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Technical Issues for Cannelloni at High Power

High Power Targetry Workshop, Malmö, May 2011

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14 Years of SINQ Experience

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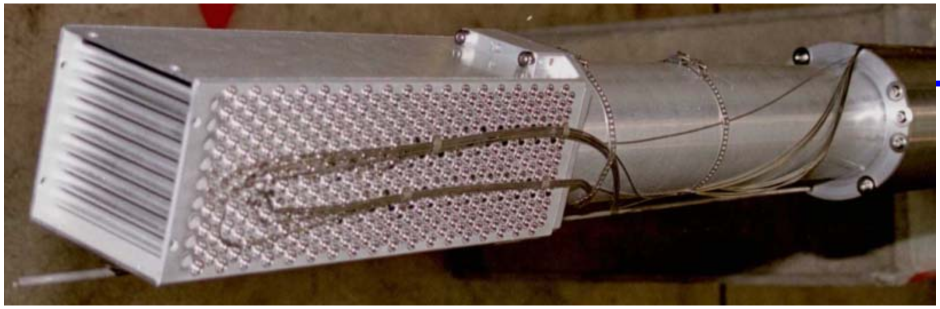
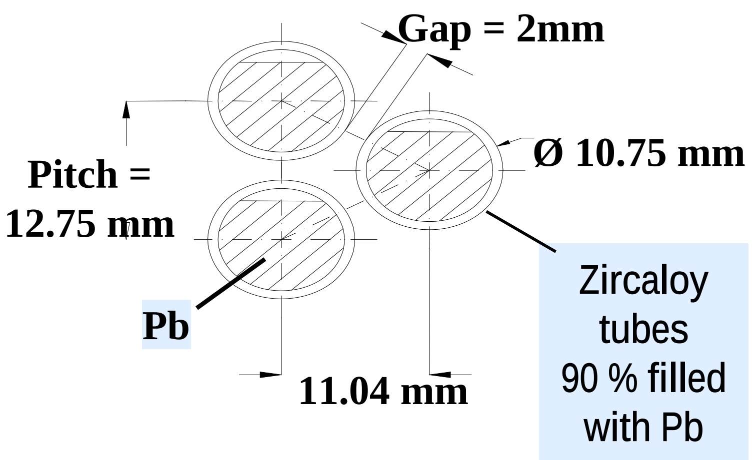
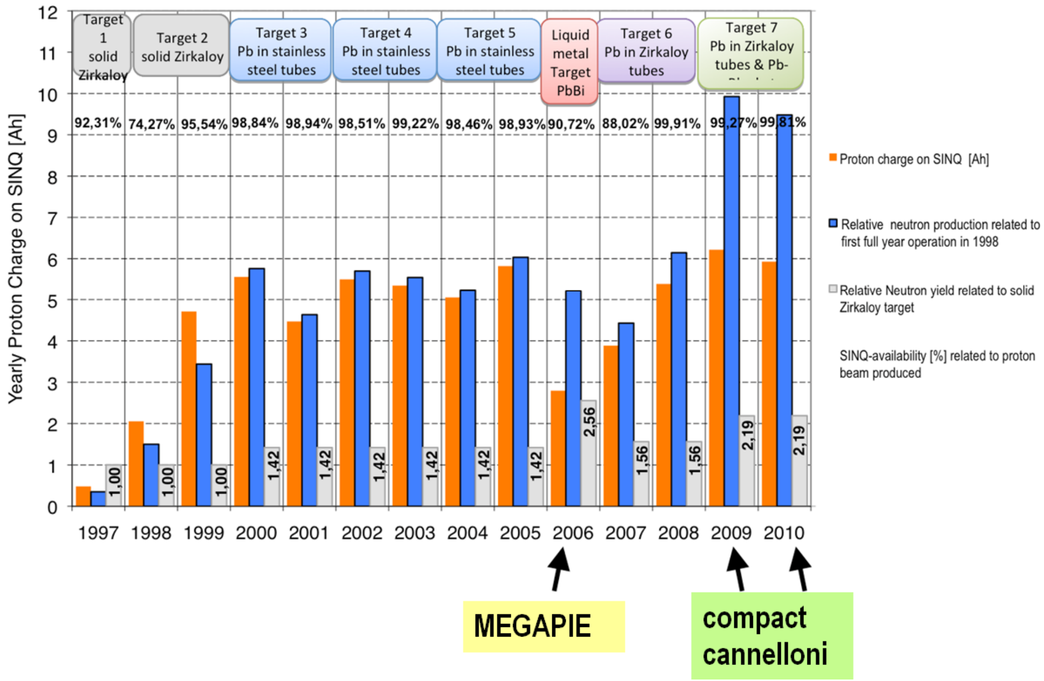
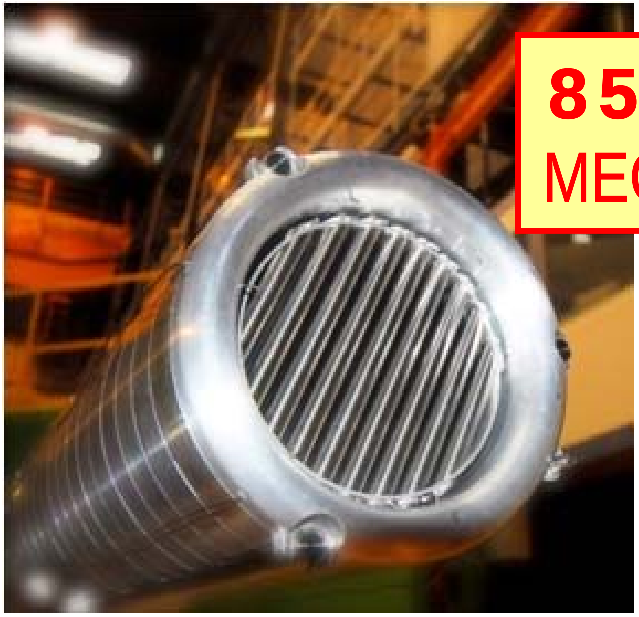








