Developments in the design of the MYRRHA spallation target

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On behalf of the MYRRHA team & IP Eurotrans WP 1.4

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IWSTM-10 Beijing

Overview

- The MYRRHA Project
- Present Status of the project
- Design of the MYRRHA spallation target
- R&D support actions
  - Thermal-hydraulics
  - Vacuum interface
  - Beam target interaction
  - Chemistry control
  - Mechanical analyses
  - Radiation damage
  - Safety analyses
- Future developments

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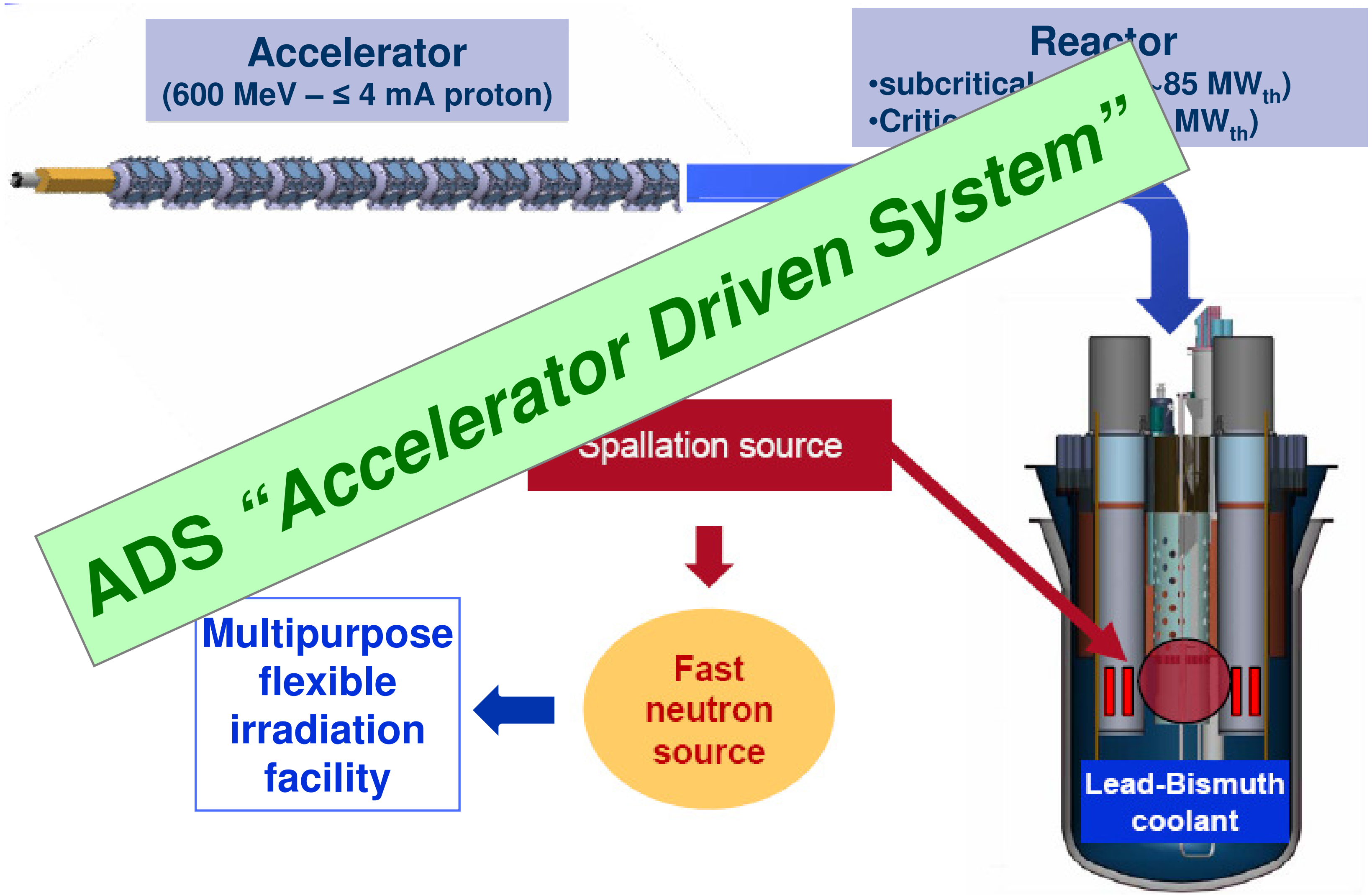
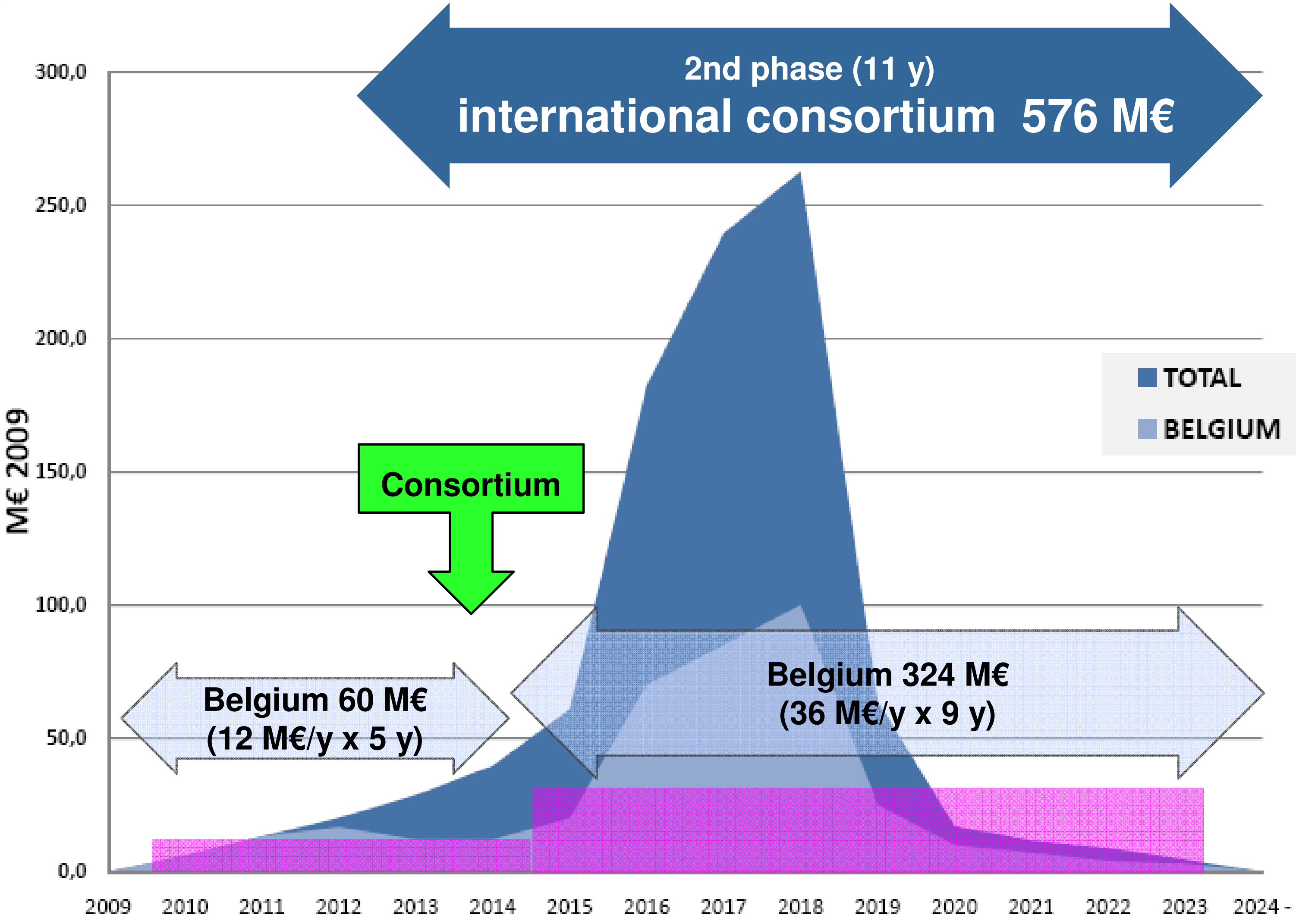
MYRRHA nuclear research fields

