Completion of Water-Cooled Backup Study

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TAC-10

Outline

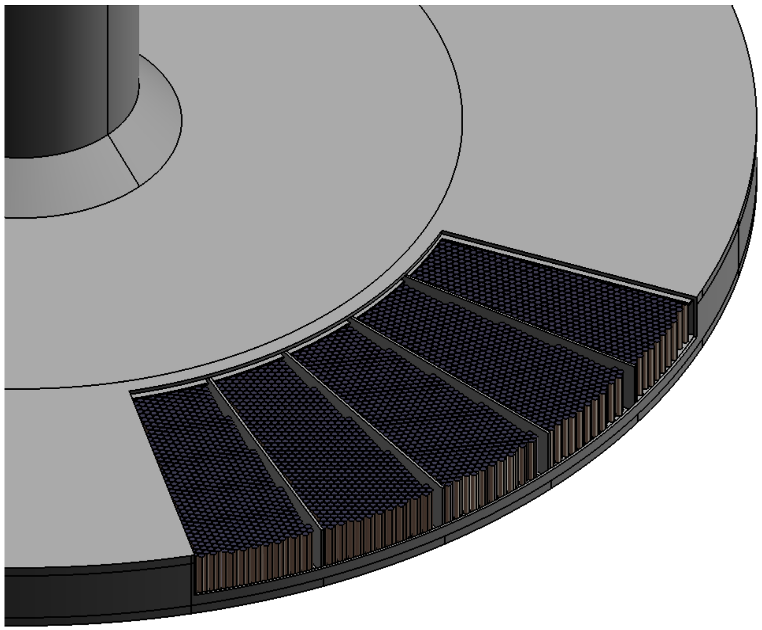
- Background
- Geometry selected for evaluation
- Neutronic performance
- Thermal and stress analyses
- Passive decay heat removal assessment
- Operational issues
- Concluding remarks

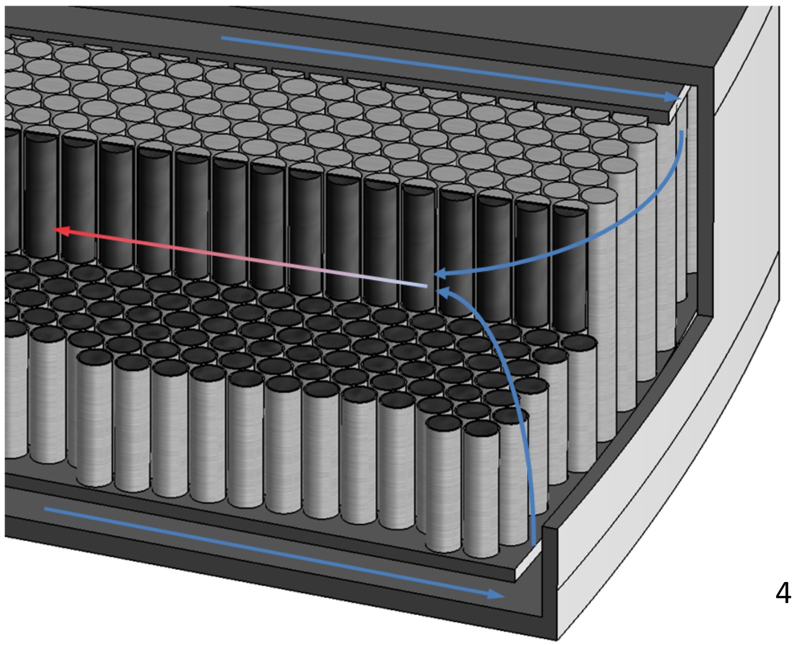
Background

- ESS baseline is a helium-cooled rotating tungsten target
- A backup water-cooled option has been evaluated as a hedge against unforeseen technical risks of the helium-cooled option
- A Water Task Force, chaired by Peter Sievers, was formed to evaluate the water-cooled option, with expertise from ESS, ESS-Bilbao, FZJ, RAL, KIT, PSI, and McManamy Consulting

Design selected for evaluation: cross-flow cannelloni geometry à la PSI SINQ target