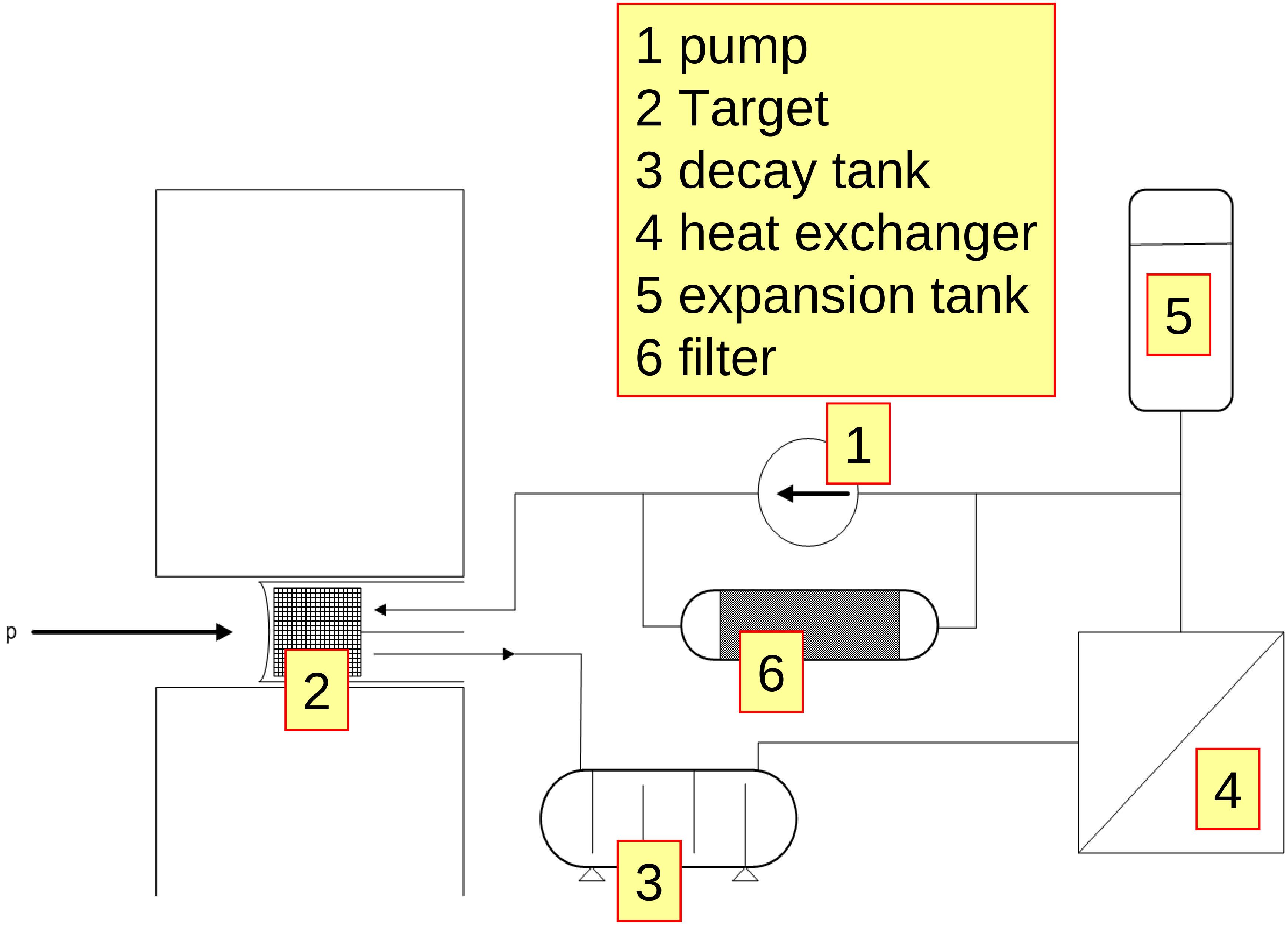
85 %
MEGAPIE

Good experience motivates consideration and preliminary assessment shows promising performance of

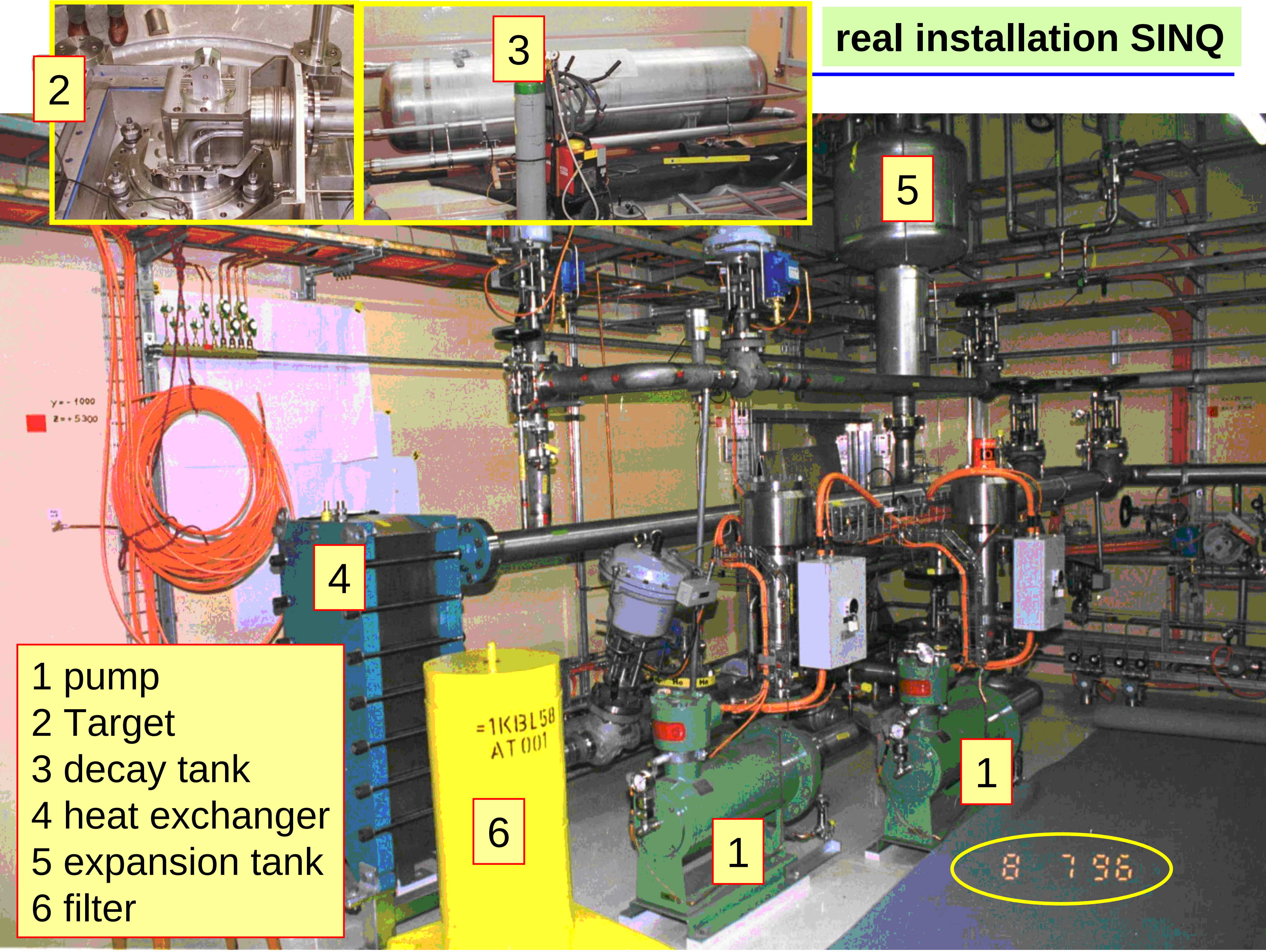
Cannelloni for ESS

NIMMA 625, 5-11 (2011), AccApp'11 Knoxville

Principal water-cooling circuit



real installation SINQ



Good experience and simple calculation confirm modest required parameter values:

$Q = m\ cp\ \Delta T$

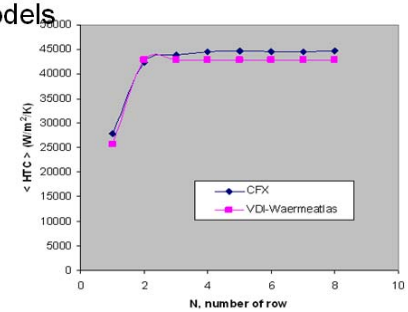
Q ……. transported heat [W]
m ……. massflow [kg/s]
cp ……. specific heat (water = 4190 J/kg K)
ΔT ……. temperature increase in coolant [K]

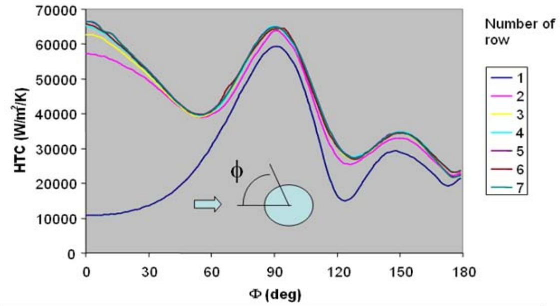
3 MW_{therm} = 35.8 x 4190 x 20, i.e. **ΔT = 20 K @ 36 l/s**

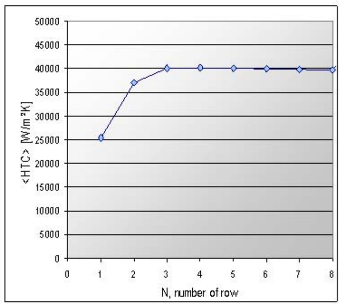
also radiological issues, handling, … are well known

