Evolution of the MYRRHA Spallation target design

From windowless loop to loopless window

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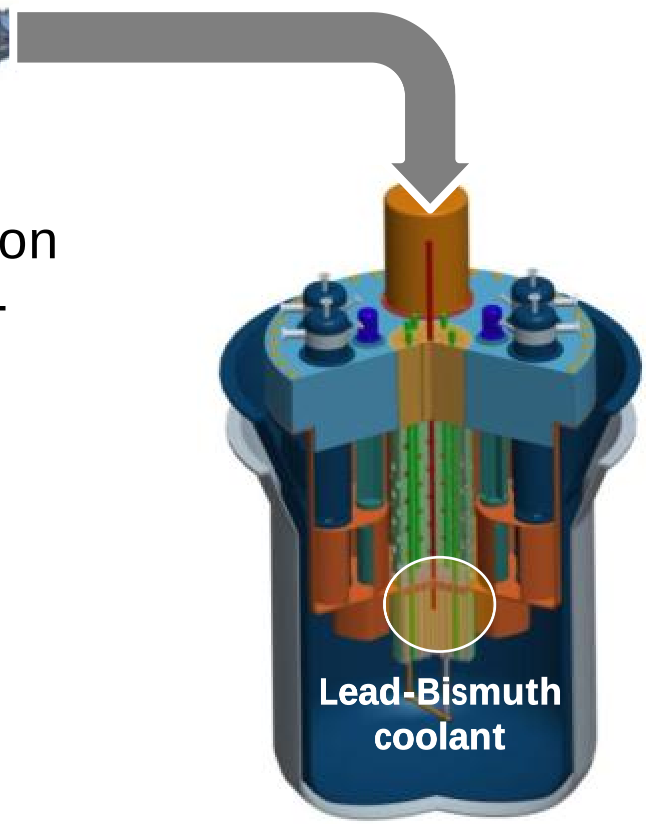
MYRRHA - Accelerator Driven System

Accelerator

(600 MeV - 4 mA proton)

Reactor

- Subcritical or Critical modes
- 65 to 100 MWth



- Demonstrate the ADS concept (coupling accelerator +spallation source + powerreactor) at pre-industrial scale
- Demonstrate Transmutation (experimental fuel assemblies)
- Fast neutron source: Multipurpose and flexible Irradiaton facility

Outline

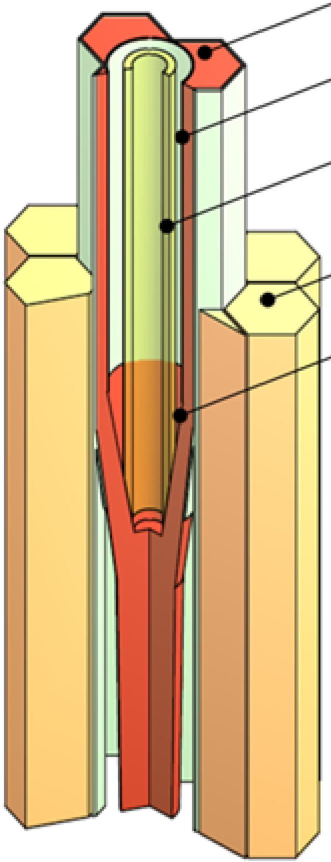
- Spallation target assembly requirements
- MYRRHA XT-ADS windowless spallation loop
- MEGAPIE experience feedback
- MYRRHA FASTEF spallation target assembly design
- R&D subjects related Spallation target assembly

Spallation target assembly requirements

- Produce sufficient neutrons by interaction of beam with target to feed subcritical core (goal k_{eff}=0,95)
- Guide proton beam to centre of subcritical core
- Guarantee cooling of the target zone
- Enable flexible operation of the reactor

