STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

MYRRHA Spallation Target Design and Qualification R&D Programme

Transformative Hadron Beamlines Workshop
July 21st – 23, 2014, BNL, Brookhaven (NY), USA

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Presentation outline

1. Present status of MYRRHA Design
2. Evolution of MYRRHA Spallation target design
   From windowless to window design
3. MYRRHA Window target design
4. MYRRHA Window target support R&D
   Ongoing and new needs
5. Conclusions

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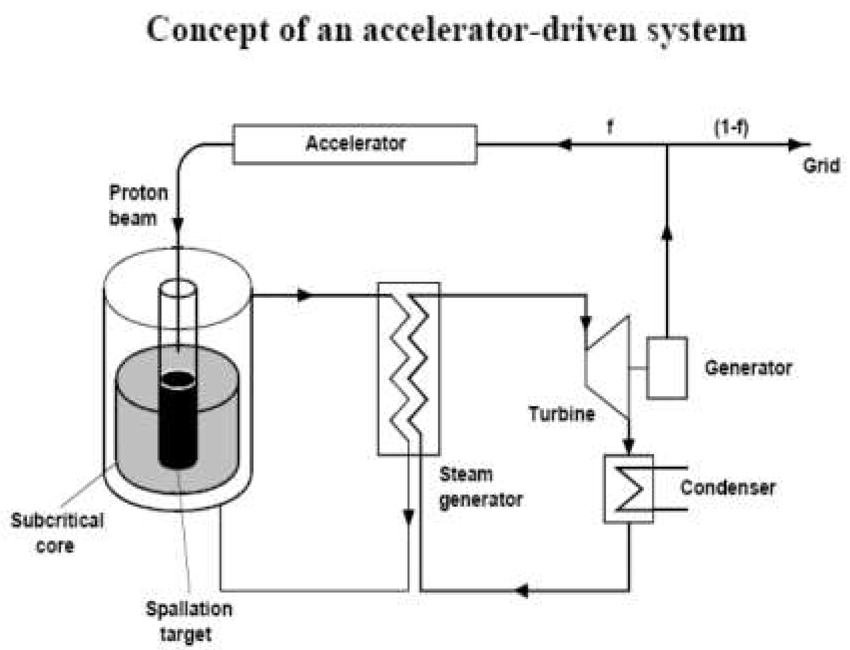
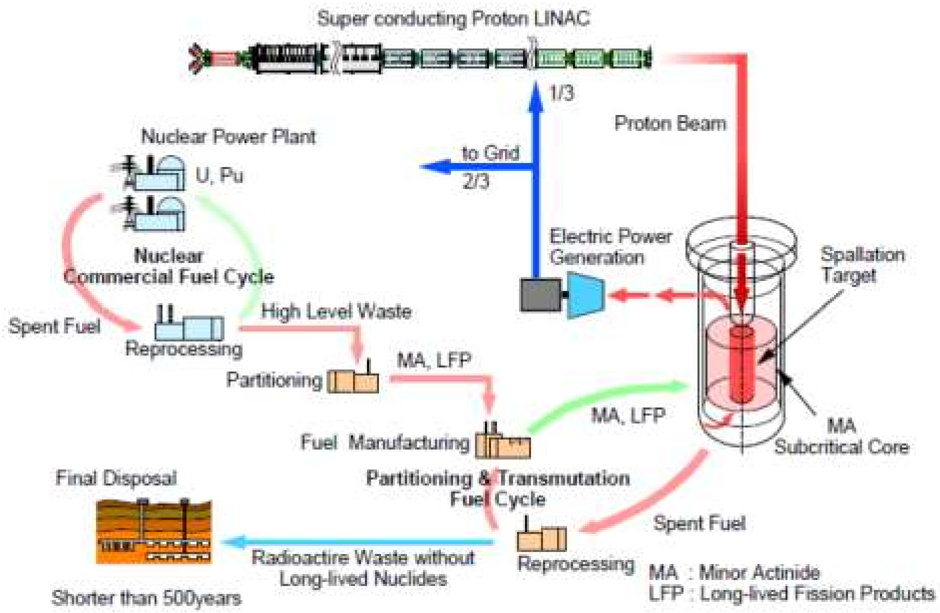




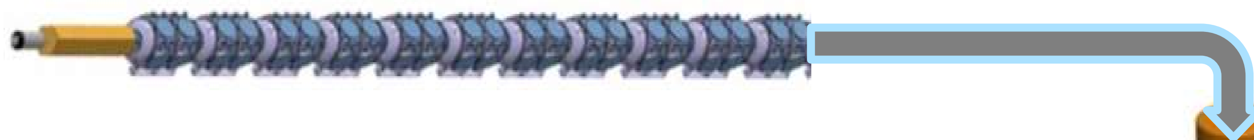
An **Accelerator-Driven-System** is:

- a subcritical neutron multiplication assembly (nuclear reactor, $k_{eff}<1$),
- driven by an external neutron source,
- obtained through the spallation mechanism with high energy (~ 1GeV) protons,
- impinging on massive (high Z) target nuclei (Pb, Pb-Bi, W, Ta, U).

MYRRHA - Accelerator Driven System

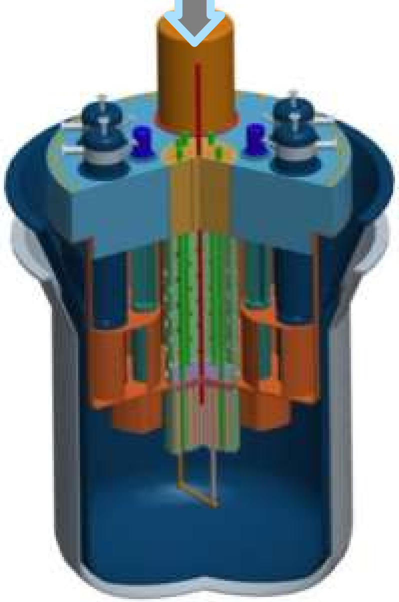
Accelerator	
particles	protons
beam energy	600 MeV
beam current	2.4 to 4 mA
mode	CW
MTBF	> 250 h

Reactor	
power	~85 MW_{th}
k_{eff}	0.95
spectrum	fast (flexible)
fuel	30 to 35% Pu MOX
coolant	LBE