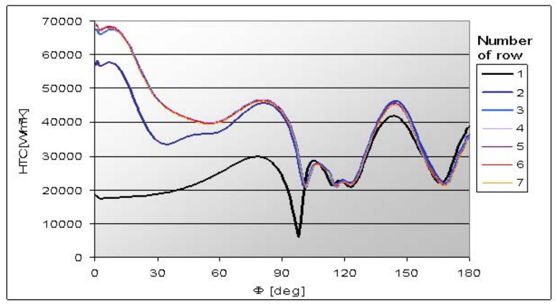
water-cooling, limits

Averaged and local convective heat transfer coefficients for the first few rows with a gap width of 1.5 mm, v=1 m/s,Tbulk=40° C; coarse k ε vs. fine SST CFX-models









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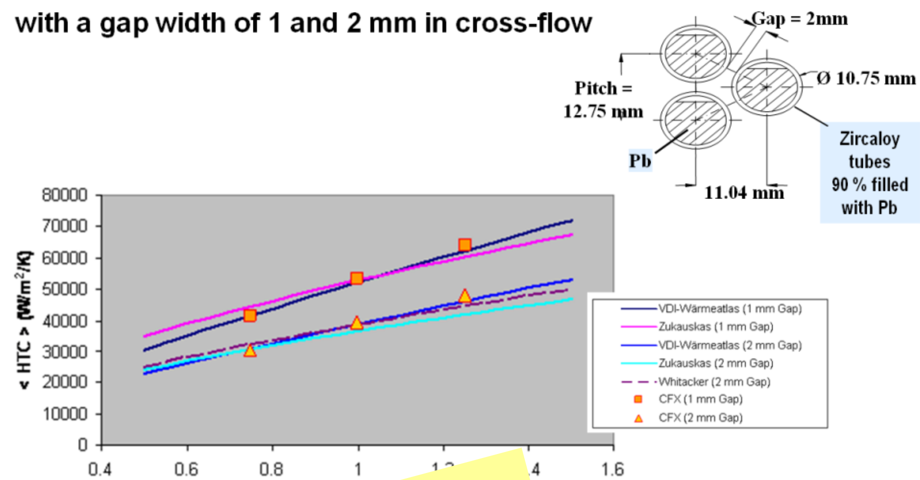
Convective cooling

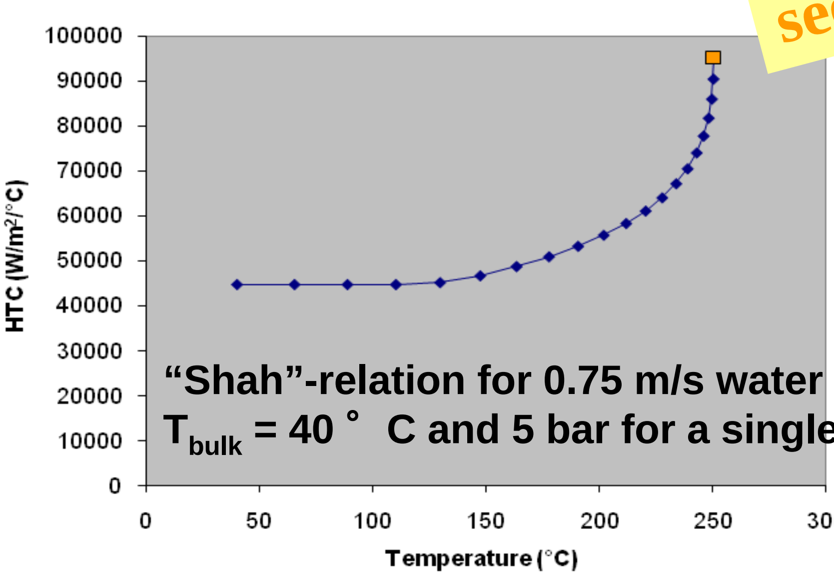
Convective heat transfer and pressure loss of cannelloni bundle with a gap width of 1 and 2 mm in cross-flow



G. Heidenreich

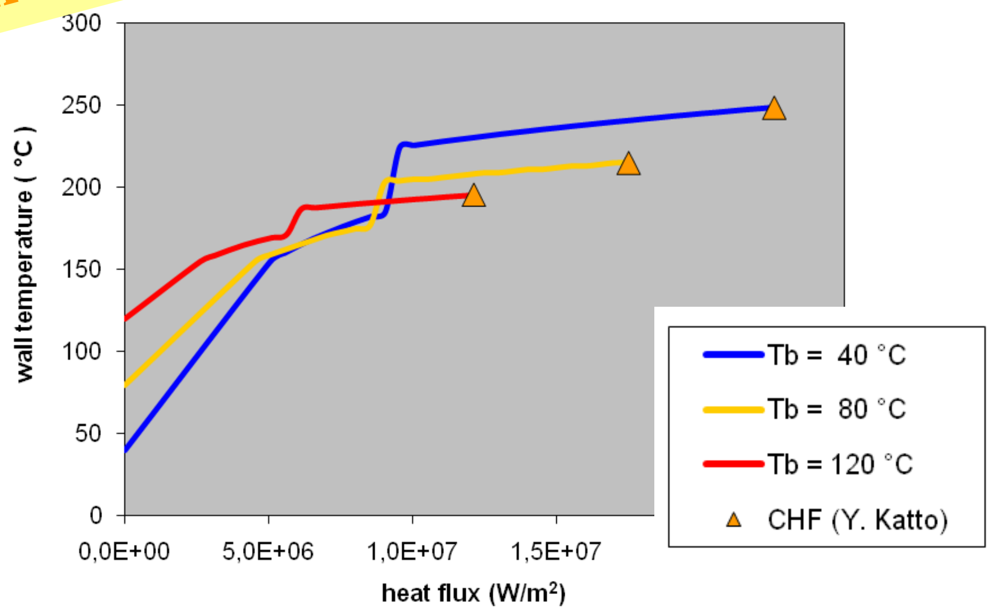
see presentation R. Milenkovic

Water offers reserve:



"Shah"-relation for 0.75 m/s water flow at T_{bulk} = 40 ° C and 5 bar for a single tube

$_{sat}$=160°C, v=1m/s, gap=1.5mm



Many configurations are possible, some examples:

0) crossflow, along beam direction, horizontal tubes, circular / rectangular geometry (SINQ, UCN)