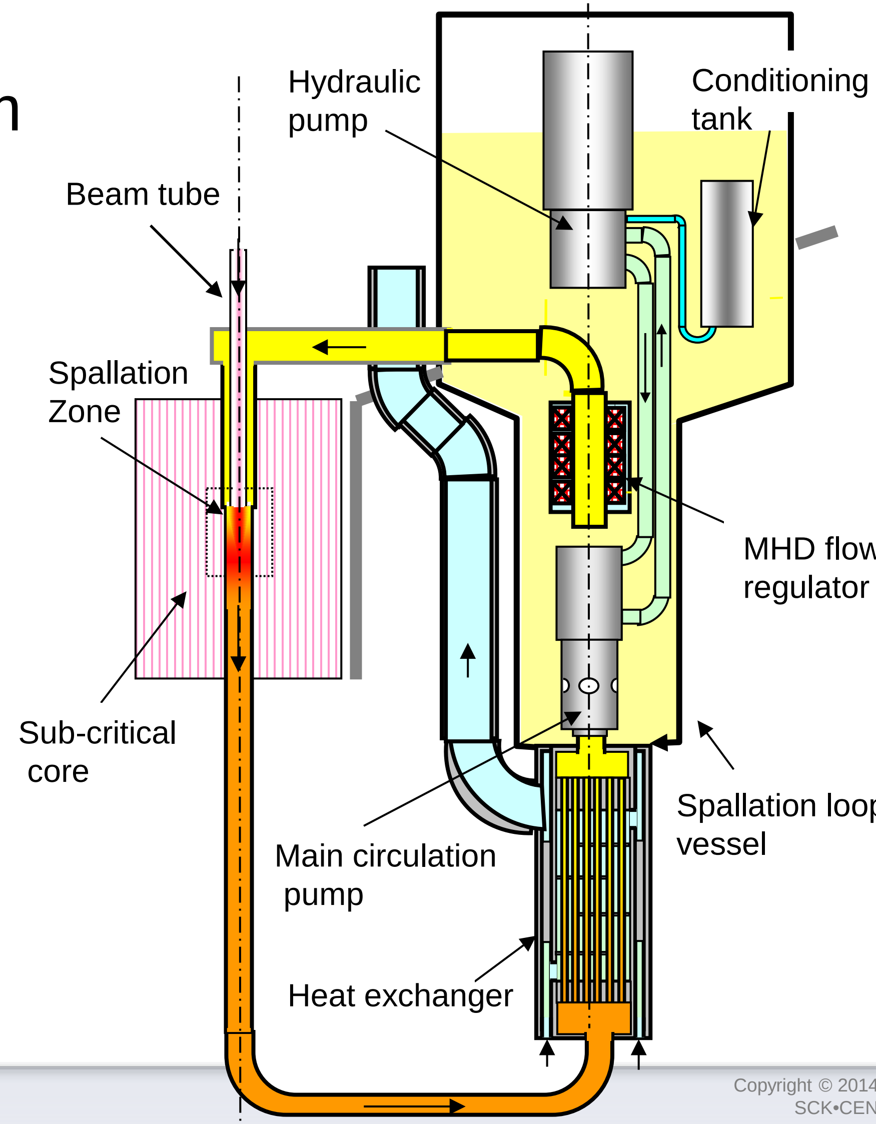
(2008)
MYRRHA XT-ADS windowless spallation loop

- Initial accelerator : Cyclotron of 350 MeV
  - High energy deposition in structural materials
  - Unacceptable irradiation damage in window
- Solution : Design without window
  - Dedicated closed Lead Bismuth target loop
  - Proton beam enters target at free surface
  - 3 central core positions