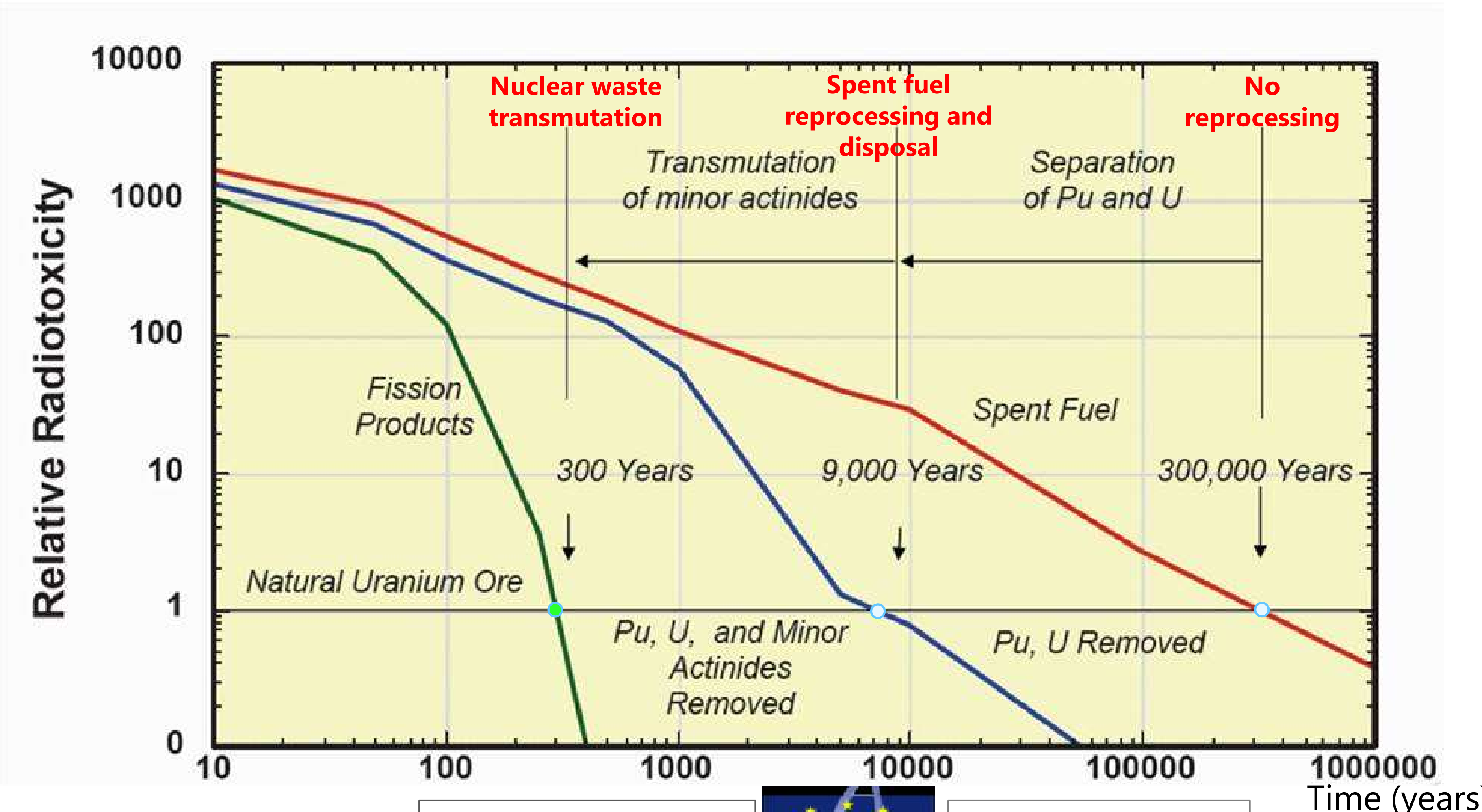


- Demonstrate the **ADS concept** (coupling accelerator + spallation source + power reactor) at pre-indust. scale
- Demonstrate **Transmutation** (experimental fuel assemblies)
- Fast neutron source: **Multipurpose and flexible Irradiaton facility**

Target	
main reaction	spallation
output	$2{\cdot}10^{17}$ n/s
material	LBE (coolant)
power	2.4 MW



Nuclear waste: transmutation impact



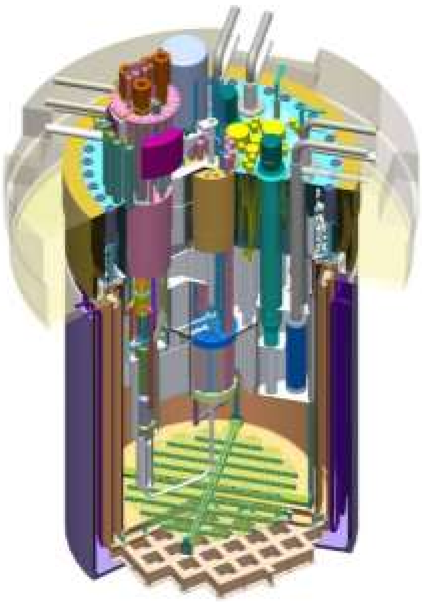
US DOE estimation, LWR fuel, burn-up: 50 GWd/MT, 5 years in-pool cooling

Duration Reduction: 1000x

Volume Reduction: 100x

Design History of the MYRRHA reactor

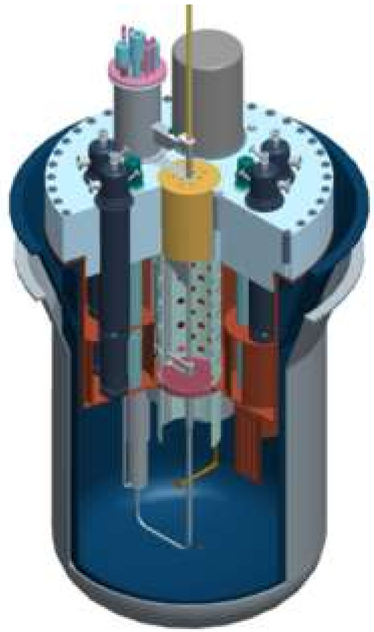
(details see HAA seminar Snyder room Bldg 911A on 7/23/2014)



Draft 2

2005

⇨



XT-ADS

2009

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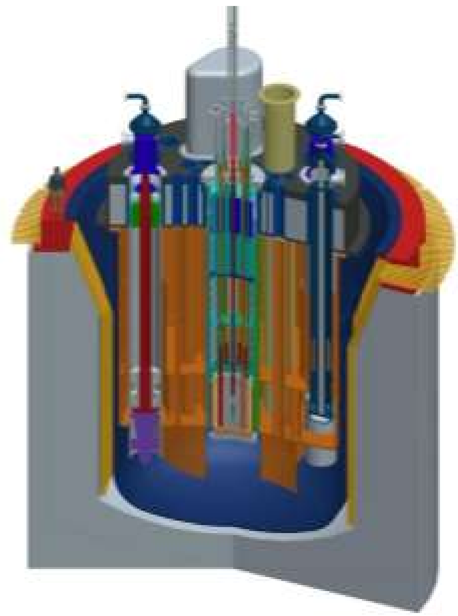

FASTEF

(**CDT Result**)

2012

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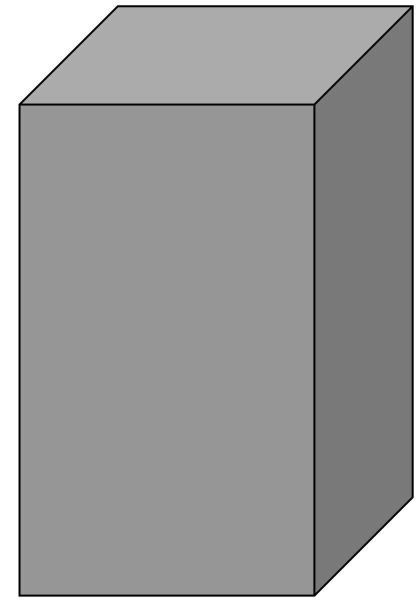


Rev. 1.6

2014

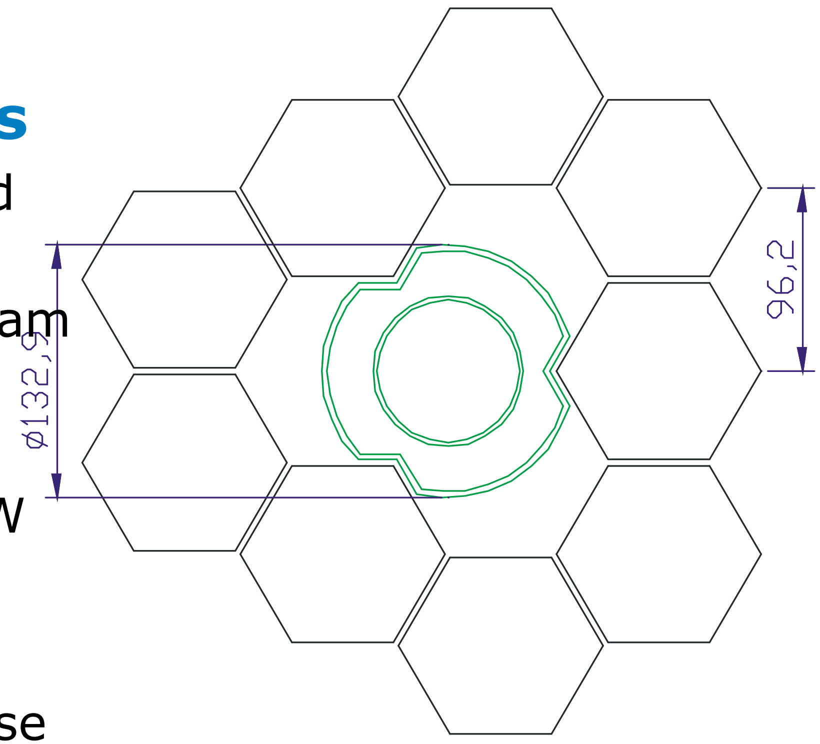
Presentation outline

MYRRHA spallation target evolution from windowless to window design

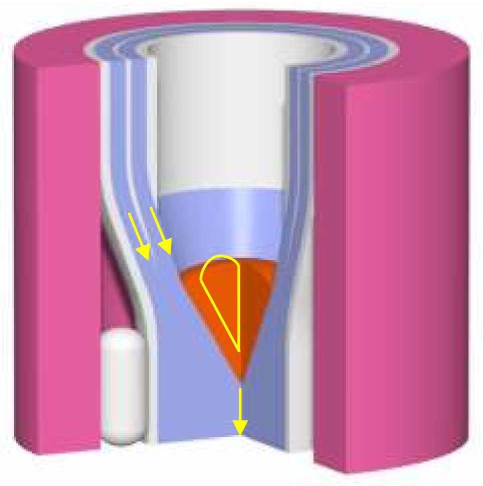
- MYRRHA accelerator technology & beam characteristics
  - Cyclotron (1998 ➔ 2002) towards LINAC (2003 ➔ …) ➔ windowless
  - 350 MeV*5 mA (… ➔ 2008) (windowless) ➔ 600 MeV*2.4 mA ➔ window (2009)
  - Current density > 50 µA/cm^2 (till 2008), no window material can survive ➔ 600 MeV*2.4 mA ➔ window (2009)
- Spallation loop geometry simplification ➔ window (2009)
  - Windowless needed a separate loop to guarantee:
    - Needed LBE flow
    - Avoiding volatile spallation products leaving the free surface to the beam line
    - Avoiding interaction of proton beam with LBE in recirculation zone
- Safety authority requesting the window a barrier