1) „flat nose“, crossflow bottom up, horizontal tubes

2) „flat nose“, crossflow sideways, horizontal tubes

3) „flat nose“, crossflow sideways, vertical tubes

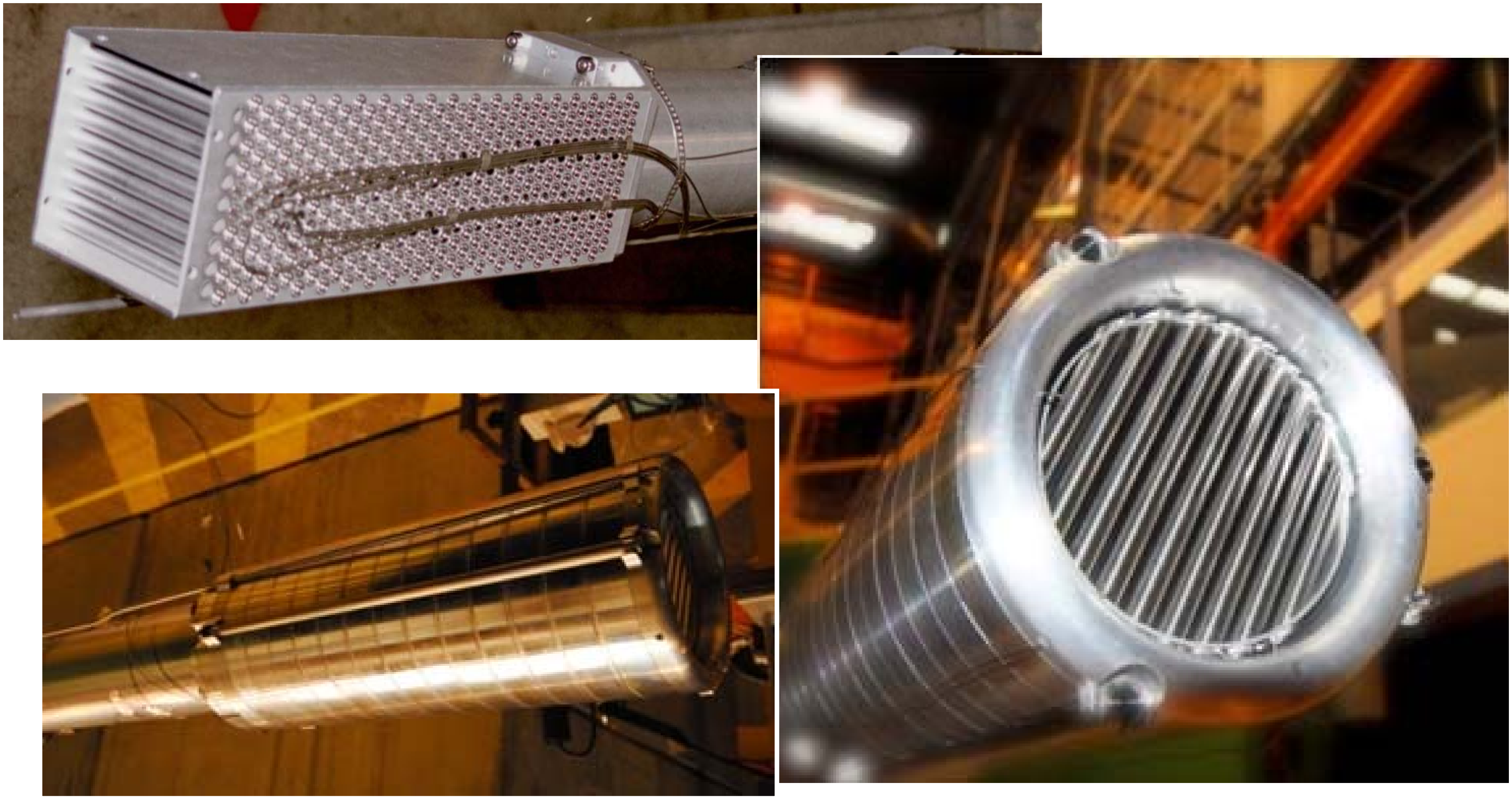
4) System layout on platform

5) Last step: continuously rotating wheel

6) …..

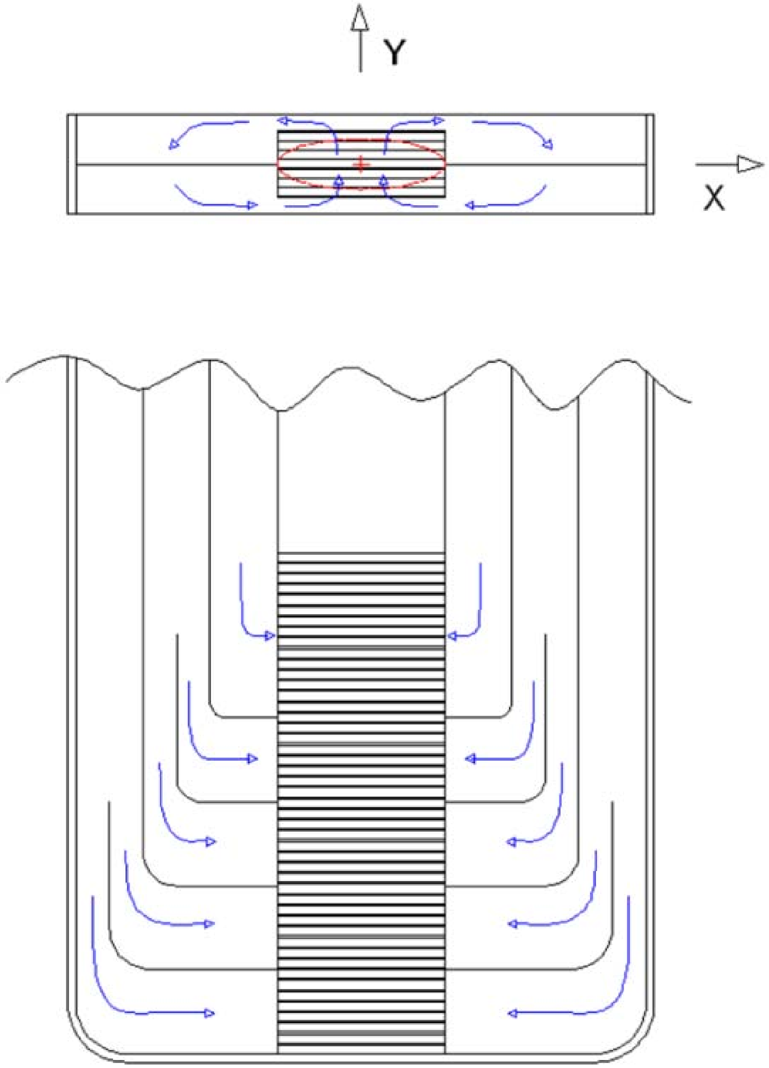
configuration 0

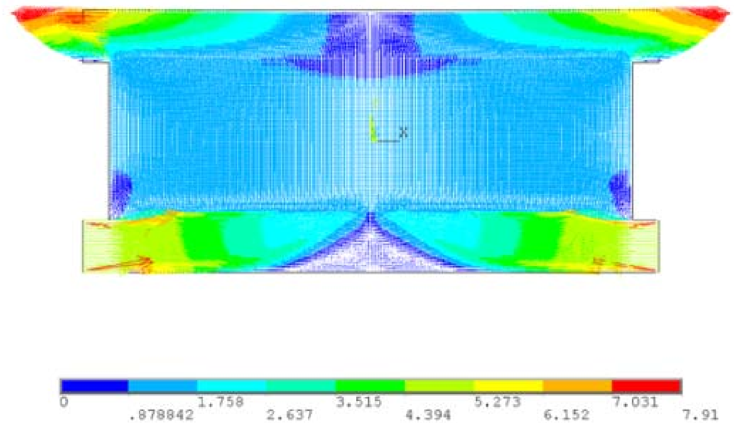
crossflow, along beam direction, horizontal tubes, circular / rectangular geometry (SINQ, UCN)



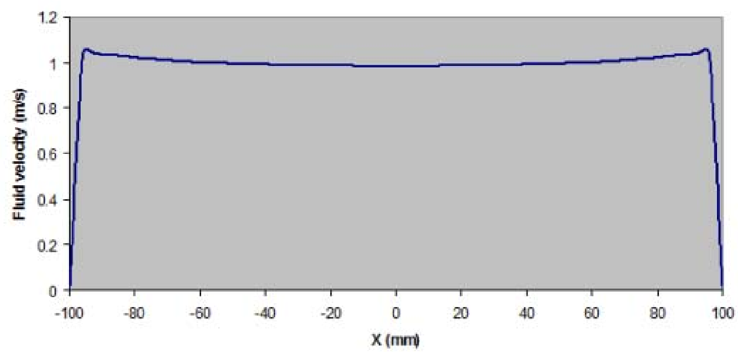
Well established, requires ~300 cm^2 cross-section

„flat nose“, crossflow bottom up, horizontal tubes





CFD 2D Flow distribution V (m/s)