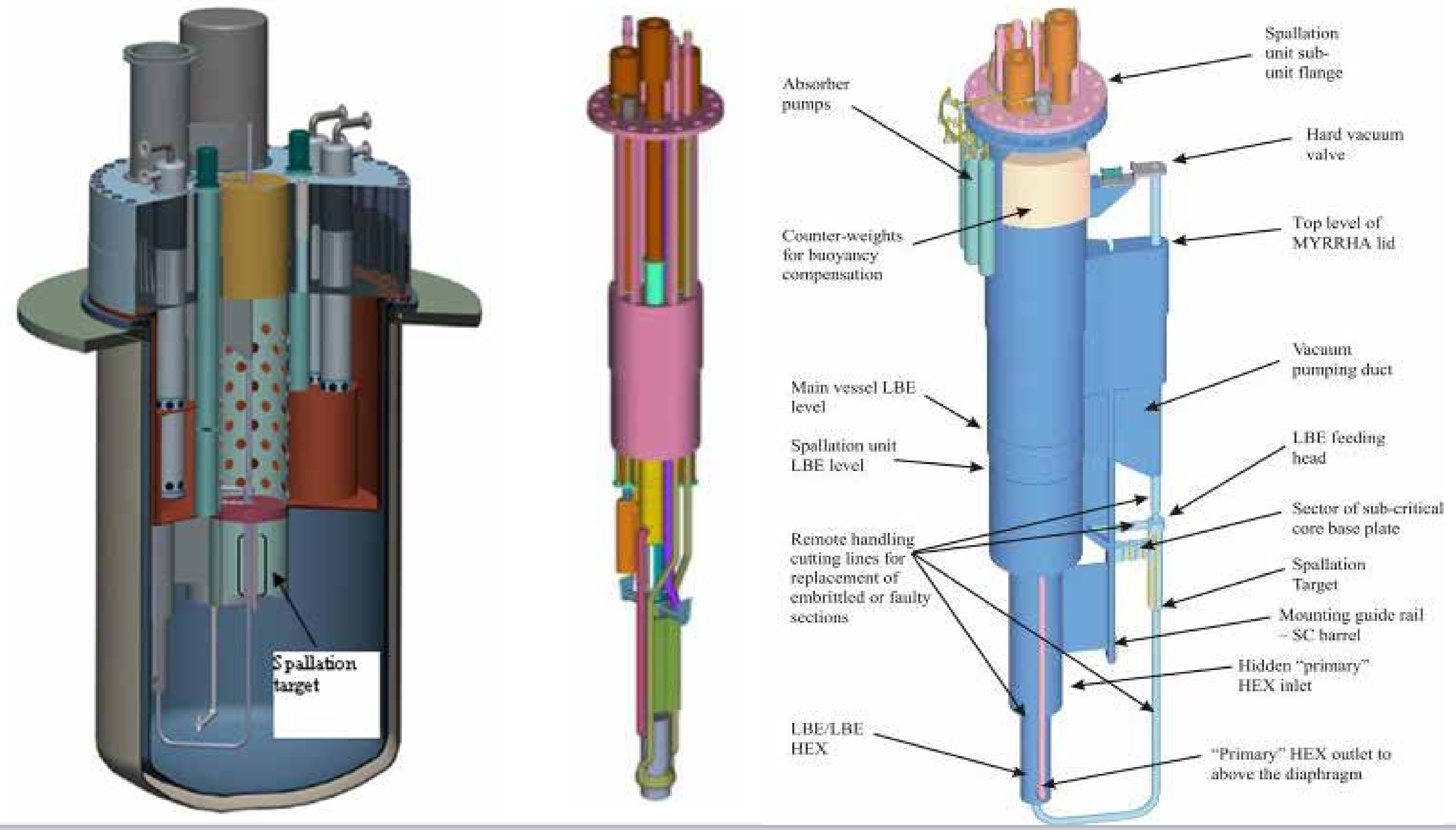


MYRRHA XT-ADS windowless spallation loop

- Inventive but complex system
  - Loop closed around the core
  - Components submerged in LBE
  - Challenging control of free surface level, recirculation, splashing and evaporation
  - Removable sub-unit with active components for maintenance
  - High irradiation damage of structural parts



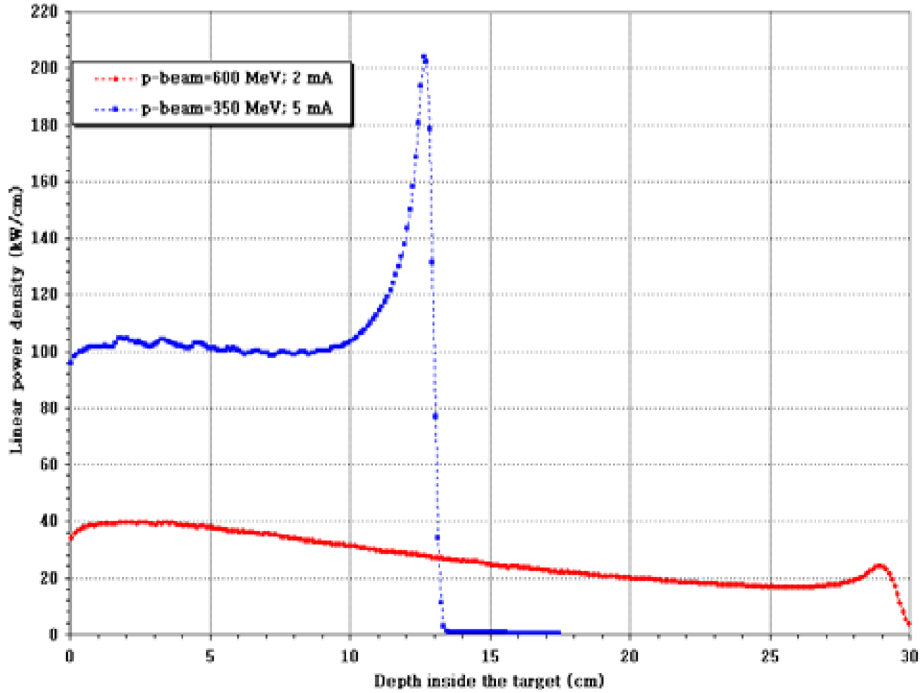
MYRRHA XT-ADS windowless spallation loop



To loopless window spallation target

- Change from cyclotron to linac (1998-2003...)
  - Beam power increased from 350 to 600 MeV (2003-2008)
  - Re-evaluation of concept Windowless-Window (2009-...)