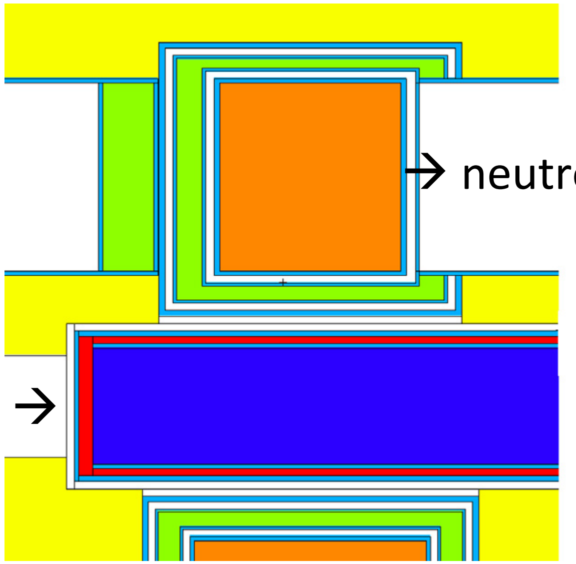
- Zircaloy-clad tungsten with helium-filled gap
  - Tungsten rod dimensions: 10 mm ø by 80 mm tall
  - Clad thickness: 0.5 mm
- Packing fractions: 61% W, 14% Zr, 25% D_2O
- Target wheel segmentation into 33 sectors



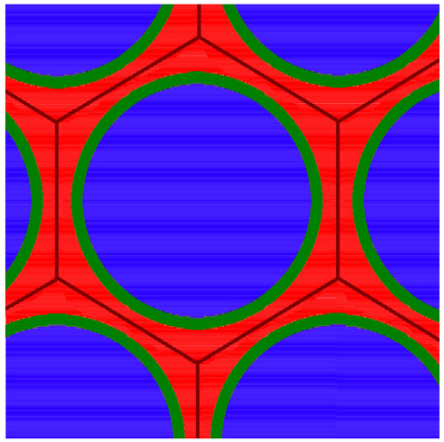


Neutronic performance

- Cold source brightness of the water-cooled cannelloni geometry is 86% of that for the baseline helium-cooled geometry
- Lower performance principally attributed to the lower tungsten volume fraction

