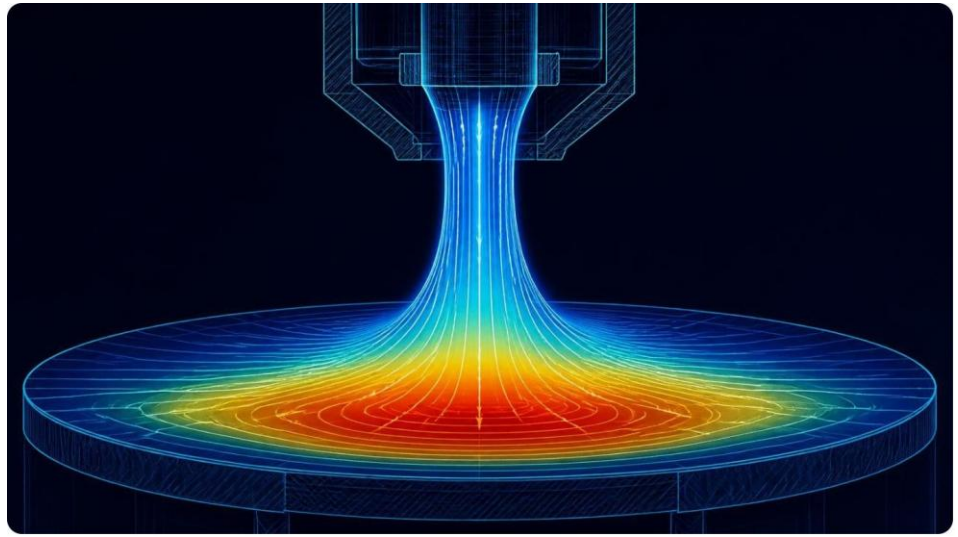
Advantages

- high heat-removal capability
- mature technology
- proven reliability

Challenges

- corrosion
- water chemistry
- activation products

Helium cooling



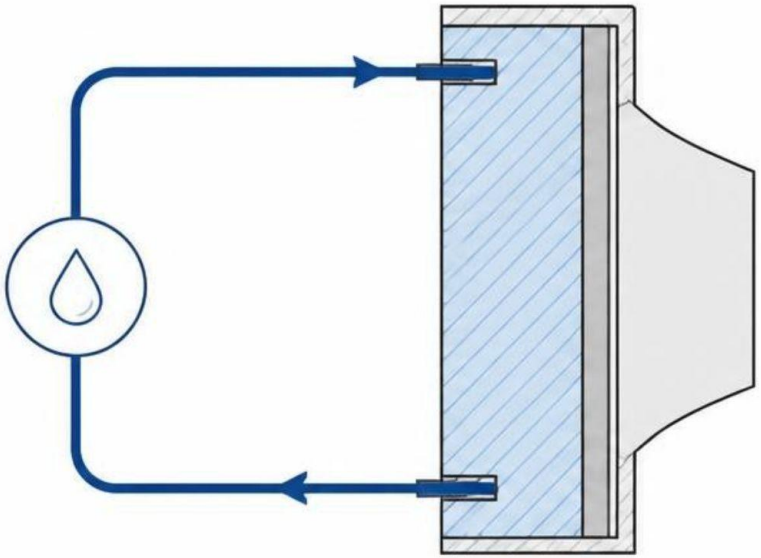
Advantages

- Chemically inert
- No corrosion
- Surface cooling
- Window cooling

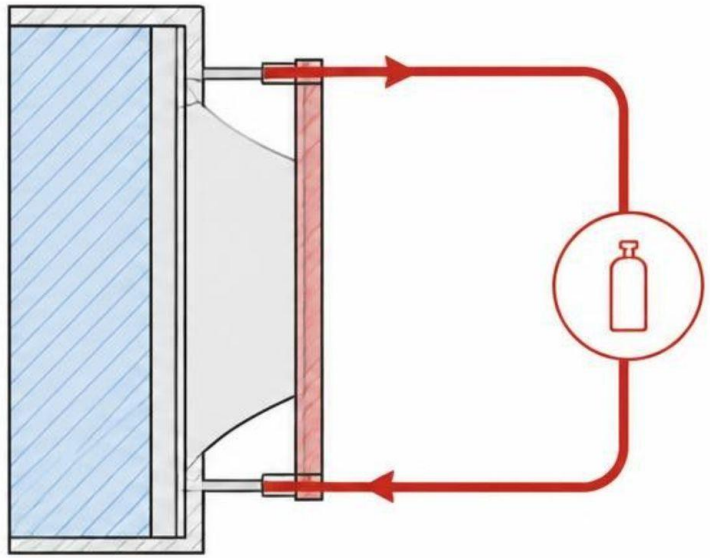
Open research topics

- Jet cooling
- Nozzle optimization
- Flow distribution

Water + helium: current best practice



Water:
bulk heat removal.



Helium:
front-face protection,
temperature peak reduction,
window cooling.