Proton energy [MeV]	350	600
Source neutron yield per incident proton	5.8	14.6
Beam current [mA]	5	2
Beam power [MW]	1.75	1.2
Fraction of heat deposit in target zone [%]	81.7	62
Convective cooling [MW]	1.43	0.75
Bragg peak/plateau	2	0.5



MEGAwatt PIlot Experiment

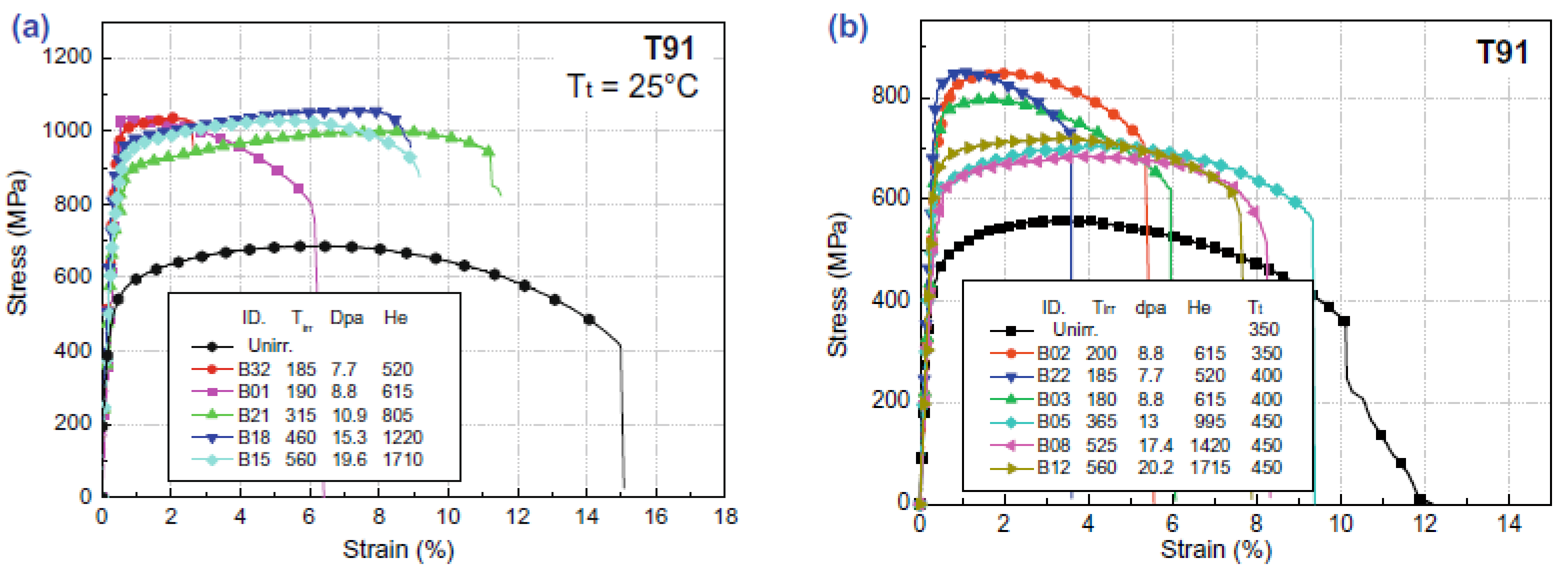
- SCK•CEN participated from the beginning of the project
  - Design of temperature control system
  - Material research

MEGAPIE experience feedback

- Material selection
  - Choice for T91 window
- Design methods
  - Proof of simulation tools
    - Neutronics (MCNPX)
    - Thermal hydraulics (CFD)
    - Mechanical analyses (fatigue, FE)
- Material research results