MYRRHA Spallation target design characteristics (… ➔ 2005)

- Spallation Target in the Centre of the ADS
- **Target boundary conditions**
  - Produce ~10^{17} neutrons/s to feed subcritical core @ k_{eff} ≈0.95
  - Accept 350 MeVx5 mA proton beam
  - Space limitation: three central assemblies
  - Evacuate deposited heat 1.43 MW
  - Erosion limit: v_{LBE} < 2.5 m/s
  - Lifetime: ~ 1 year
  - Flexibility in use (MYRRHA purpose as experimental irradiation machine)

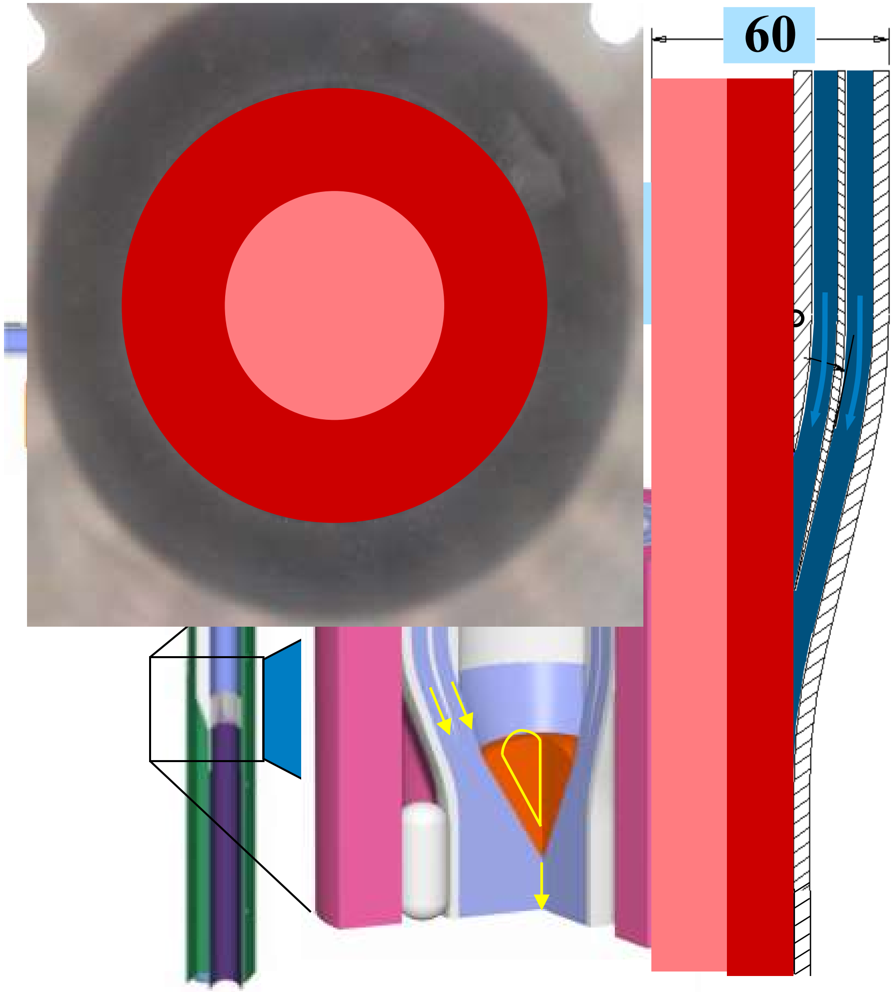


Target Design Conceptual properties



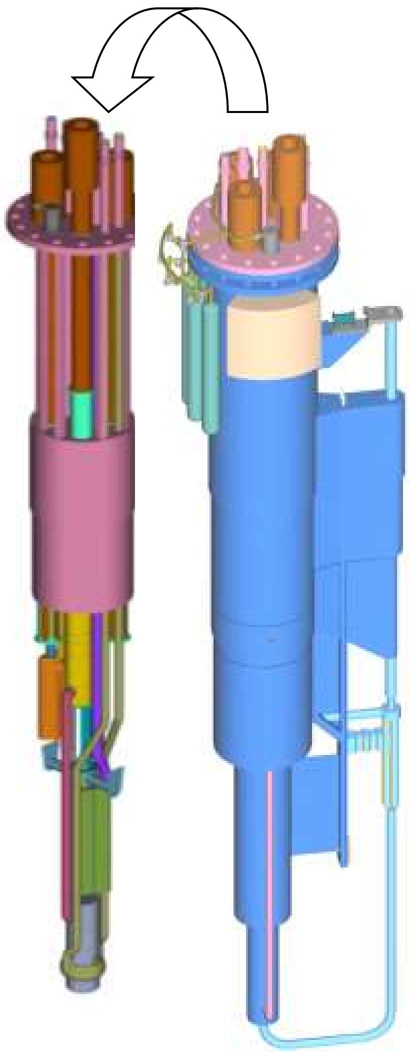
- Windowless target
  - ➢ Space considerations
- Vertical coaxial confluent LBE flow
  - ➢ Space consideration
  - ➢ Free surface formation
- Target inflow via 3-feeder design
- Toroidal beam shape
- Off axis LBE servicing
  - ➢ Leave top & bottom of subcritical core free
    - ⇒ Accessibility experimental radiation device
  - ➢ Main part of the spallation loop away from high radiation zone
    - ⇒ Lifetime

Windowless Spallation target issue to solve



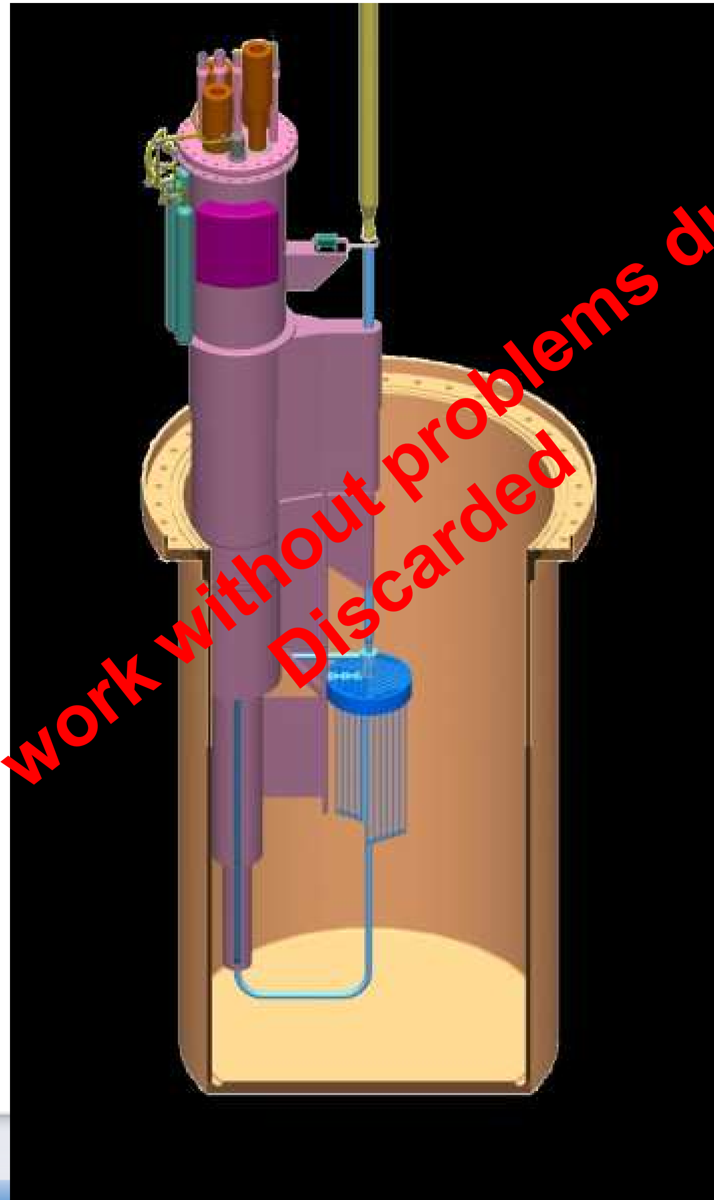
- Formation of target free surface
  - Confluence of Vertical coaxial flow
  - Drag limited inlet flow
  - Driving force : gravity
  - Level : balance inlet-outlet flow
  - Recirculation zone : control
    - Level balance Δh_{max}=3 mm
  - Feedback necessary
    - LIDAR level detection
    - fast MHD pump
  - Proton beam distribution
    - Avoid recirculation zone heating

Remote handling compatibility



- Service by remote handling
  - ➢ Entire spallation unit removable from main vessel after core unloading
    - ♣ avoid criticality issues
    - ♣ safety
    - ♣ in situ commissioning
  - ➢ Separate sub-unit with all active elements
    - ♣ servicing without removal of spallation loop
  - ➢ Closed outer housing
    - ♣ yearly replacement of spallation zone (embrittlement)
    - ♣ replacement of HEX
- Remote handling requirements
  - ➢ handling : machine; instrumentation
  - ➢ cutting; welding; ...