Microchannel cooling

Benefits

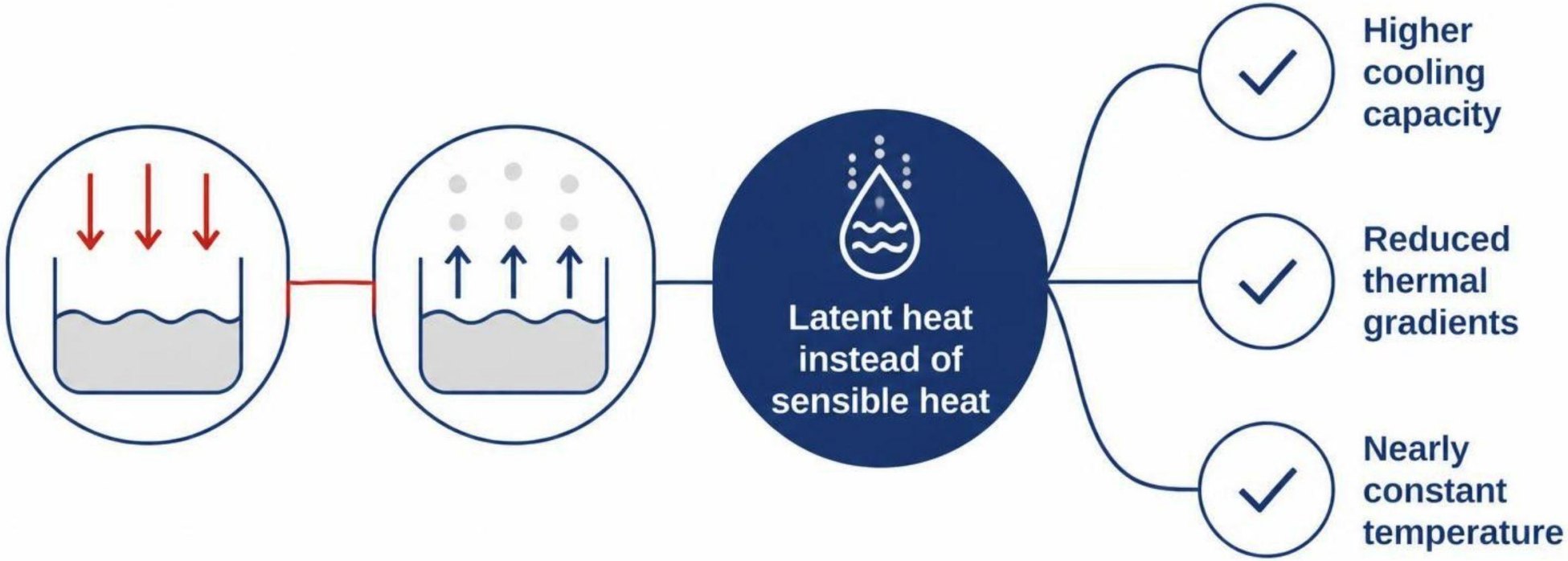
- High heat-transfer coefficients
- Compact geometry
- Uniform temperatures
- Reduced thermal resistance

Challenges

Manufacturing, reliability, radiation effects



Two-phase cooling: latent heat instead of sensible heat

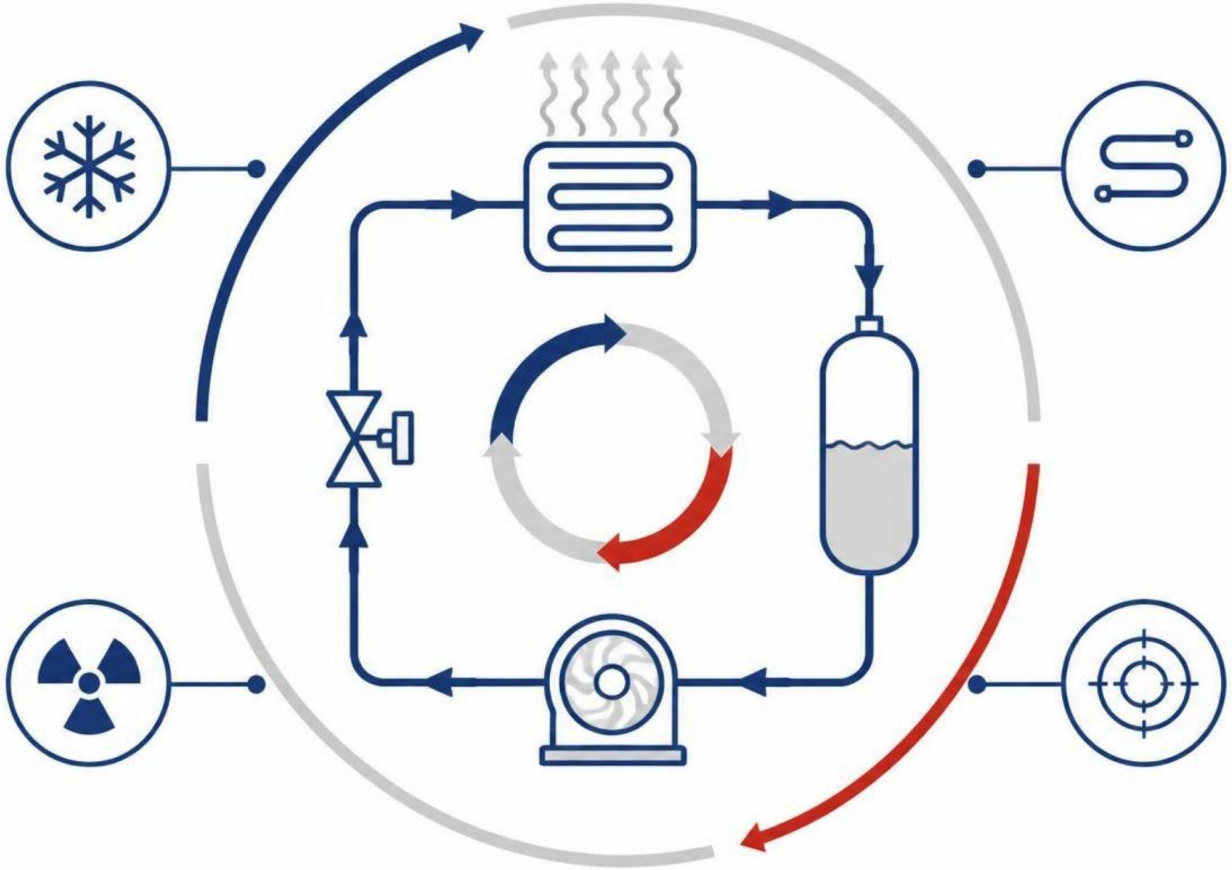


High-Performance Cooling for High-Power Targets

2PACL CO_2 technology

Developed for CERN detector cooling. Growing Interest from Large AI Data Centers.

- Accumulator-controlled evaporative CO_2 loop with small-diameter piping
- Controlled cooling temperature range -40°C ÷ +25°C



Two-phase cooling - opportunity for accelerator targets?