MEGAPIE experience feedback

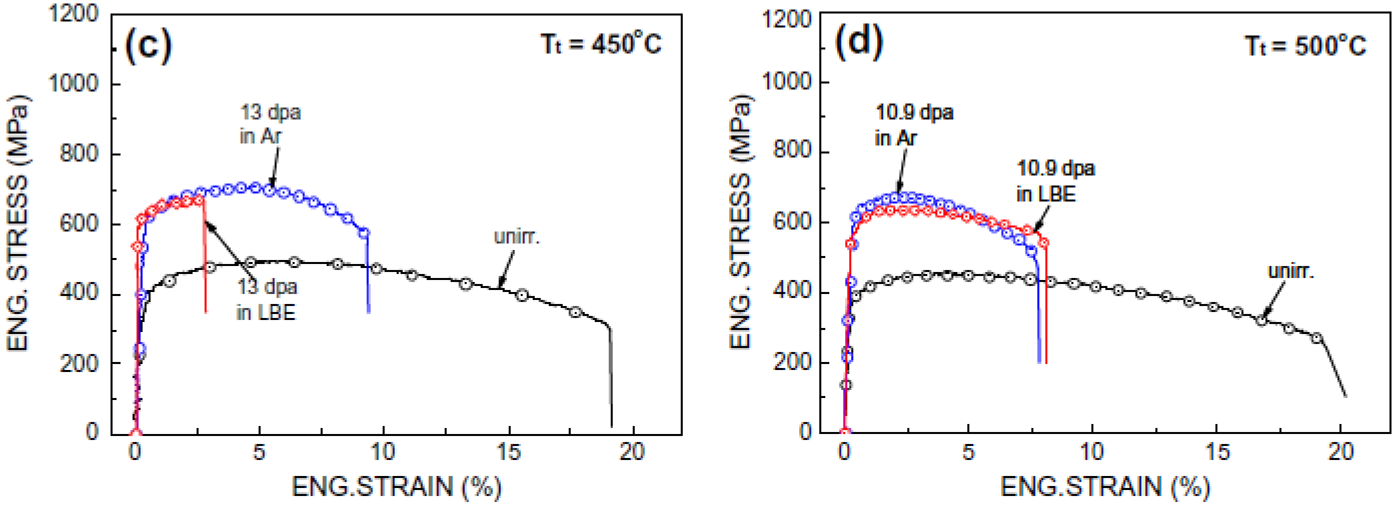
- Effects of proton irradiation on ferritic-martensitic T91
  - He-embrittlement induces shift in DBTT
  - Low temperature irradiation: DBTT(200°C) at about 10 dpa
- STIP-3 : ductility at higher irradiation temperature up to 20dpa



Z. Tong, Y. Dai/ Journal of Nuclear Materials 398 (2010) 43–48

MEGAPIE experience feedback

- Liquid metal embrittlement
  - No additional embrittlement due to LBE at high T (above 450°C)
  - STIP-2 results



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MEGAPIE experience feedback

- LBE corrosion
  - Stringent Oxygen control in MYRRHA
  - Maximum allowed temperature range up to 470°C for structure in contact with LBE (outside window temperature)
  - Slow process, of less relevance for window with limited stand time

MEGAPIE experience feedback

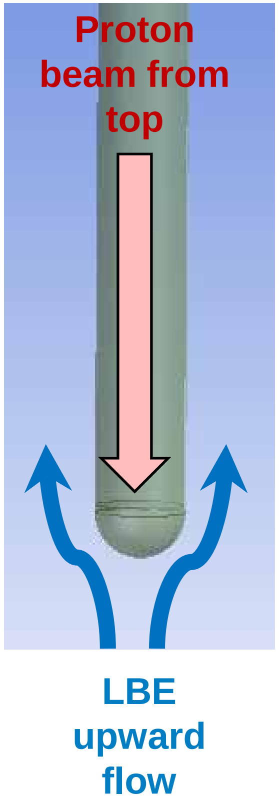
Above all and best proof

- Successful operation record of MEGAPIE
  - 1MW target, 4 months operation 1,74 mA
  - Estimated window temperature around 470°C
  - 10.000 thermal cycles/yr due to beam trips
  - Window loading: 2,8 A.h

Ø **Conclusion: MYRRHA window in T91 at operating temperature range between 450 and 500°C is feasible**

MYRRHA FASTEF spallation target

- Primary coolant LBE as target material
  - No dedicated loop: simplification of design
    - No active components, no free surface,
      no separate LBE conditioning
    - Beam tube ending on hemispheric window T91
      in centre of the core
- Main challenges
  - Limiting material damage
  - Cooling of the target zone
  - Optimisation of window temperature range (stagnation point)