Windowless spallation target loop interconnecting with the core

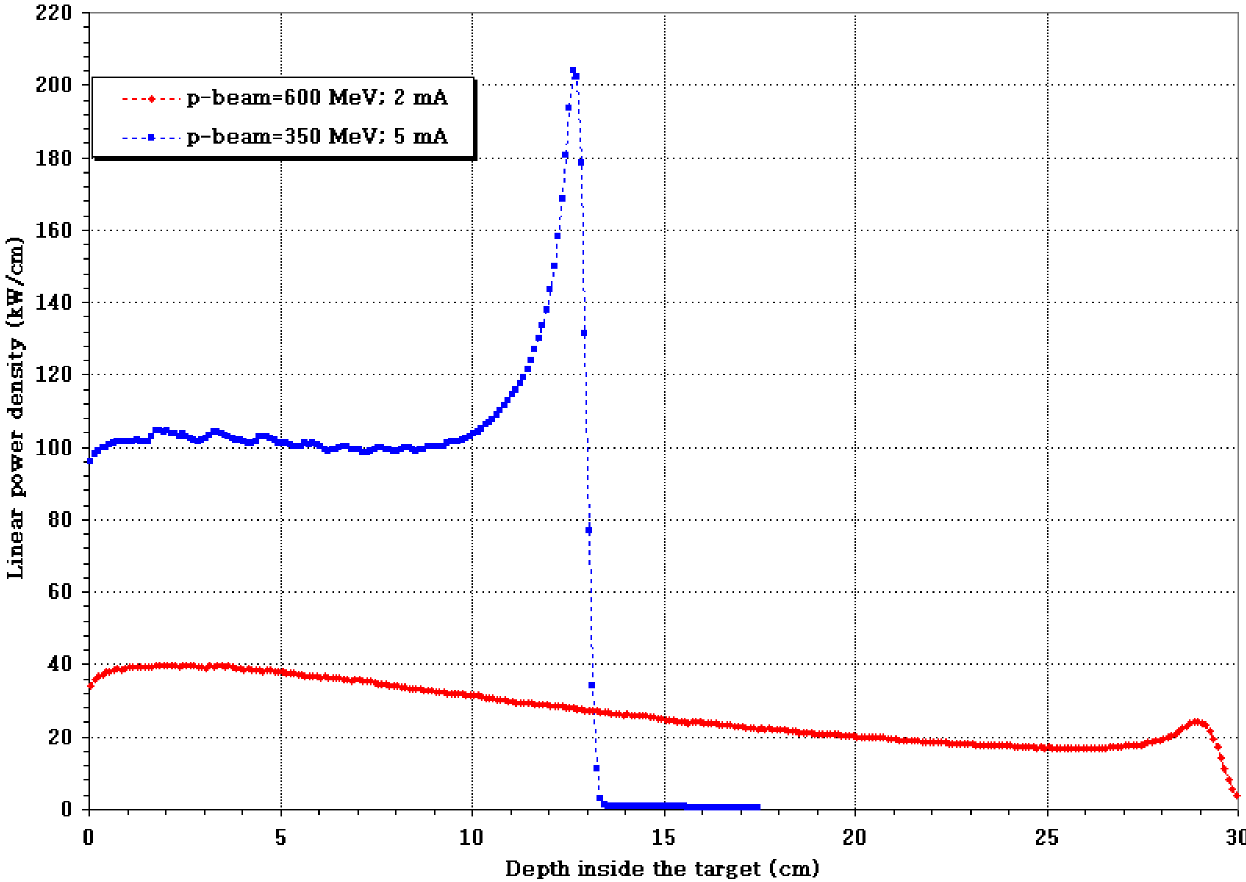


To complex to work without problems during 30 years!

Discarded

Proton Energy changed from 350 MeV to 600 MeV

- Ip reduced
  - Impact current density on window
  - Impact power density
- FA enlarged
  - Impact current density
- Window target design becomes thinkable
- MEGAPIE exp. Promising results



Go Window !

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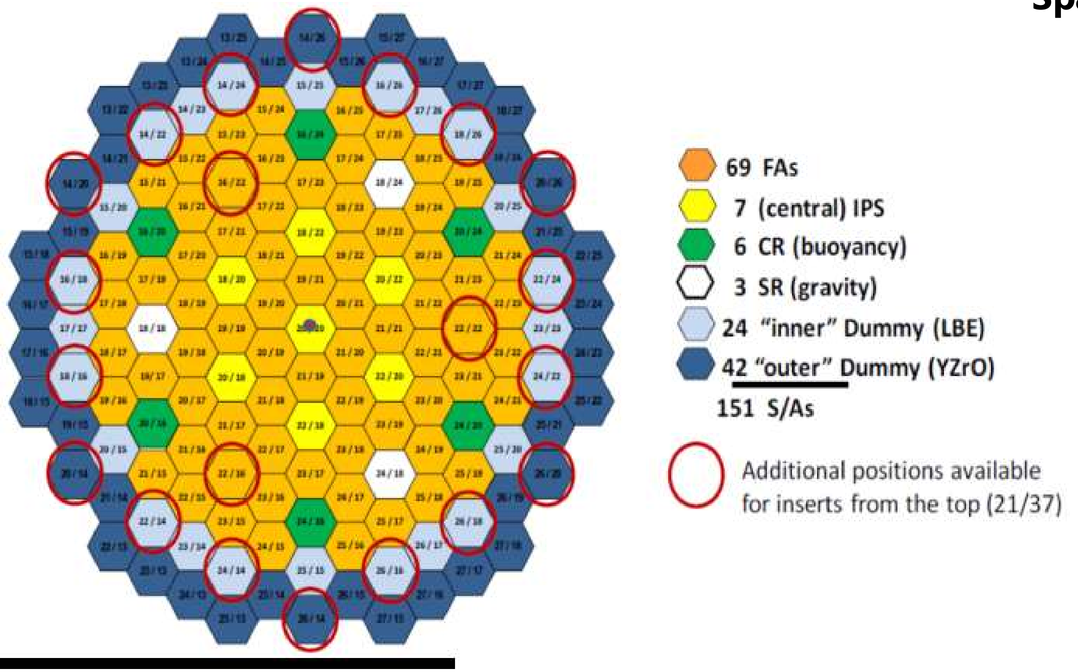
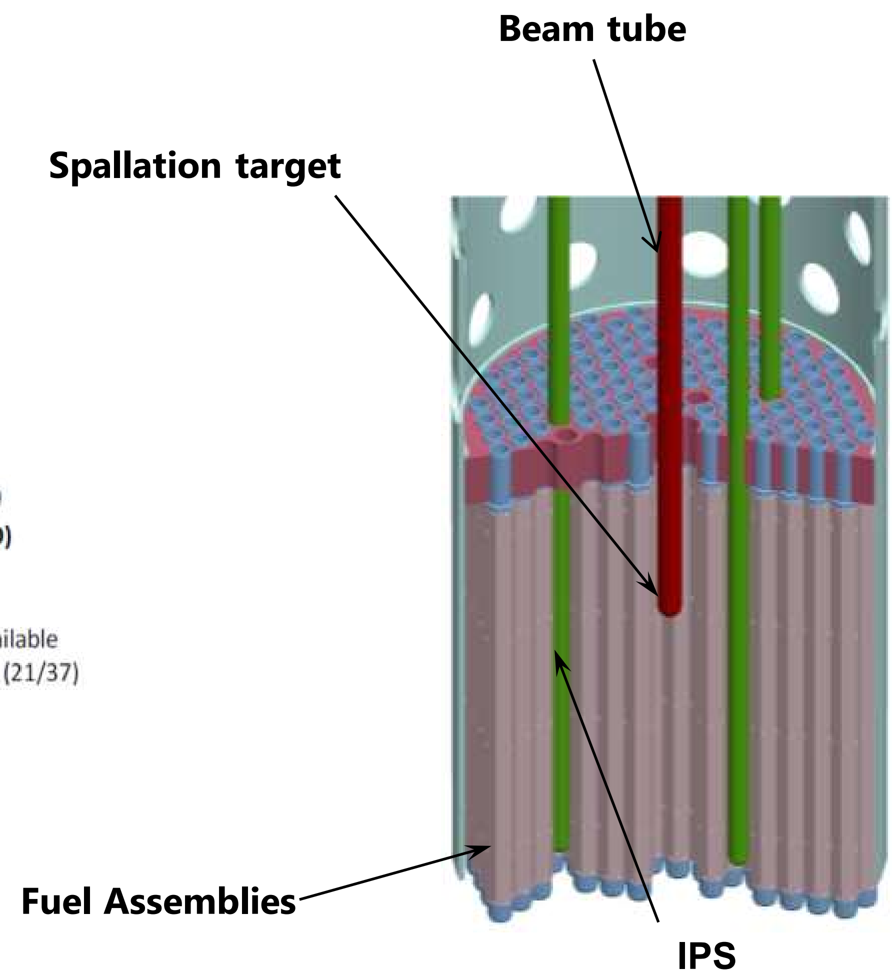
MYRRHA Window target concept in a central fuel position