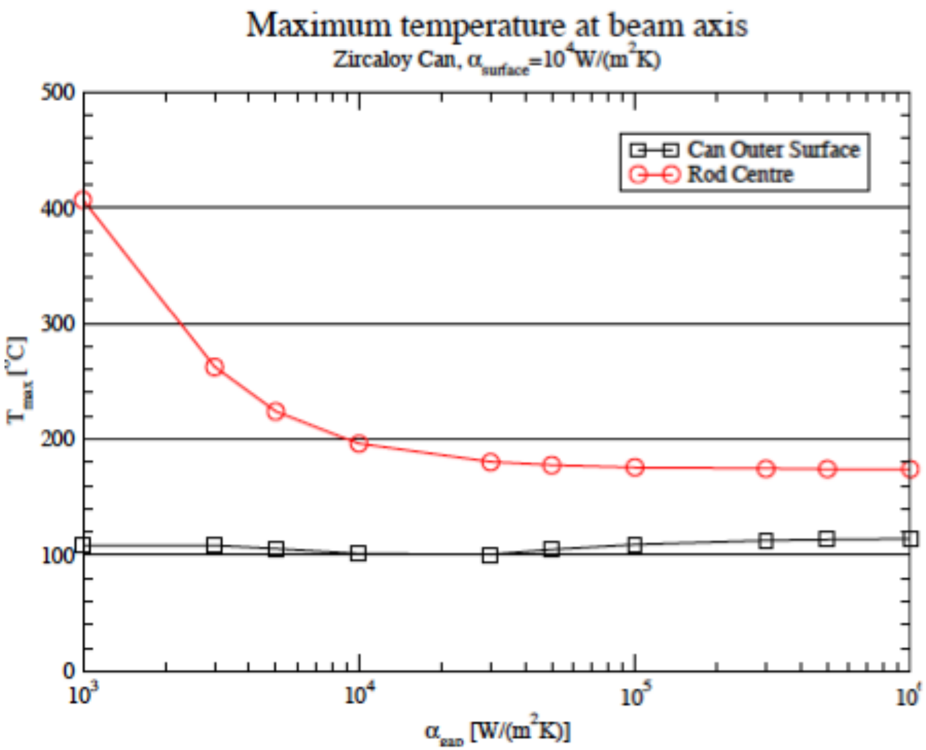


Modelling detail of cannelloni



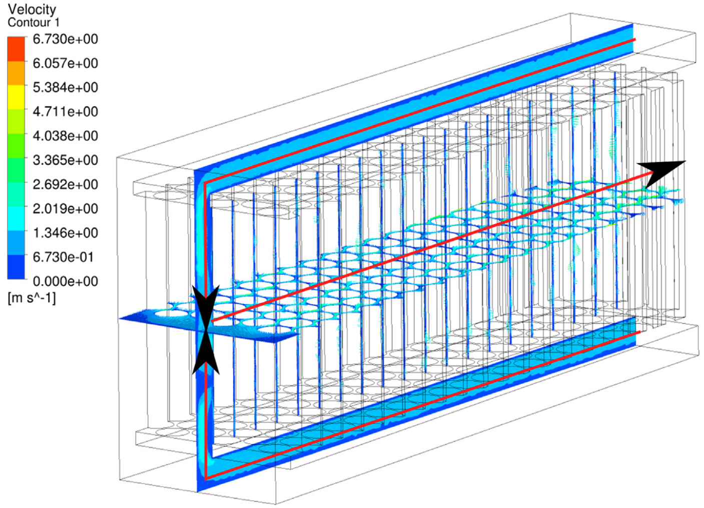
Tungsten temperature depends on the thermal contact at the tungsten-zircaloy interface

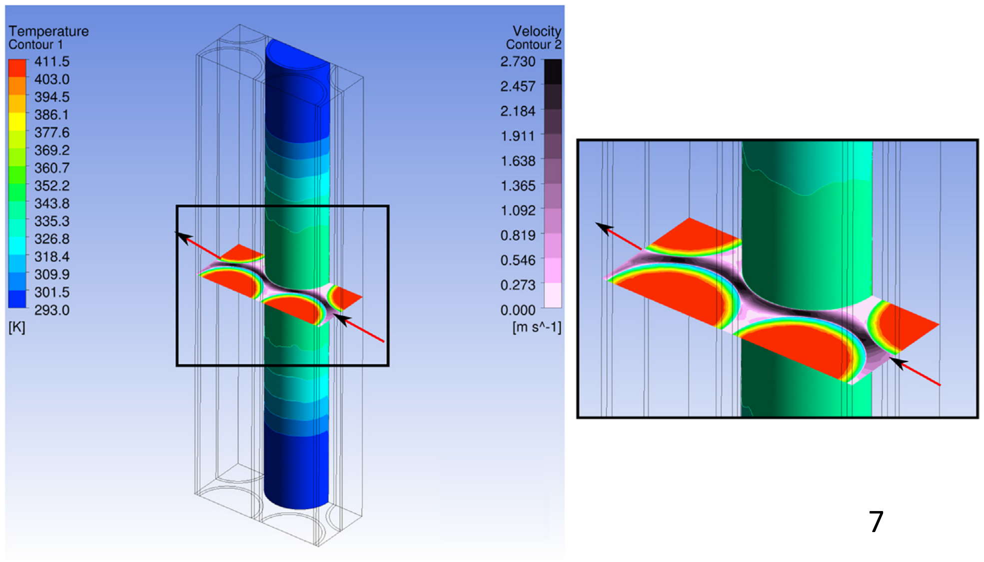
- The conductance between tungsten and zircaloy is weakly dependent on the contact pressure between 0.1 and 10 MPa
- Concern about the residual stresses in the zircaloy tube from press fitting motivates a 10-µm gap filled with 1 bar helium, for which the gap conductance is $2 \cdot 10^4$ W/m$^2 \cdot$K
- Sensitivity analysis shows the peak tungsten temperature is only weakly dependent on the gap conductance so long as it exceeds 10^4 W/m$^2 \cdot$K