Proven:
detector cooling, high heat flux

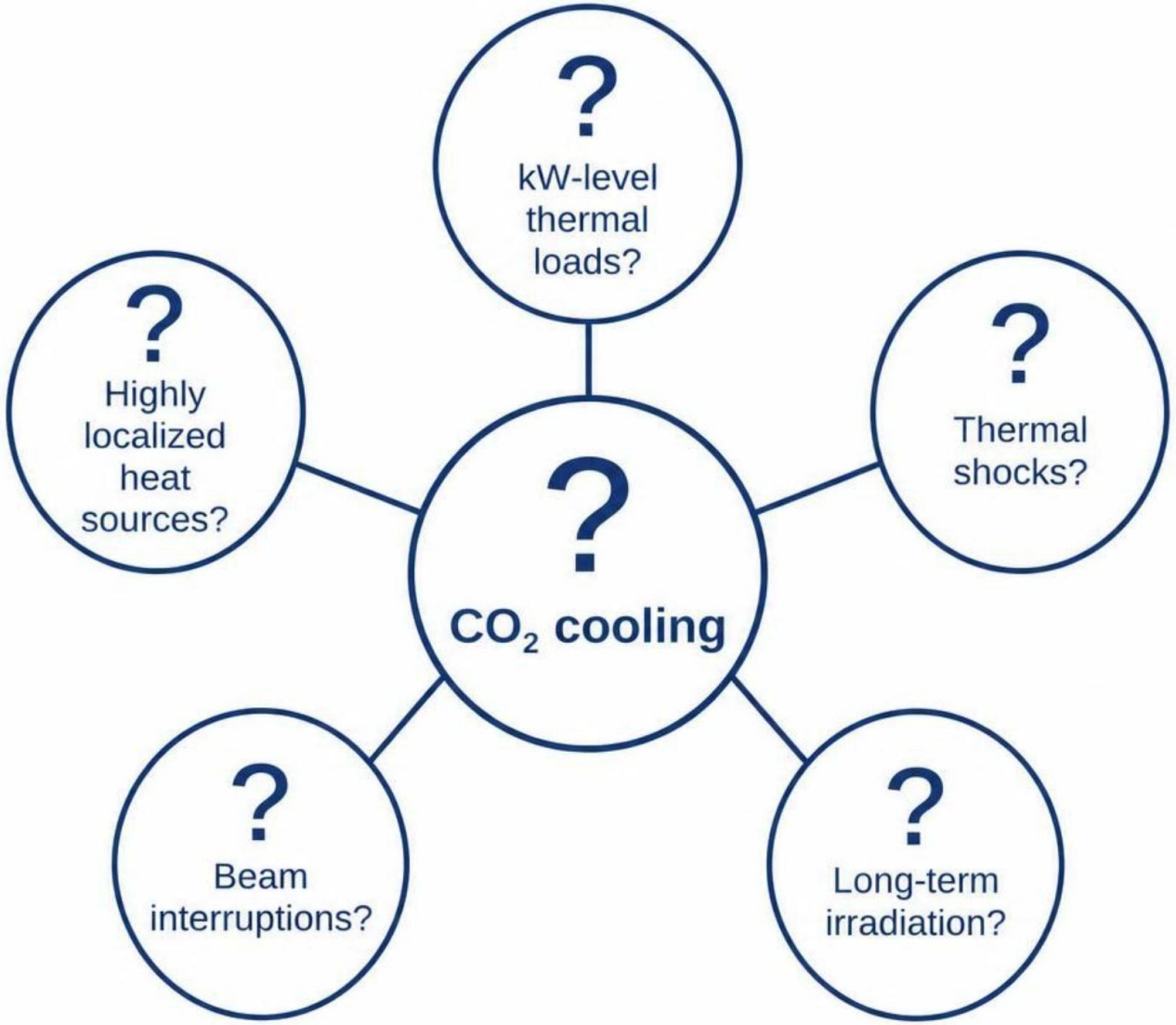
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Future Accelerator Targets

Not yet demonstrated:
radioisotope targets, irradiation targets, beam-intercepting devices.

A new research direction.

Can CO_2 cooling handle in High-Power Targets…?



These are open research questions, not demonstrated capabilities, and they define the work ahead.c

but…

In general, phase-change cooling through evaporation is significantly more efficient than conventional water cooling, especially in high heat flux applications.

EXPERIENCE I

MARTA and 2PACL CO_2 cooling

Developed in collaboration with CERN (EP-DT group).

Krakow University of Technology 亩 CERN



- Designed for experiments requiring thermal stability
- Flexible cooling platform
- Commercialized with industrial partners
- **25 units deployed worldwide** (CERN and major high-tech research facilities in Europe, USA, Canada, and India)
- 1 MARTA unit available at the Krakow Univrsity of Technology for testing/research
- Technology readiness demonstrated in long-term scientific operation

Strategic opportunity: transfer CERN-related cooling know-how to future accelerator facilities.