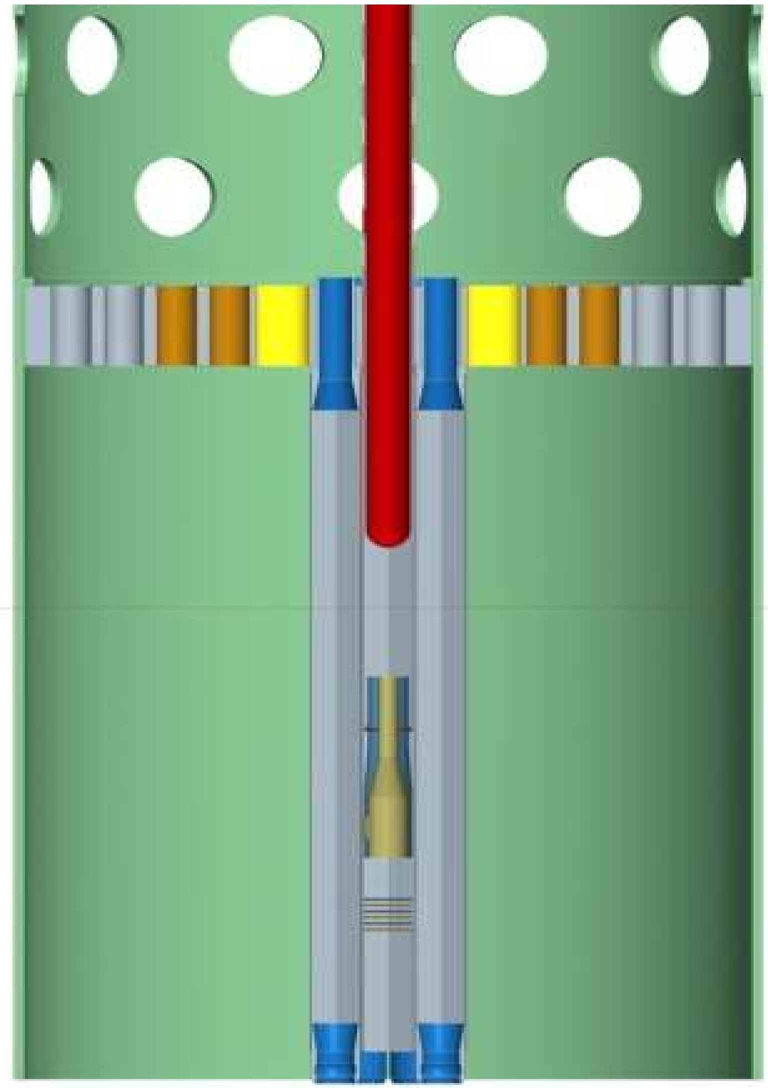
- 151 positions
- 37 multifunctional plugs



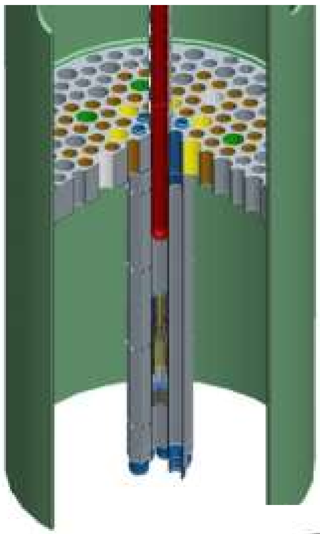


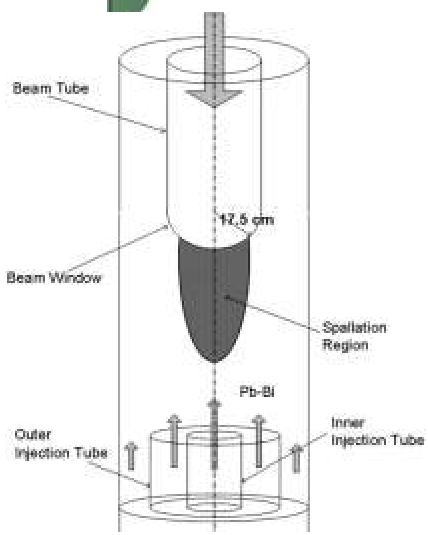
MYRRHA Window target design Global view

- Beam Tube contained in a heaxagonal wrapper such as a fuel assembly
- Spallation target material = Core coolant = LBE
- No separate loop needed
- Volume under de window target to be used for material irradiations for fusion



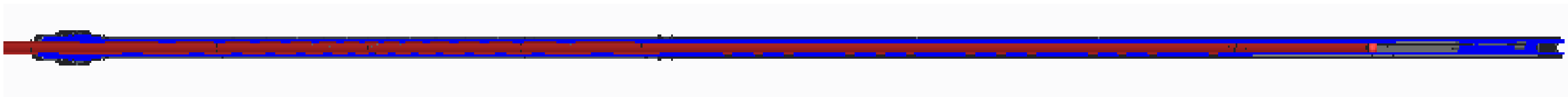
Spallation target window in the reactor core



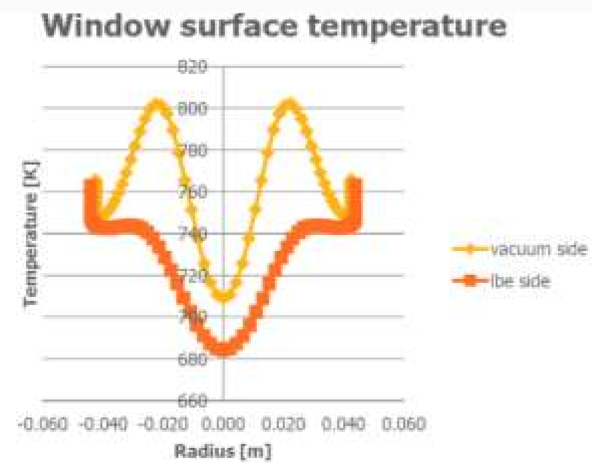


- Produces about 10^{17} neutrons/s at the reactor mid-plane to feed subcritical core @ keff=0.95
- Fits into a central hole in core
  - Compact target
  - Remove produced heat
- Accepts megawatt proton beam
  - 600 MeV, 3.5 mA → ~2.1 MW heat
  - Cooling of window is feasible
- Material challenges
  - Preferential working temperature: 450 – 500° C
  - Service life of at least 3 full power months (1 cycle) is achievable

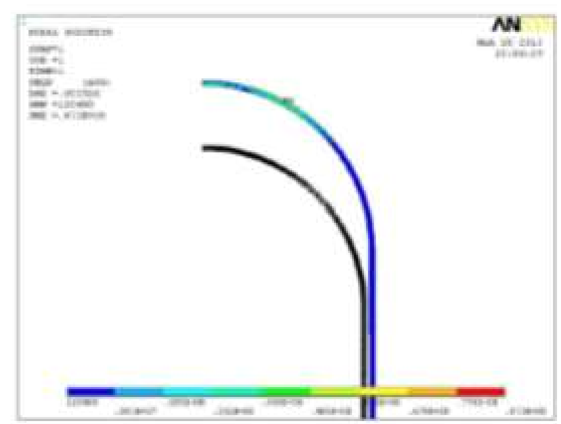
Spallation Target



- Mechanical analysis
  - Performed by TE
- Advanced level of design
  - In collaboration with TE
- Manufacturability check
  - Performed by TE
- Integration of fusion material testing experiment