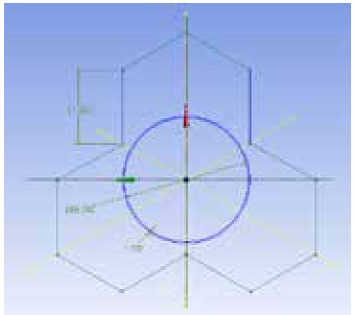


MYRRHA FASTEF spallation target

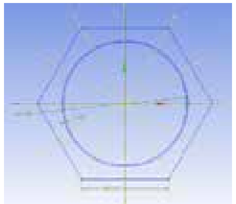
- Goal
  - Minimum 1 cycle or 3 full power months of operation
  - 3,5mA @ 600 MeV
  - Flexibility for operation
    - Spallation target assembly designed as an In Pile Section (IPS)
    - Connected to beam line at reactor cover

MYRRHA FASTEF spallation target

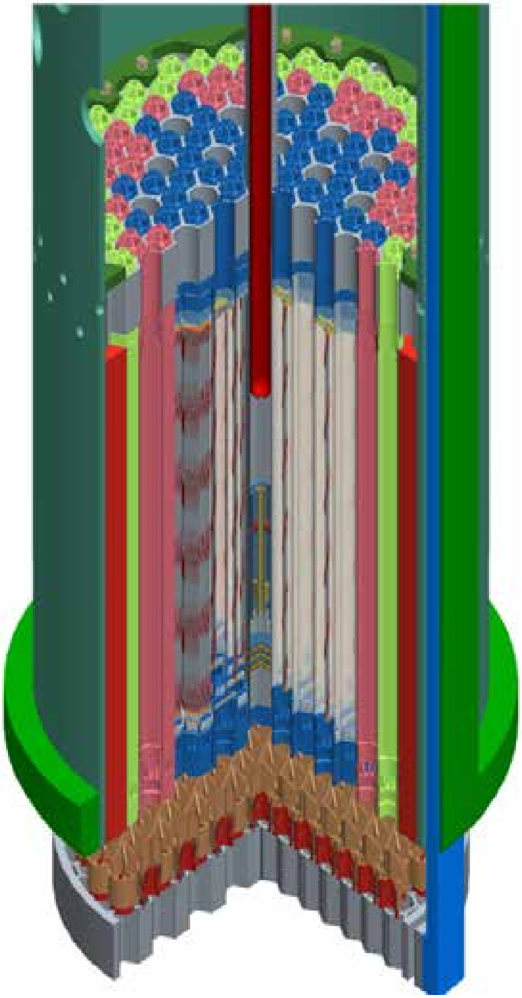
- Power estimation (3,5mA@600MeV)
  - Heat load in LBE : 62% of beam power = 1,3 MW
    - Targeted temperature increase LBE: 200°C (270-470°C)
    - Resulting mass flow rate LBE: 45kg/s
    - Flow area needed (to stay below 2m/s) : 0,022m²



3 central positions of FA with 91 pins



1 central position of FA with 127 pins



- Target fits in 1 core position when FA is enlarged from 91 to 127 pins

MYRRHA FASTEF spallation target

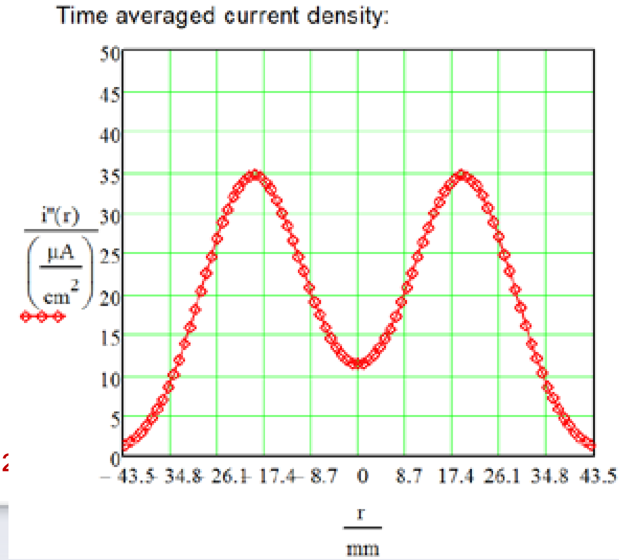
- Current density estimation
  - Beam tube diameter: 87,7mm (remains within 1 position)
  - 3,5mA flat distribution on flat plate : 62µA/cm²
    - Challenging compared to maximum value MEGAPIE of 52µA/cm²