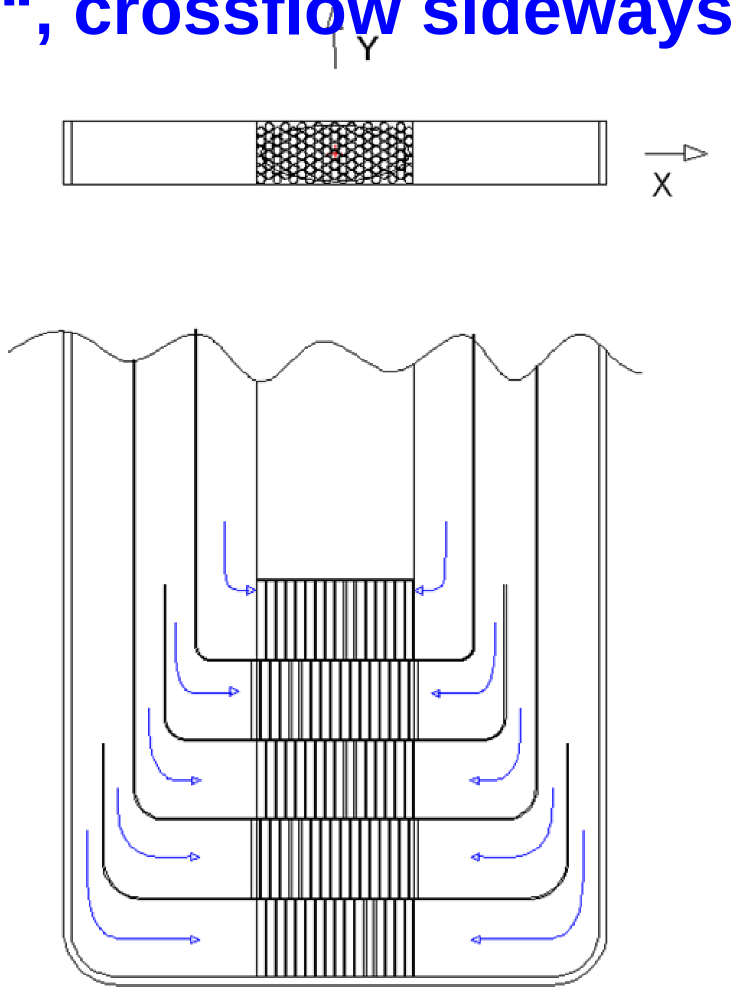
G. Heidenreich

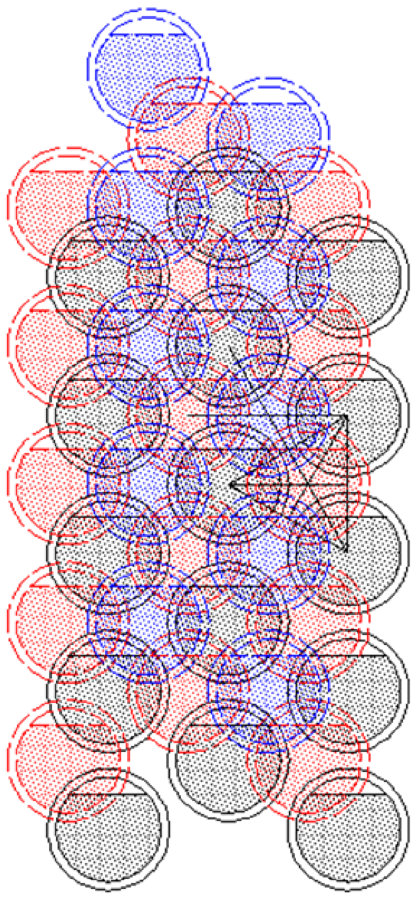
Flow distribution along x-axis

V (m/s) = f(x), y=0

sideways connections are not in the way to the moderators

„flat nose“, crossflow sideways, horizontal or vertical tubes





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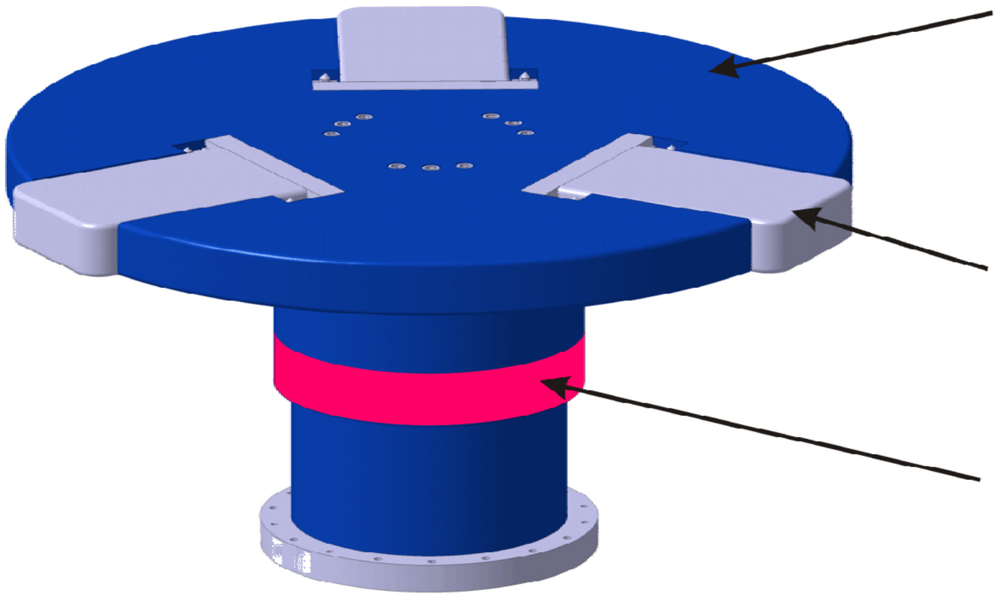
connections are even less in the way, (...continuous rotation)

(vertical tubes with essentially solid filling only)

System layout on platform



Starting in stepping mode allows for gradual build up of experience, qualification of new components in the peculiar spallation environment and for continual upgrades. The possibility of quickly swapping between inserts ensures maximum availability.

Completing the remainders of the wheel with optimized reflector material could partly compensate for the lower density compared to more dense tungsten.

swapping targets at end of life (.....> continuous rotation)

Continuously rotating wheel(s)

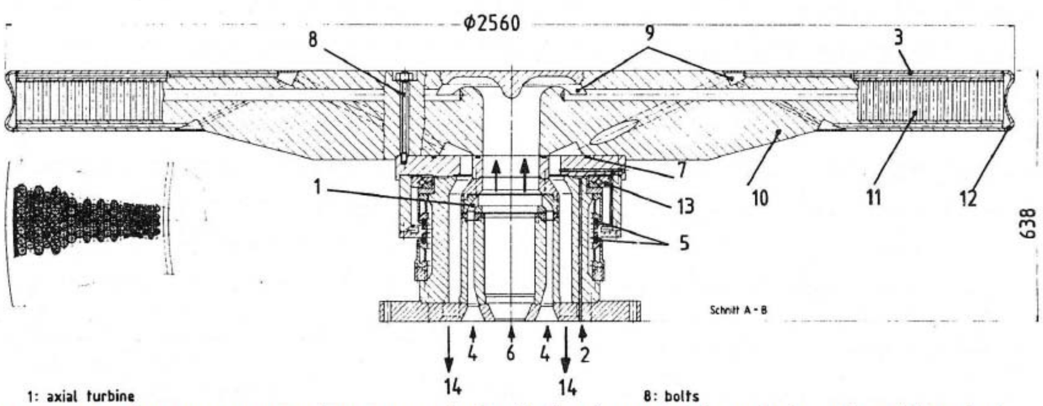
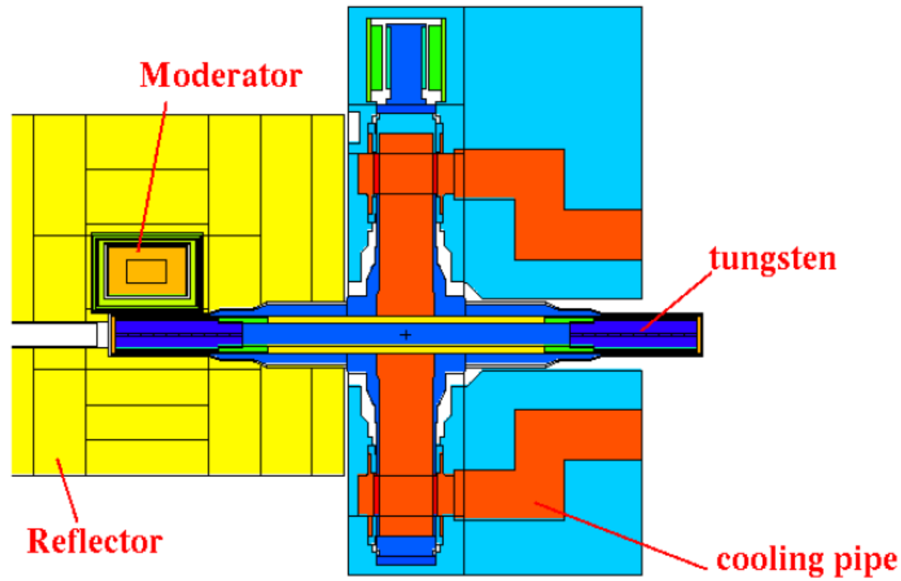