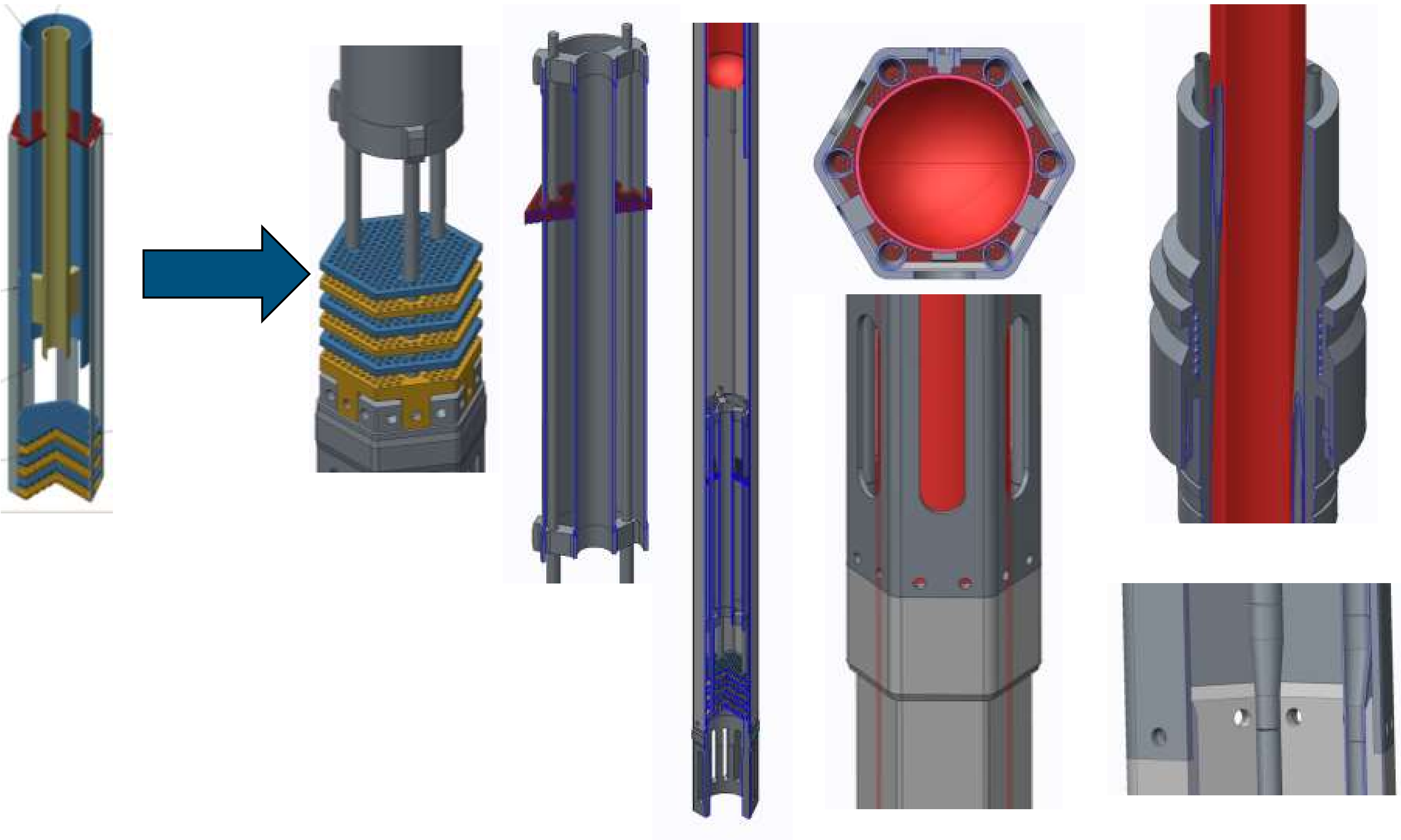


- Thermomechanical results



Von Mises stress due to thermal gradient

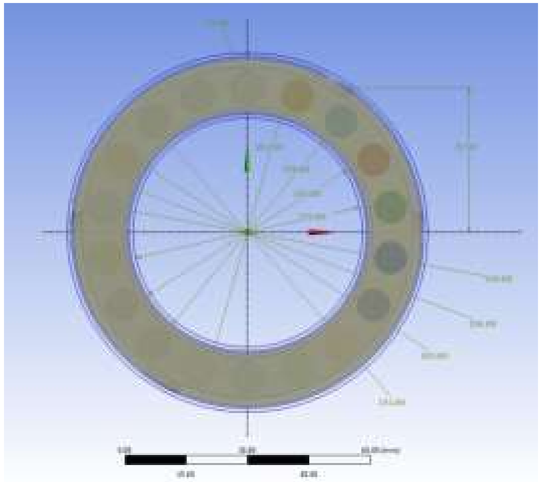
Details of MYRRHA Spallation Target

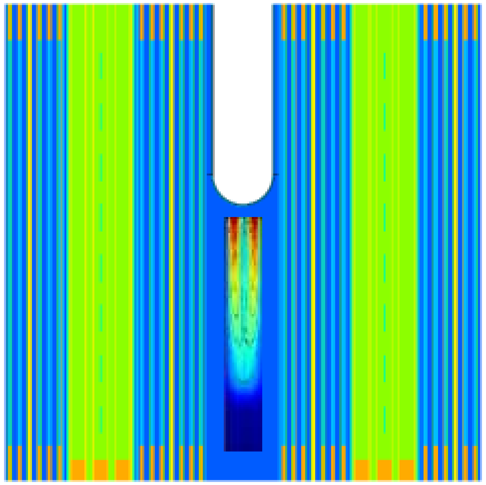


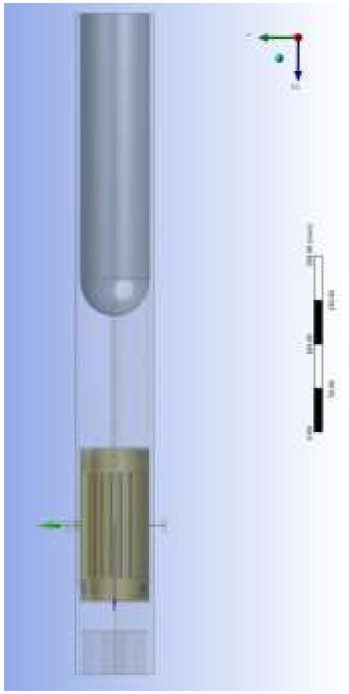
Irradiation capabilities in the spallation target

Core lay-out:

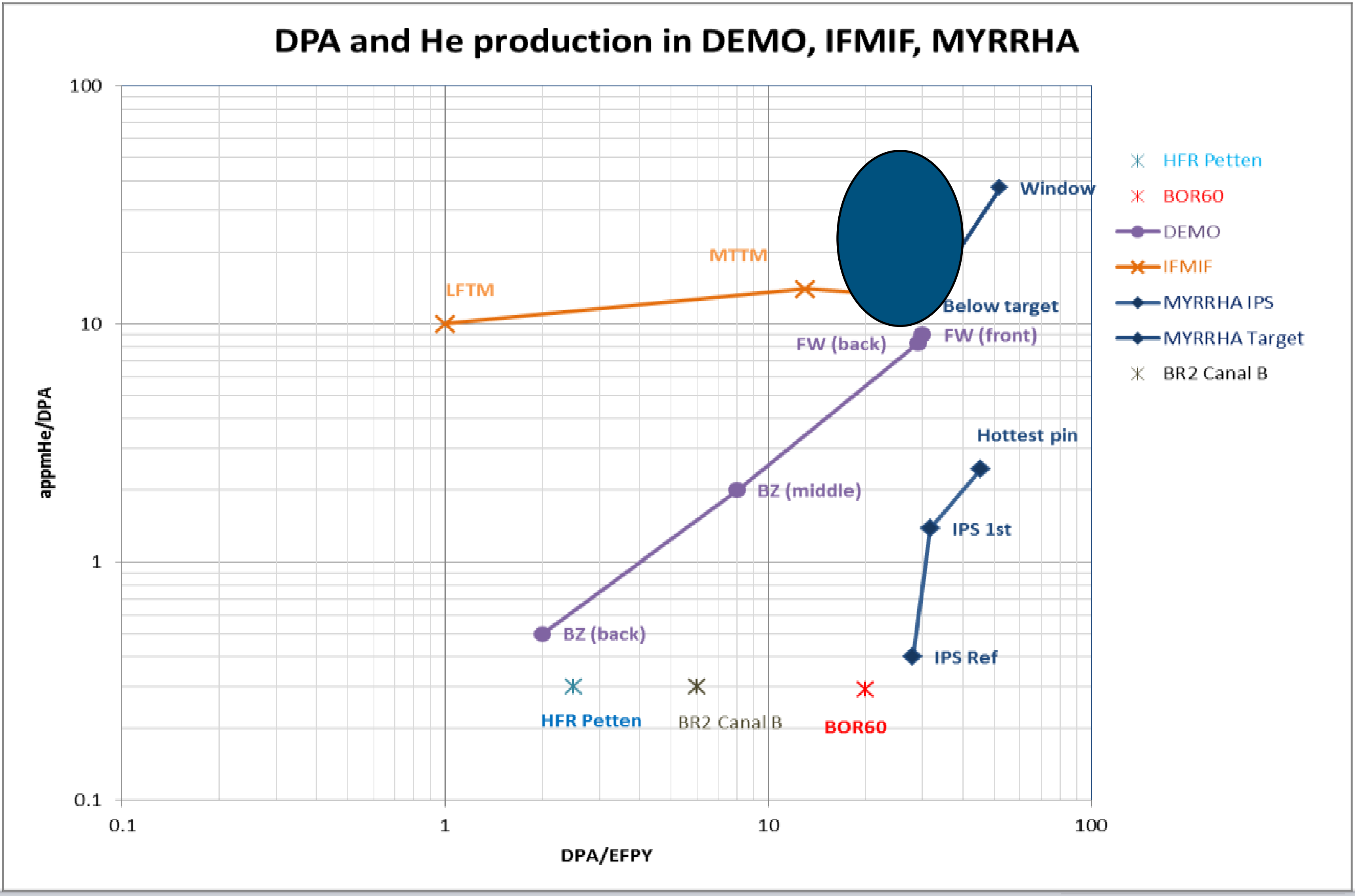
- Irradiation in sub-critical mode
- 600MeV proton beam hitting the beam tube, with spallation directly in reactor coolant LBE, creating high energetic neutrons
- Sample holder cooled by He
- Sample temperature range: 200°C – 550°C
- Sample temperature = controlled







MYRRHA for fusion irradiations



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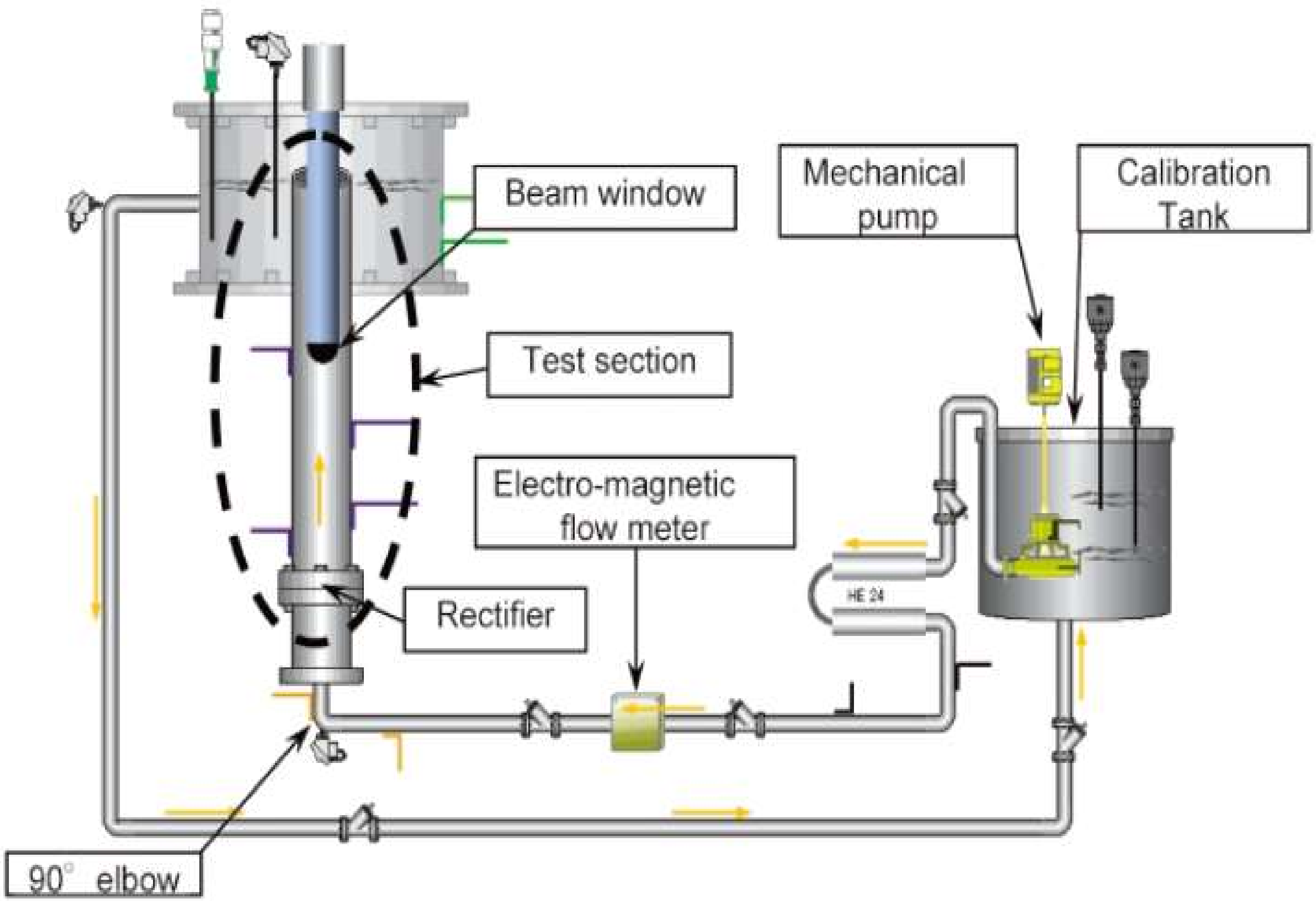
MYRRHA Window spallation target R&D programme

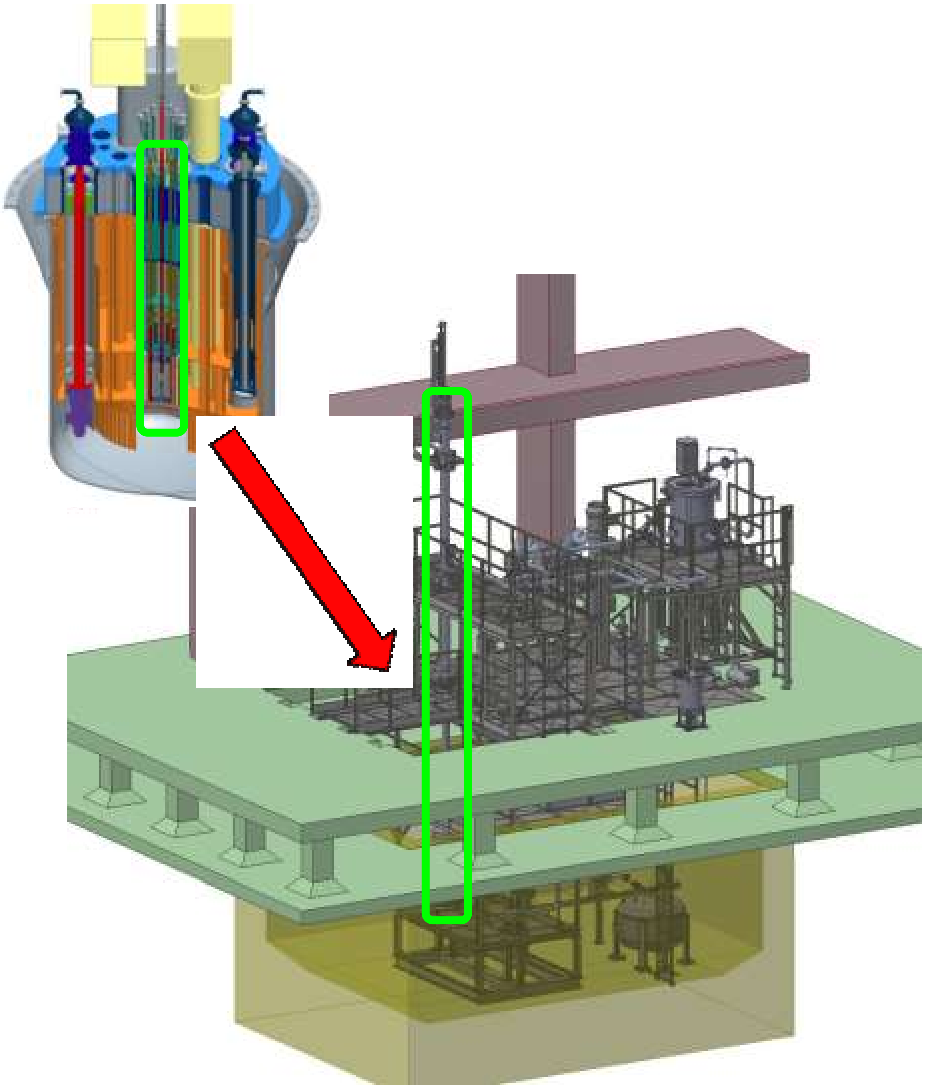
- Feedback experience from MEGAPIE (design, LBE control, material testing, spallation products inventory)
- Material irradiation in BR2 (MTR, Mol, BE) and in BOR-60 (FR, Dimitrovgrad, RU)
- Window coolability in JLBL-3 loop at JAEA (Tokai, JP)
- Fuel scale Thermal-hydraulic and mechanical testing in COMPLOT loop at SCK•CEN (Mol, BE):
  - Flow control,
  - Erosion control,
  - Coolability,
  - Flow induced vibration
- Volatile spallation products control and mitigation
- Beam footprint shaping and control