01

Detector Cooling

02

2PACL

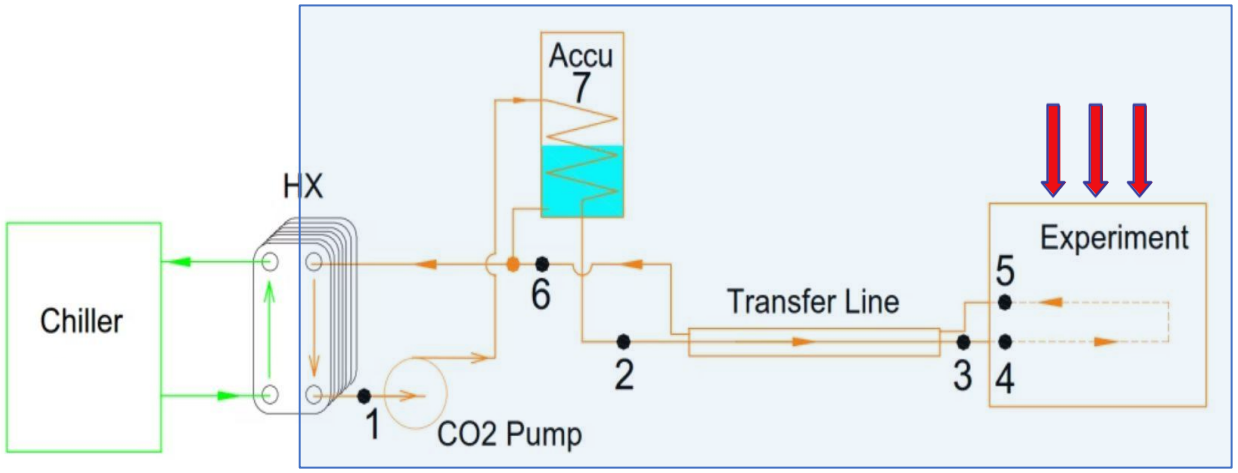
03

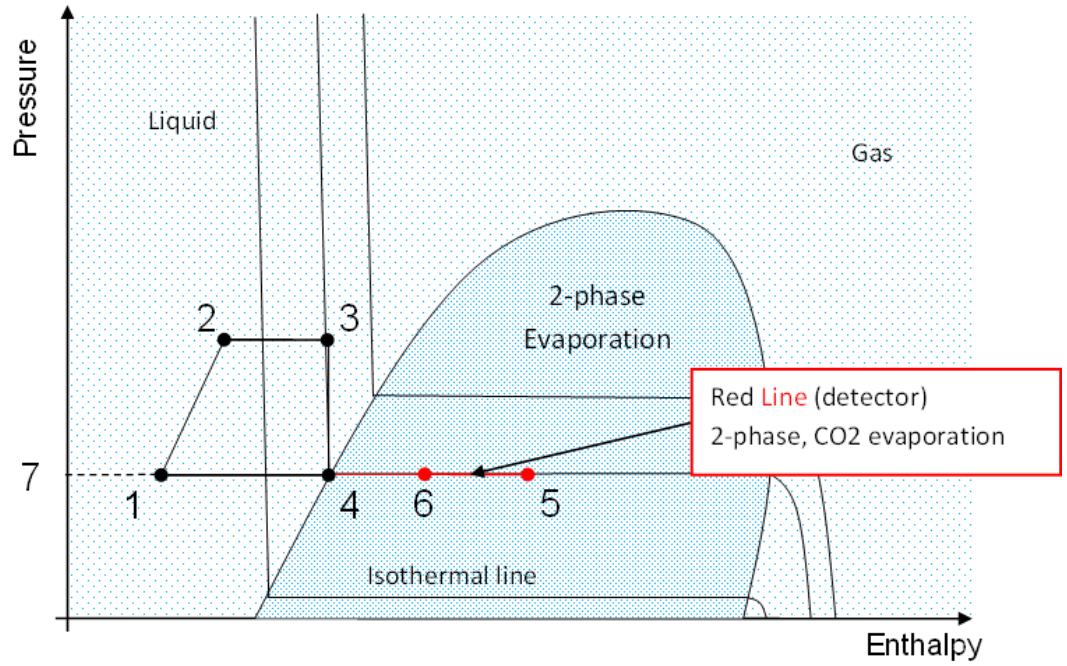
Future Accelerator Targets

EXPERIENCE I

2PACL CO_2 cooling in MARTA

Experiment = Target

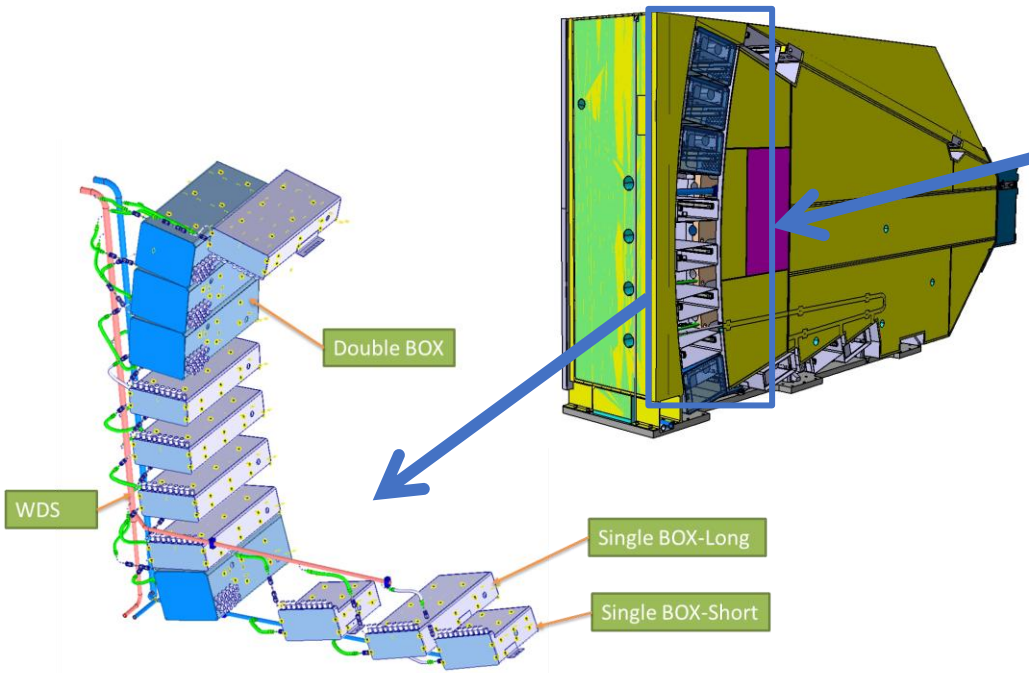


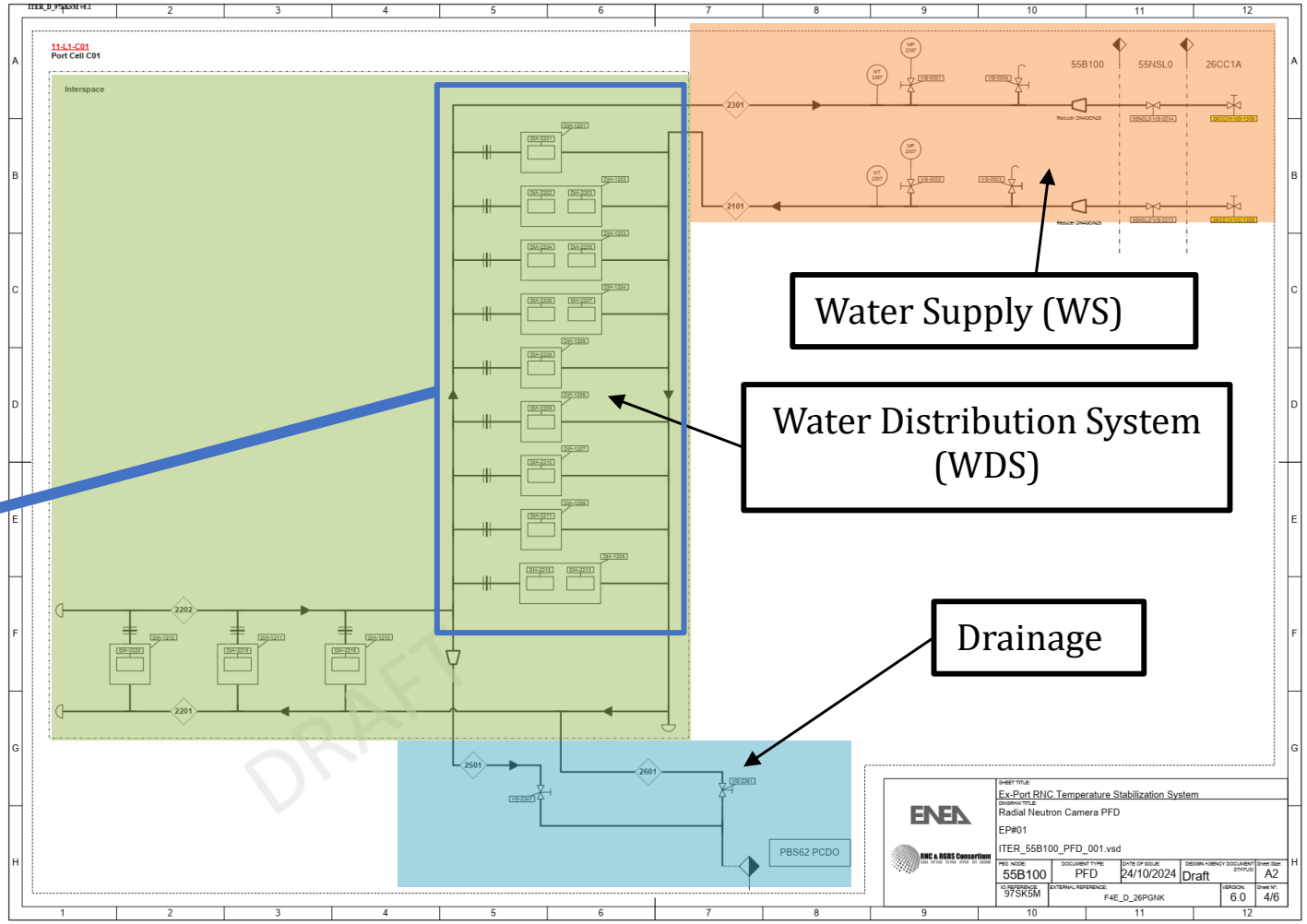


- Rapid and precise control of CO_2 evaporation temperature
- Operating range: ambient temperature to –35°C
- Available cooling power 300 W @-30 ° C