Figure 53: Rotating target mounted on a water hydraulic bearing and drive unit featuring sliding rind seals (SNQ 1984)



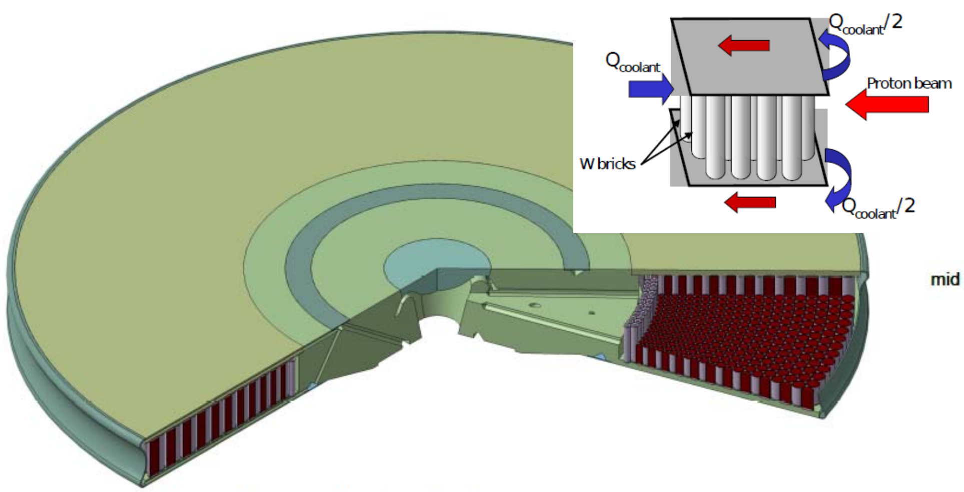


Figure 51: Cross-flow low density configuration

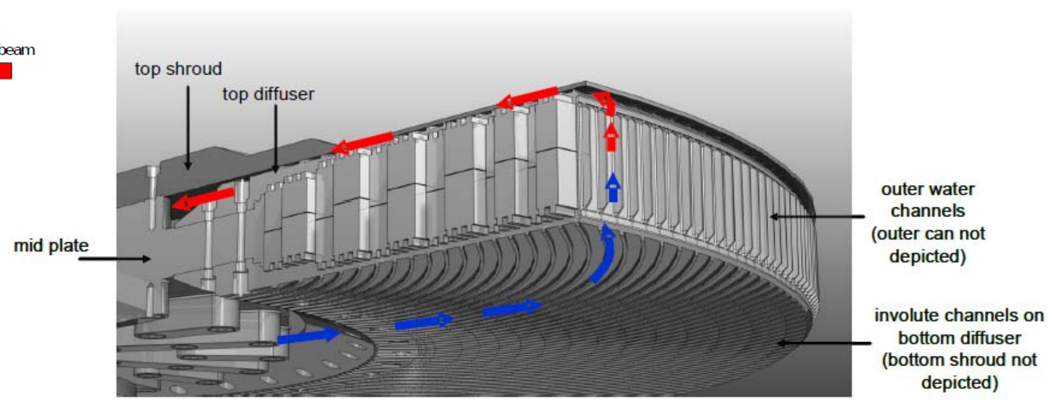


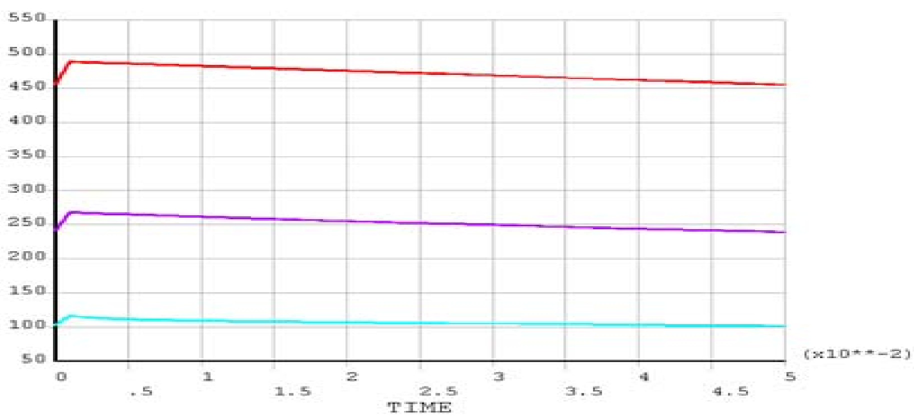
Figure 2: Cold-plate cooling system

cannelloni ...> panzarotti …> canned tungsten blocks

beam conditions I

Peak temperatures after pulse for cannelloni (conf.1)