Window coolability in JLBL-3 in Japan

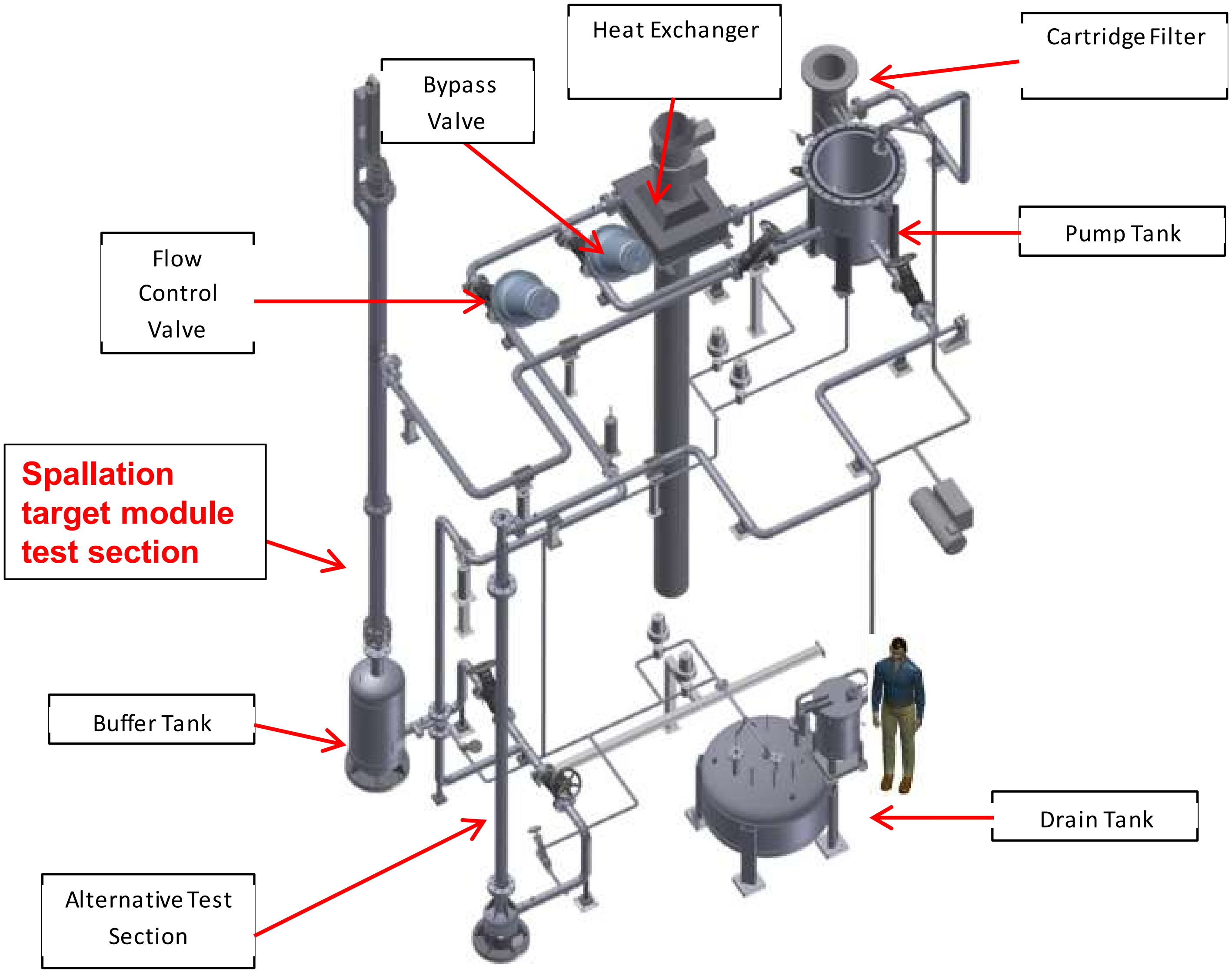


COMPLOT Multipurpose Th-H scale 1/1 test loop

- **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 fuel channel/IPS at full height
  - LBE as working fluid
  - Isothermal loop
  - Interchangeable test modules

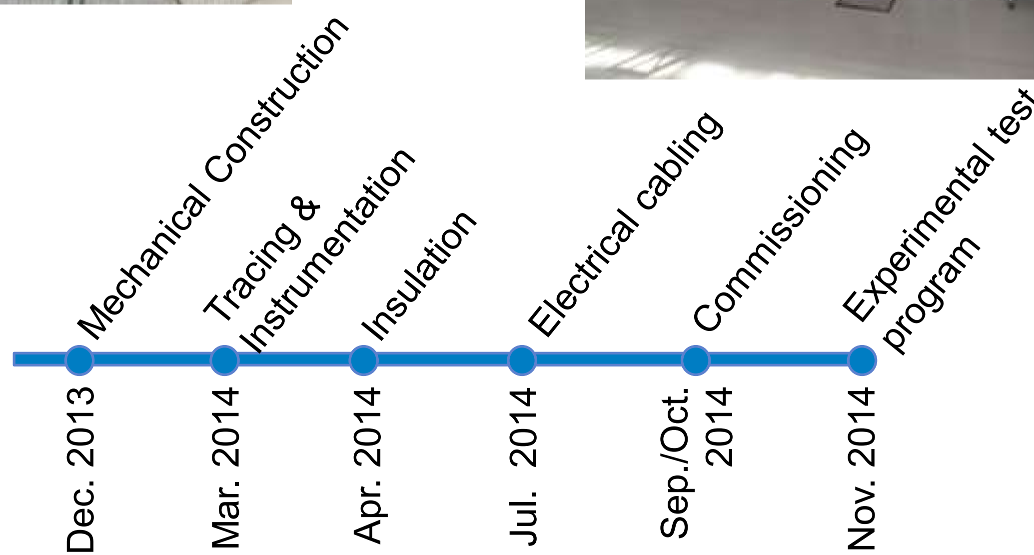


COMPLOT Assembly



COMPLOT: Status and planning

- COMPLOTconstruction completed



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Conlusions

- MYRRHA spallation target design has undergone a very heavy and dedicated R&D programme:
  - Windowless: from 1999 to 2008, including:
    - Numerical design and experimental validations:
      - Hydraulic design: H_2O, Hg and Pb-Bi
      - Control of the free surface stability and numerical tracking: H_2O, Hg and Pb-Bi
      - Beam interaction with free surface : WEBExpIr (**W**indow **E**lectron **B**eam **Exp**eriment **Ir**radiation)
      - Material irradiation
  - Window: from 2009 to …
    - Numerical design and experimental validations:
      - Hydraulic design: H_2O, Pb-Bi
      - Feedback from existing experiences and facilities
      - Mechanical impact of long term operation: FIV, Corrosion/Erosion
      - Material irradiation (feedback from MEGAPIE + Specific irradiations)
      - Volatile spallation products mitigation in case of window rupture
- Extra needs presently identified:
  - Beam line protection from contamination in case of window rupture
  - Beam footprint shaping and controlling (reliability aspects)
- **Don’t hesitate to change your mind when solving problems with too complex solutions**

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