    Material damage 6*30*24*0,052= 225mA.h/cm² peak
- With Gaussian profile, peak load at stagnation point

ð Sweeping Gaussian profile

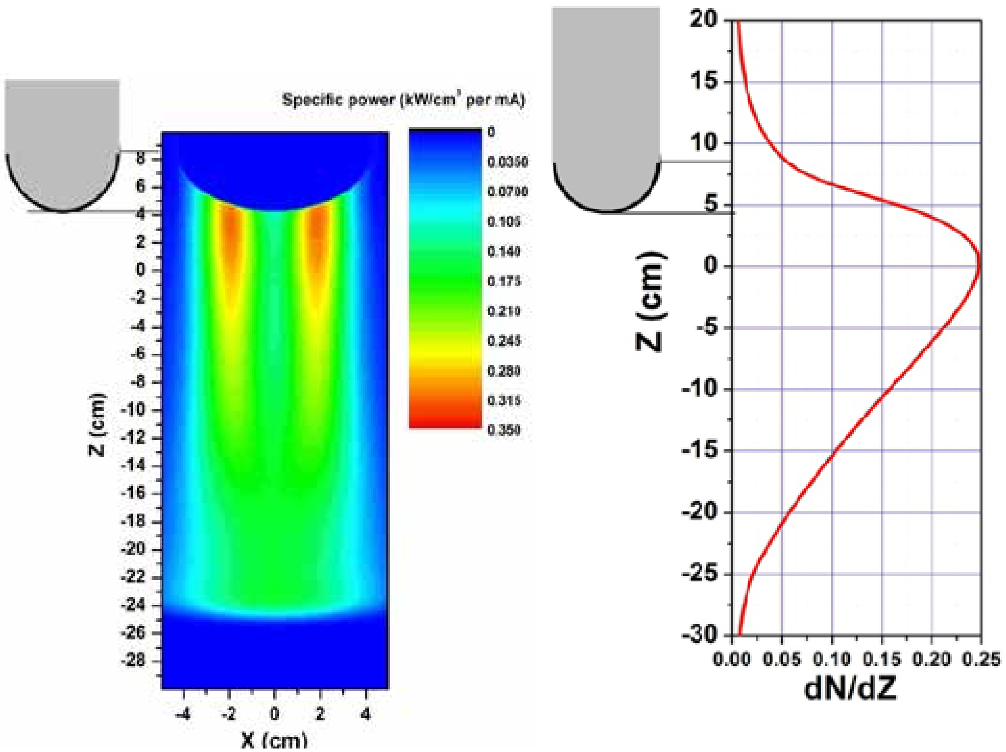
- Sweeping radius 21,5mm
- $\sigma_{Profile}$ 9,5mm
- Maximum current density 35µA/cm²/mA

Material damage 3*30*24*3,5*0,035mA/cm²=265mA.h/cm²



MYRRHA FASTEF spallation target

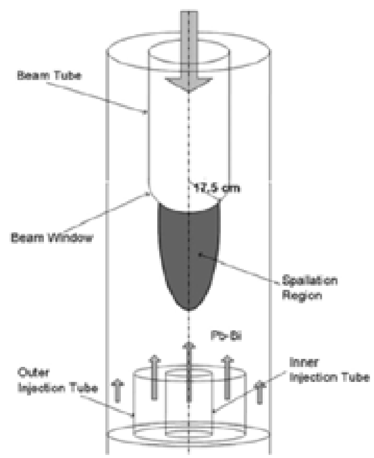
- Detailed simulations MCNPX
  - Neutron production
  - Heat input in LBE
  - Heat input in Window
  - Material damage
    - Helium production
    - Dpa