ITER Radial Neutron Camera (RNC)

- IFJ PAN as a Project Partner (Team Leader: D. Bocian)
- Cooling-system design (final design phase)
- Thermo-hydraulic analyses
- CFD simulations
- Heat-removal optimization
- Reliability assessment

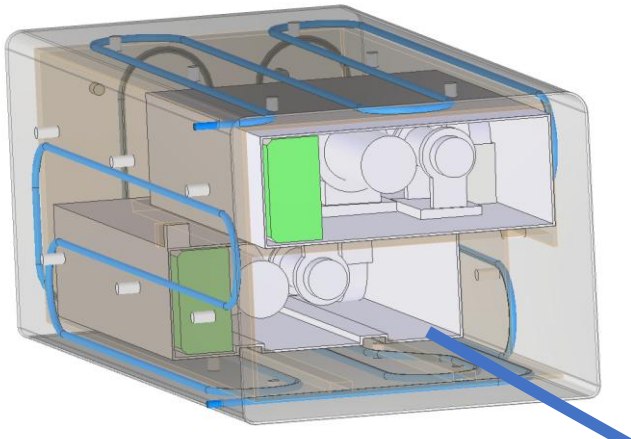


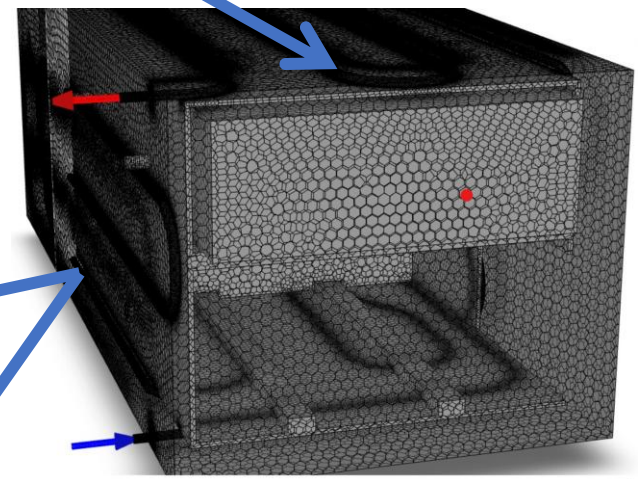


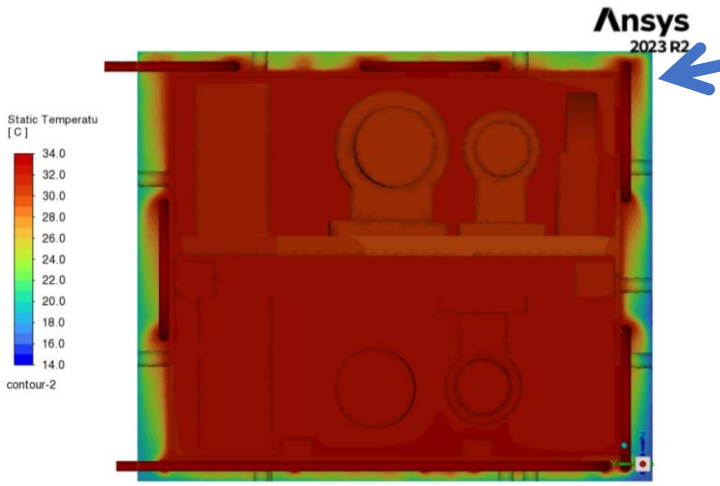
EXPERIENCE II

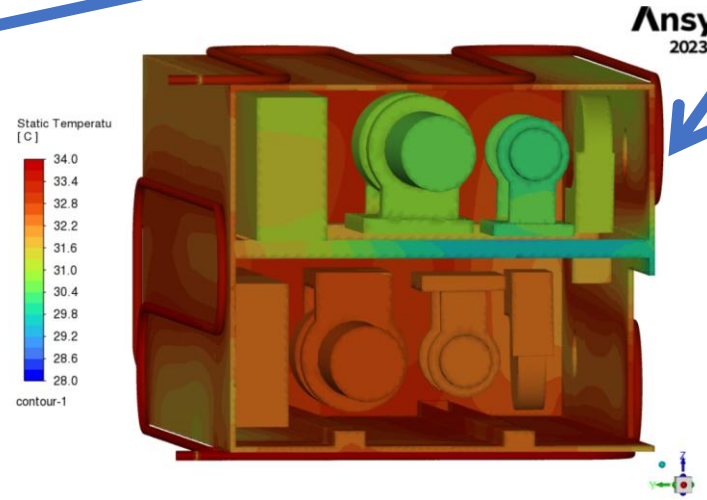
ITER Radial Neutron Camera (RNC)