during 50 ms



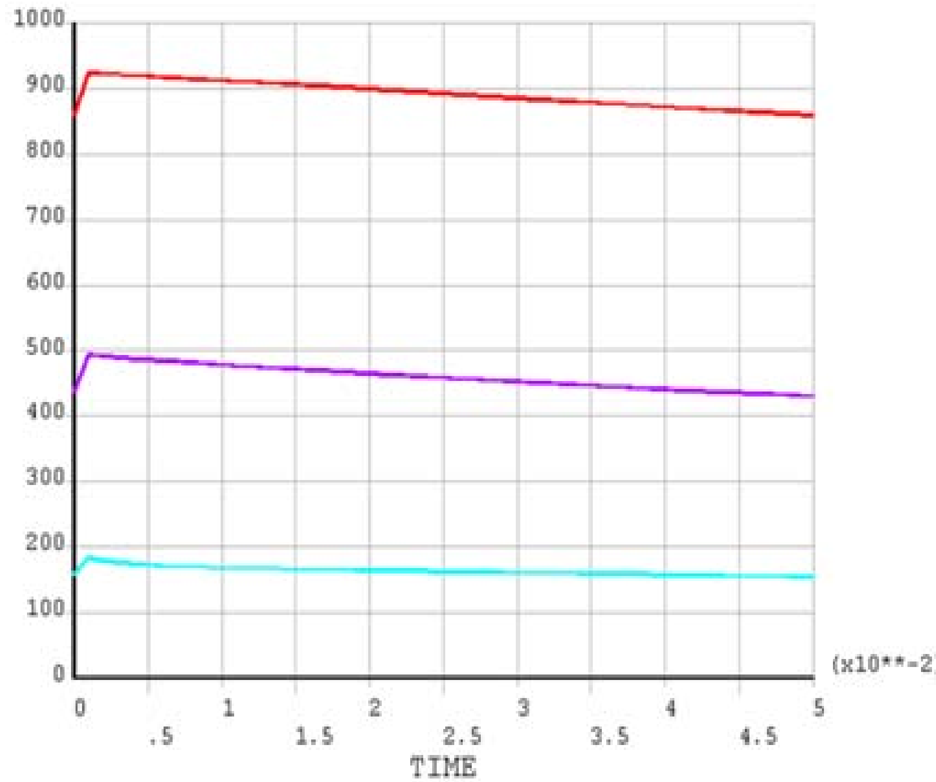
Temperature Cannelloni external surface

Temperature Cannelloni internal surface

Temperature in Pb Center

Mean current density: 21.2 µA/cm²

sigma_x * sigma_y = 50 x 30 mm



Mean current density: 42.4 µA/cm²

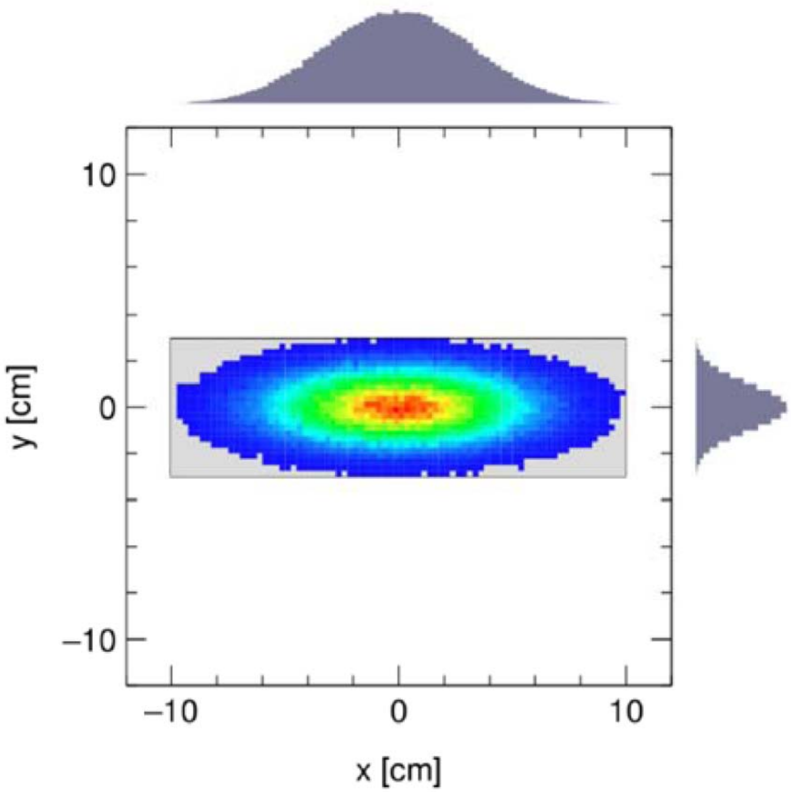
(for maximum loaded location)

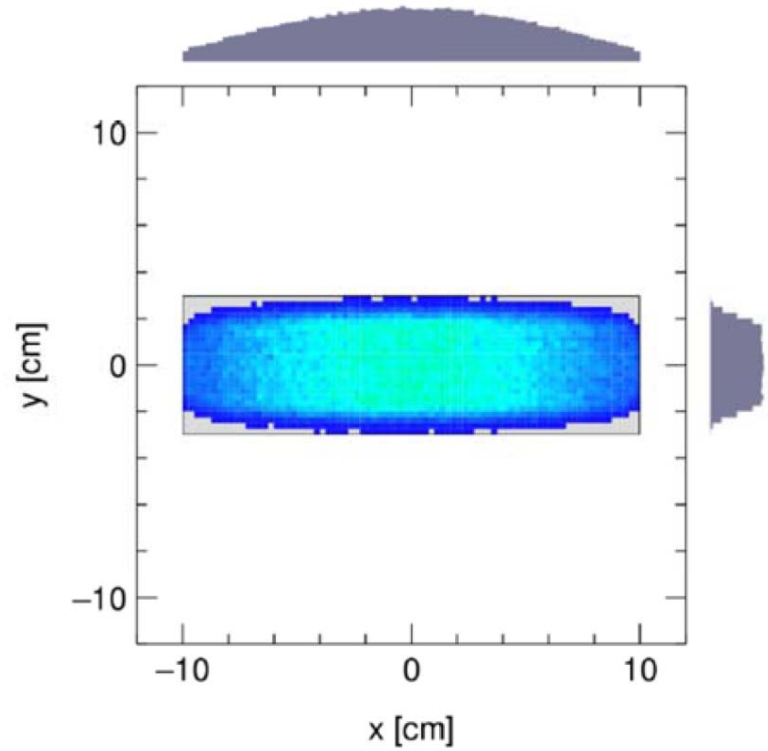
sigma_x * sigma_y = 50 x 15 mm

A wide / flat beam profile relaxes conditions significantly for any target

there are ways to improve on the reference beam:

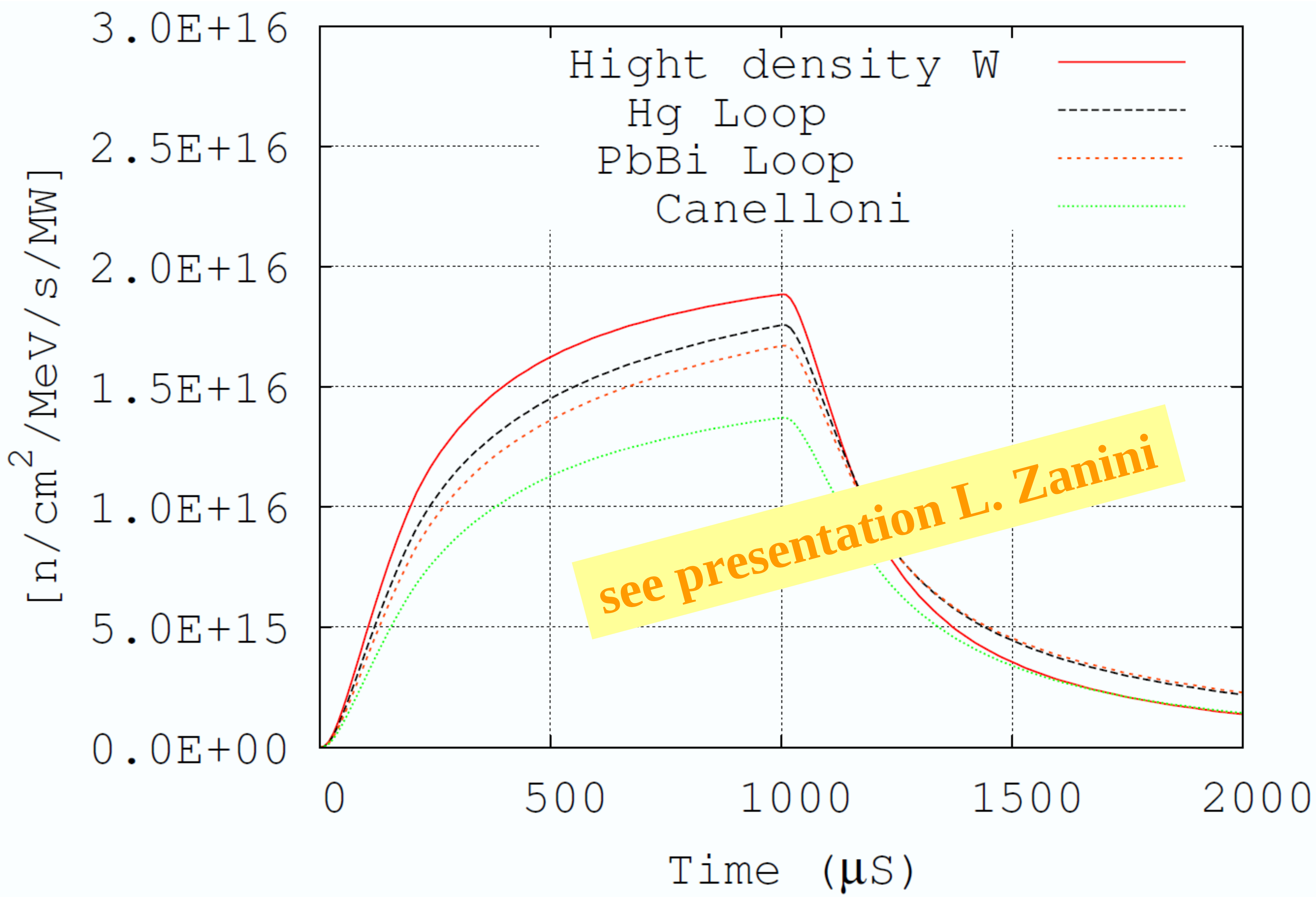
Reference conditions:
5 MW, 2.5 GeV, 2mA (average),
sigmaX=5 cm, sigmaY=1.5 cm,
duration 1 ms, repetition rate 20 Hz
peak current density: 42.44 µA/cm²