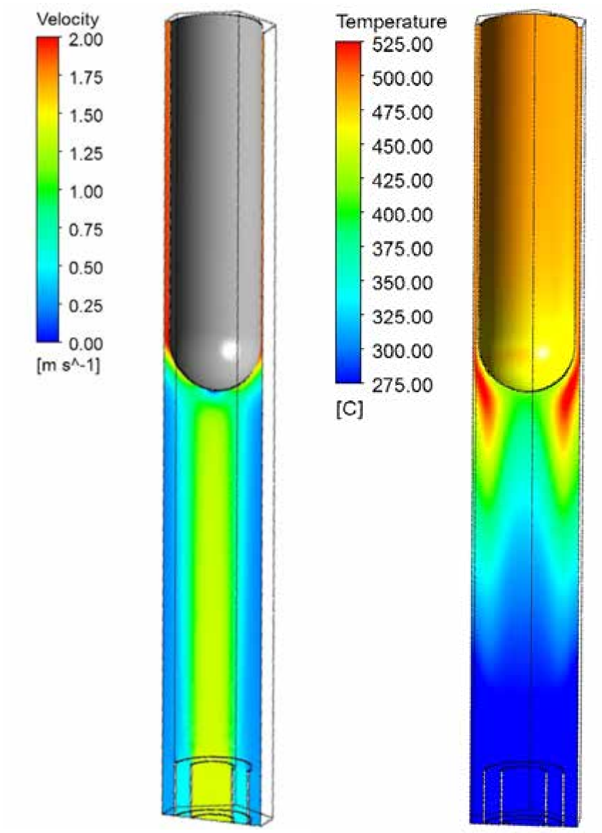
- FASTEF version 1.6
  - 1 Cycle beam current from 1,68 to 2,45mA: 22dpa and 1192 appmHe

MYRRHA FASTEF spallation target

- Detailed simulations CFD
  - Multi tube concept
    - Optimise guide tubes



  - Temperature evaluation LBE, window
  - Velocity verification



R&D subjects related Spallation target assembly

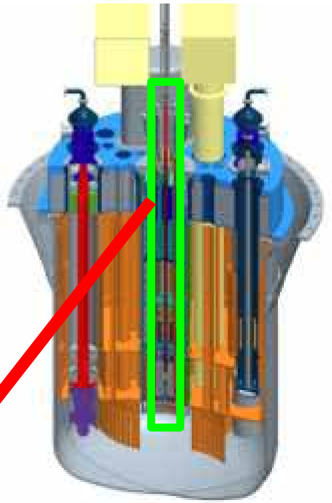
- Feedback experience from MEGAPIE (design, LBE control, material testing, spallation products inventory)

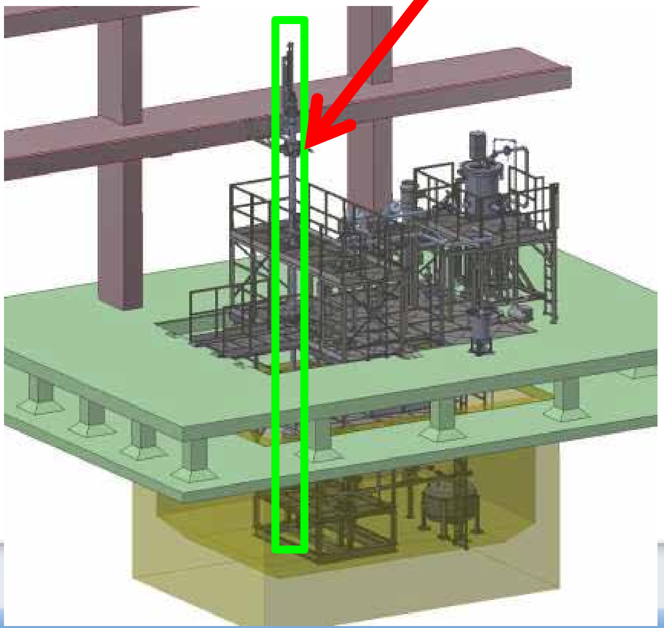
- Window coolability in JLBL-3 loop at JAEA (Tokai, JP)
  - Simulation verification and validation

- Full scale Thermal-hydraulic and mechanical testing in COMPLOT loop at SCK•CEN (Mol, BE):
  - Flow control,
  - Erosion control,
  - Coolability,
  - Flow induced vibration

R&D subjects related Spallation target assembly

- **COMPLOT** = **COM**ponent **LO**op **T**esting
  - Characterisation of hydraulic and hydrodynamic behaviour of full-scale MYRRHA components in LBE
    - Fuel assembly hydraulics
    - **Spallation target hydraulics**
    - Control and safety rod hydrodynamics
    - Characteristics
  - Representing one core position at full height
    - LBE as working fluid
    - Isothermal loop
    - Interchangeable test modules





Conclusions

- The evolution of the MYRRHA spallation target design towards a window design without loop was greatly influenced and only possible by the work done within the MEGAPIE-project and the MEGAPIE-experience

- Don’t hesitate to change your mind
when solving problems with too complex solutions
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