- Cooling-system design
- Thermo-hydraulic analyses
- CFD simulations – global model and submodels
- Heat-removal optimization
- Reliability assessment





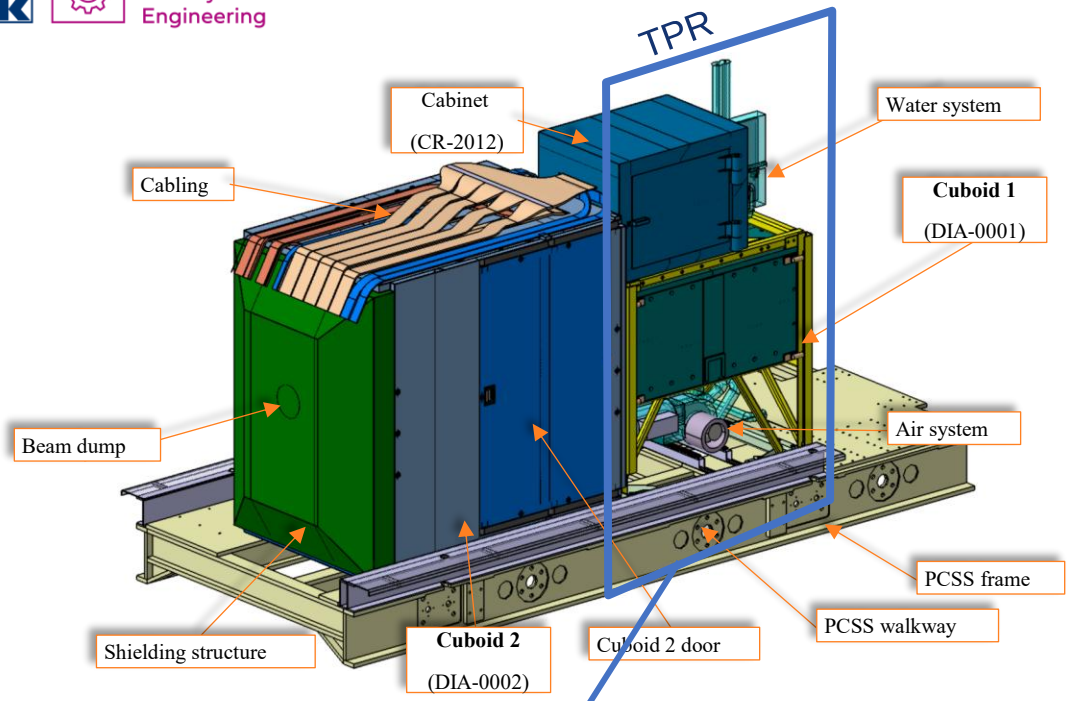


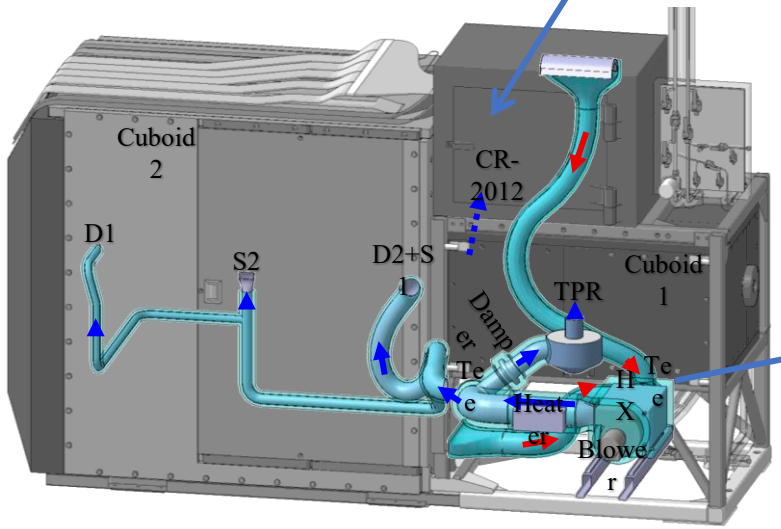


EXPERIENCE III

ITER High Resolution Neutron Spectrometer (HRNS)

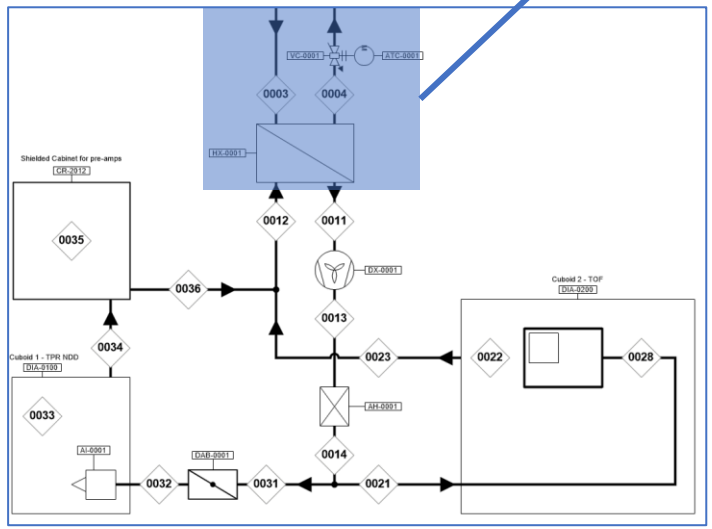
IFJ PAN as a Project Partner (Team Leader: M. Scholz)
Thin-Proton Recoil (TPR) design
Cooling system conceptual design
Thermal stabilization
Cooling-loop integration
Thermo-mechanical analyses
Reliability studies