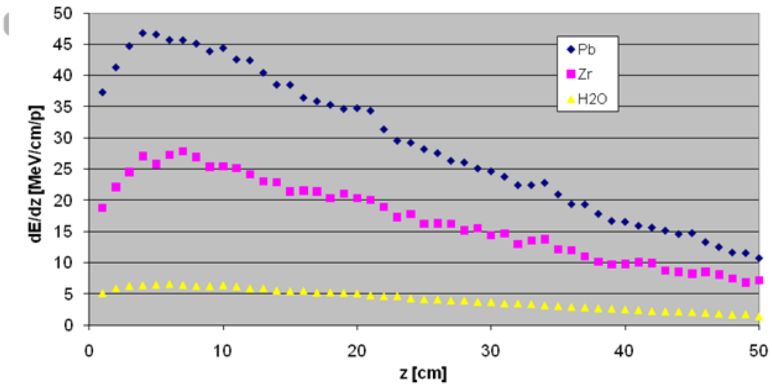
- **adding 2 octupoles in HEBT already reduces peak by 35 %**
- **with a sophisticated multipole system a flat profile (+/- 7 %) over 200x50 mm can probably be achieved**

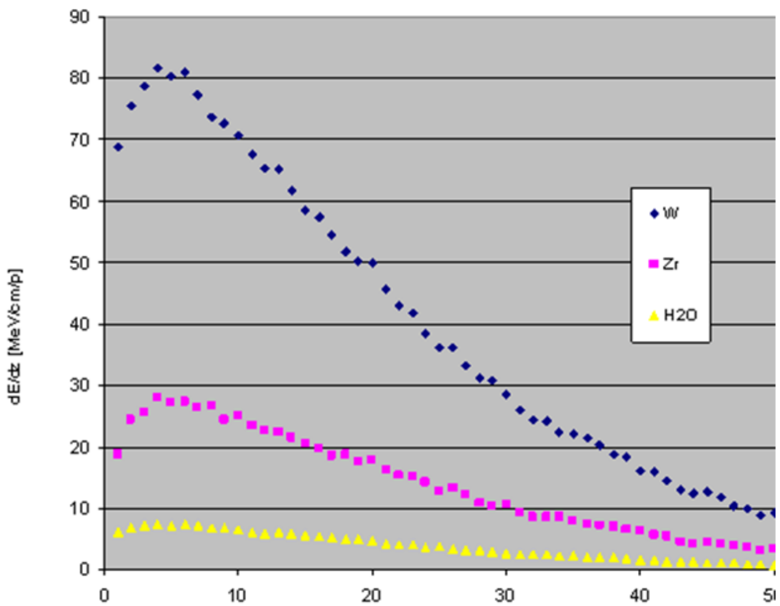
Preliminary result: Cannelloni produce 82 % of LBE
(H_2O coolant, lead filling)



replacing lead by tungsten increases density & brilliance and neutronic yield:

Energy deposit (Pb-Cannelloni) @ 2500 MeV





Energy deposit (W-Cannelloni) @ 2500 MeV

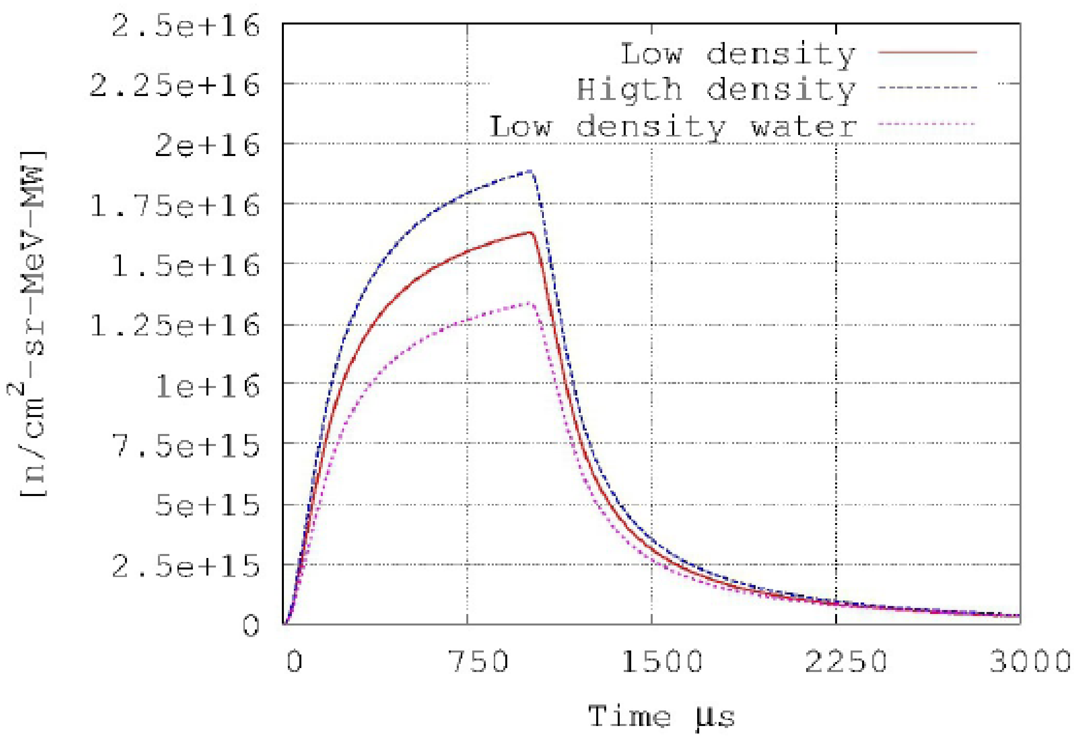


Figure 58: Brightness at 10 meV on moderator surface. Pulse length 1 ms.

example geometry full wheel:

100% tungsten

75 % tungsten

75 % tungsten & 25 % light water

Cannelloni offer minimum risk and maximum safety

- Limited development required (14 years in SINQ)
- Very high availabilty proven / expected
- Water-cooling offers relatively convenient handling
- **Cannelloni open widest options for improvements**

  (e.g. Cannelloni on a wheel can handle > 5 MW)
- Low building-, operations- and decommissioning cost
- Licensing and public acceptance are relatively easy
- Price to pay: some initial reduction in neutronic yield

Suggested Further Steps:

- **Simulations:**

  Optimize Geometry / Coupling for Cannelloni Target

  (Target, Moderator, Reflector, Beam Lines, Shielding)

- **Simulations & Experiments:**

  Verify Cooling Limits in Representative Set-Up(s)

- **Re-Assessment:**

  Size of & Response to Repetitive Stresses

- **Urge Linac to provide Least Pointed Beam Profile**

Acknowledgements

G. Heidenreich, K. Geissmann, and many more

3 more slides on criteria / evaluation

Cannelloni in the light of main Selection Criteria, OVERVIEW

Criterion	Pro	Con	remarks
Cost (building, op., decom.)	X		Low, relatively conventional water cooling
Performance		x	Limited, “diluted target“
Safety	X		High, lead, water and zircaloy make the least harmfull inventory reasonable possible
Devel. Risk	X		Low, 14 years of SINQ experience
Availability	X		High, quick replacement on wheel
Maintainability	X		High, hands-on access to cooling circuits
Upgradeability	X		High, e.g. via wheel speed up to high power

Cannelloni in the light of main Selection Criteria, SAFETY

Criterion	Pro	Con	remarks
Chemical toxicity	X		Relatively low, during operations limited Hg produced
Radio-toxicity	X		Relatively low, during operations limited Po produced
Release in op.	X		Low, only limited tritium
Release in acc.	X		Low, inventory well contained in tiny portions, low decay heat
Radiation exp.	X		Low, cooling with water
Handling	X		Most hands-on, only small inserts (or wheel) require relatively small hot cell and remote handling
Decomm. & Disp.	X		Established, relatively easy

Cannelloni in the light of some more prop. Selection Criteria

Criterion	Pro	Con	remarks
Failure tolerance	X		High, quick replacement (on wheel)
Flexibility	X		Example: SINQ, wheel opens many options
Public acceptance	X		High, (PSI experience)
Licensing	X		Comparatively easy, (PSI experience)
Damage potential to facility	X		Low, solid lead, water
Instrumentation	X		Established, relatively easy