Transient CFD simulations under pulsed proton beam conditions

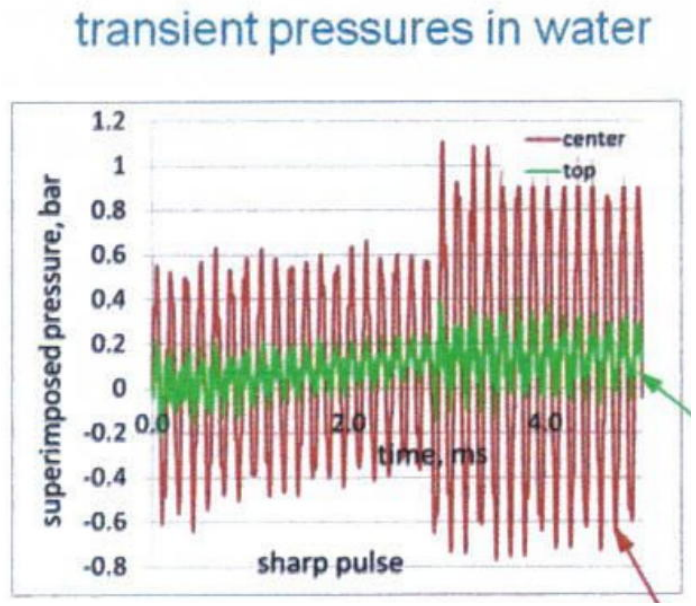
- Post-pulse temperature on the zircaloy tube is <110°C, below the boiling point of water pressurized to ≥0.2 MPa
- Quasi-steady state simulations show the maximum post-pulse von Mises stress is ~30 MPa in the zircaloy tube and <70 MPa in the tungsten core
- Maximum stress in the zircaloy tube is about half of the zircaloy-4 fatigue limit
- Peak stress in the tungsten core is about 10% of the yield stress





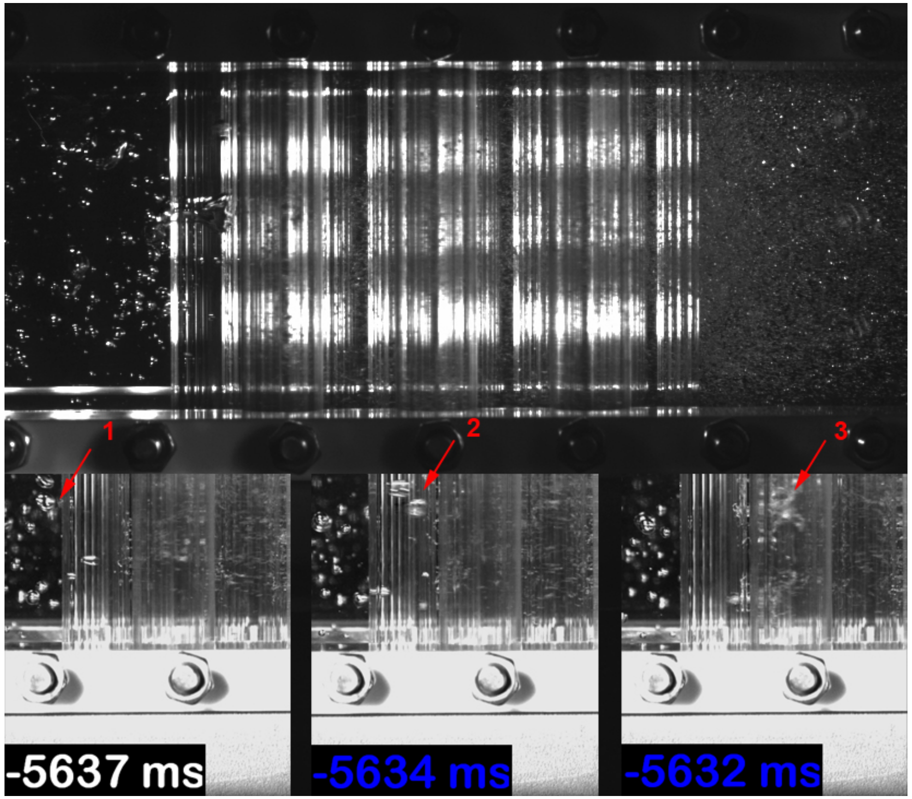
Transient pressure pulses in the water are not expected to be an issue