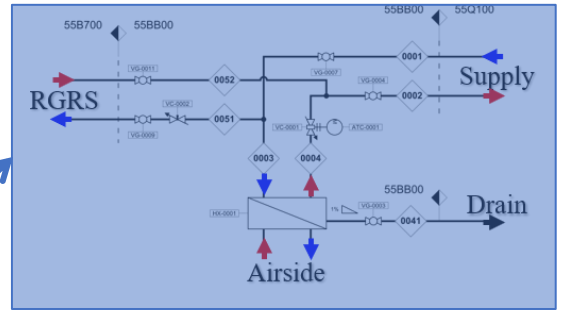




Air cooling loop

P&ID

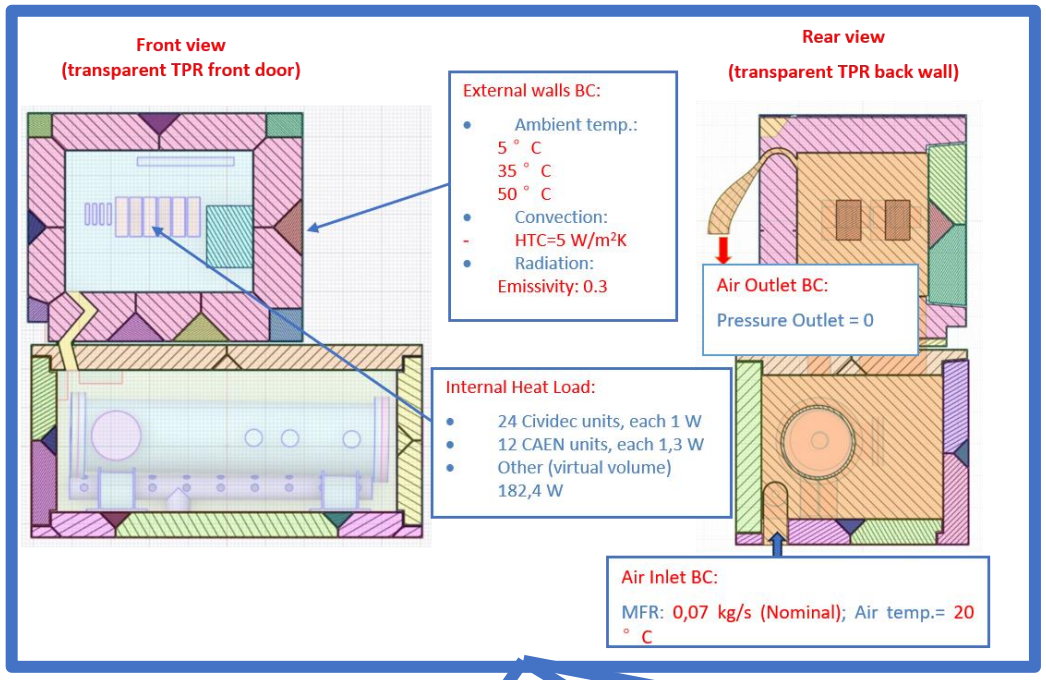


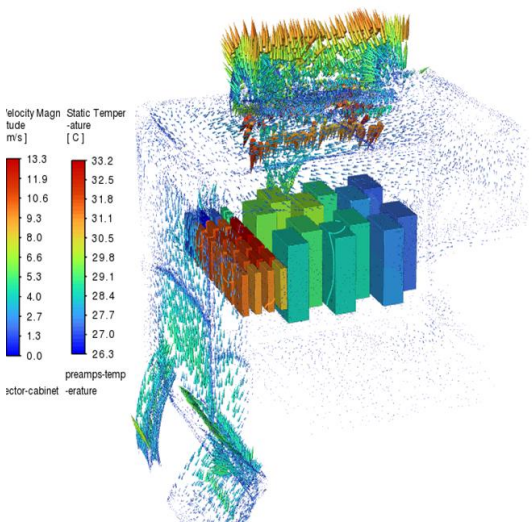


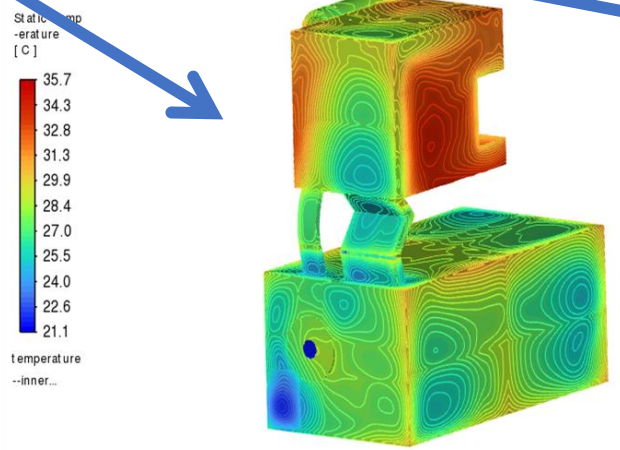
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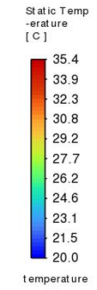
ITER High Resolution Neutron Spectrometer (HRNS)

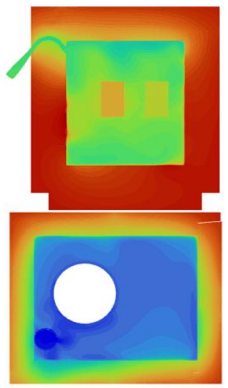
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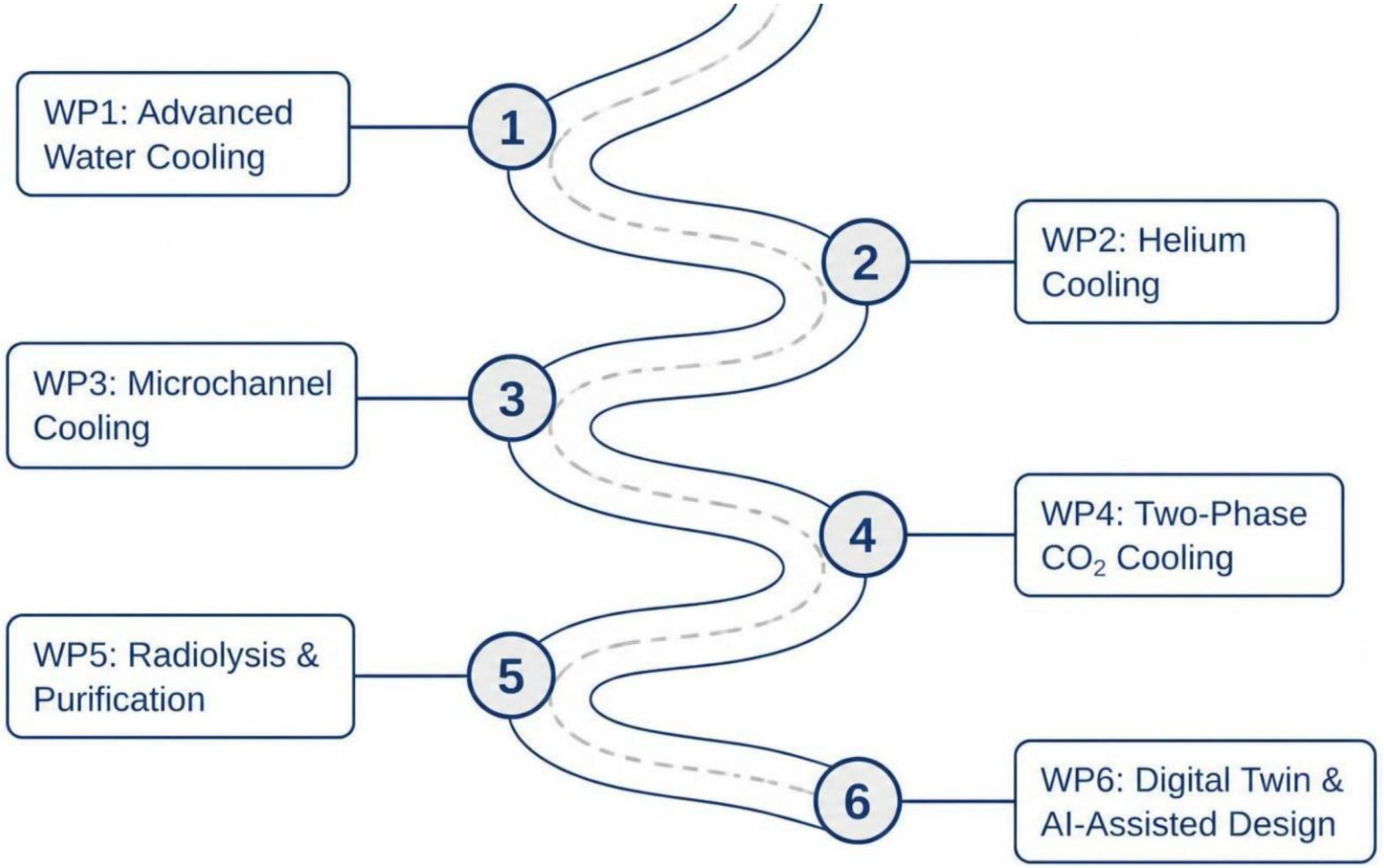






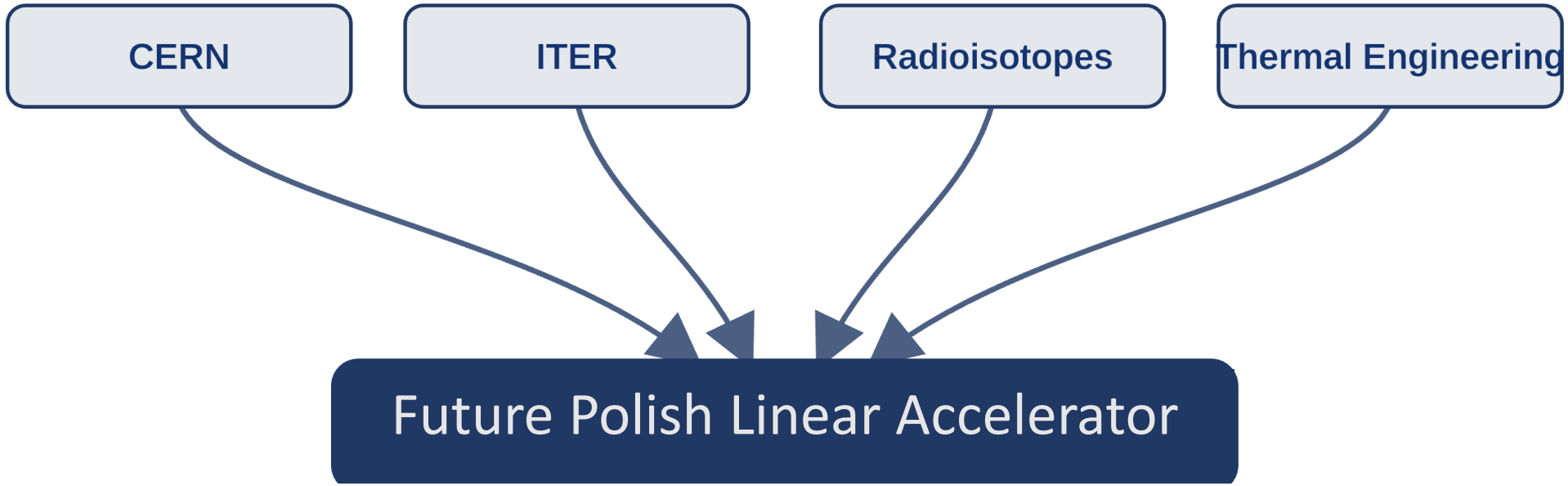


Proposal of future research programme



Conclusions

Leveraging our long-term experience, we offer expertise, dedicated testing facilities, and R&D capabilities in advanced cooling technologies for radioisotope production, material irradiation, neutron sources, beam-intercepting systems, and next-generation accelerator facilities.



Backup slides

Radiolysis and coolant purification

CO_2 radiolysis

Activated particles

Coolant purification

Long-term stability

New concept: self-cleaning cooling loops.

01 Target

02 Separator

03 Filter

04 Condenser

05 Accumulator