- Power per pulse:
  - ESS: 357 kJ in 2.86 ms
  - SNS: 23 kJ in 0.7 µs
  - LANSCE and ISIS: 3 kJ in <1 µs
- Transient pressure pulses in the water due to:
  - Thermal expansion of the water from a 4 K temperature increase
  - Thermal expansion of the cannelloni
- Analysis of confined water volume gives rise to pressures >1 MPa
- Unconfined water should greatly reduce pressure pulses



Experimental investigation of flow choking due to film boiling

- Experimental set-up: glass tube immersed in water flow
- Air or vapor bubbles introduced at the water inflow
- Air bubbles: entrained in the water, no choking
- Vapor bubbles: collapsed within 1 s
- Conclusion: flow choking is not likely for cannelloni design



Passive decay heat removal is an important safety attribute for the target

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- Maintaining tungsten below 700°C during a loss-of-coolant accident (LOCA) confines the vast majority of radionuclides to the tungsten
- ESS-Bilbao calculated decay heat data for the cannelloni geometry (45 kW at beam shutdown)
- Decay heat removal analyses were performed based on 2-D axisymmetric models

Group	SS316 emissivity	Steel shielding emissivity	Initial W temperature (°C)	Initial steel shield temp (°C)	Gap composition in double-walled shroud	Time dependence of shield temperature	Maximum tungsten temperature (°C)
ESS-Bilbao	0.66		25	25	20v% SS316 80v% water vapor	Actively cooled to 25°C	400
McManamy Consulting	0.6	0.4	100	50	100v% water vapor	No active cooling, serves as ultimate heat sink	530

Calculations indicate that passive cooling is sufficient for decay heat removal

EUROPEAN SPALLATION SOURCE

- Sensitivity analyses performed by McManamy:

Case	SS316 emissivity	Steel shielding emissivity	Shroud interstitial gap (mm)	Shroud interstitial gap material composition	Gap between shroud & shielding (mm)	Maximum tungsten temp (°C)
1	0.66	0.4	5	water vapor	20	530
2	0.3	0.3	5	water vapor	20	635
3	0.66	0.66	5	20v% SS316 80v% water vapor	20	380
4	0.1	0.3	5	20v% SS316 80v% water vapor	15	607

- Ribs between walls are important conduction paths
- Conclusion: Passive cooling of the decay heat is viable for the water-cooled backup
- Impact of the moderator-reflector system on decay heat removal from the target not analyzed, but will be for the helium-cooled option

Passive cooling is sufficient for removal of decay heat

- There was concern that safety of the water-cooled option could only be satisfied using active removal of decay heat
- The results indicate that decay heat can be removed passively, but the margin with passive cooling is not huge
- SSM condition for the start of construction is predicated on the successful realization of the helium-cooled tungsten target
  - Licensing for water-cooled option would not be automatic, and would only work if helium is proved impractical (larger margins)

Operational Issues

EUROPEAN SPALLATION SOURCE

- Scaling the water plant from existing spallation source facilities to ESS conditions should be straightforward
- Assuming 10% of tungsten-produced tritium diffuses into the heavy water produces a concentration of ~7 GBq/kg per year of operation, which is <1% of the concentration levels found in heavy water fission reactors

Concluding Remarks

- A water-cooled rotating tungsten target appears viable in terms of:
  - Neutronics
  - Thermal-hydraulics
  - Mechanical design
  - Safety
  - Operations
- Decay heat can be removed passively, but the margin with passive cooling is not huge
- The water-cooled option will be retained as a viable backup to the baseline helium-cooled option