	Challenge	Solution	MYRRHA contribution
Fission	High radiotoxic level waste	Transmutation	ADS demo
Fission GEN IV	Demonstrate concept	Build demonstrators	LFR technology demo Fast spectrum irradiation facility
Fusion	Extreme operating conditions	Material testing & development	Fast spectrum irradiation facility
Fundamental research	Pushing the limits of knowledge	Access to proton beam	Long term experiments with radioactive ion beams (RIB)
Renewable energies	Efficient power electronics	High efficiency transistors (NTD-Si)	Securing NTD-Silicon production
Healthcare	Ageing population	A long term source of medical radioisotopes	Securing radioisotopes production (existing and new ones)

Concept


Accelerator
(600 MeV – ≤ 4 mA proton)
Reactor
•subcritical
~85 MW$_{th}$)
•Critic
MW$_{th}$)
ADS "Accelerator Driven System"
Spallation source
Fast neutron source
Multipurpose flexible irradiation facility
Lead-Bismuth coolant

Financial picture : 960 M€ investment



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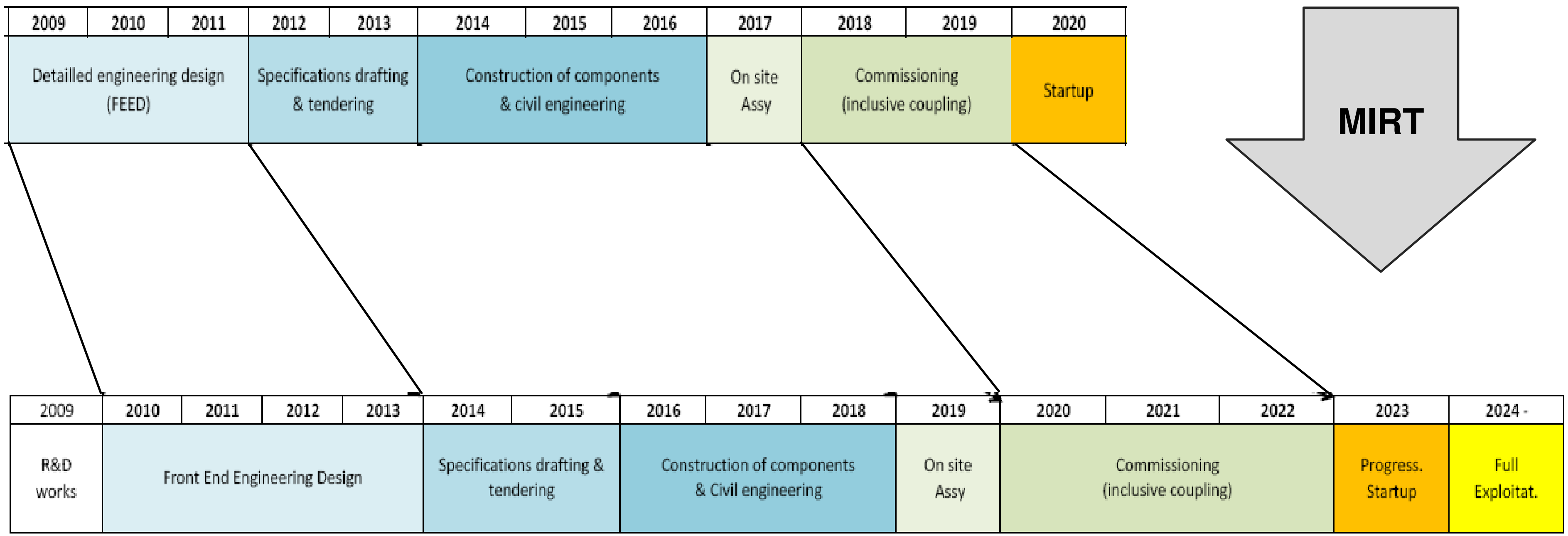
Funding the next phase of work: 2010-2014

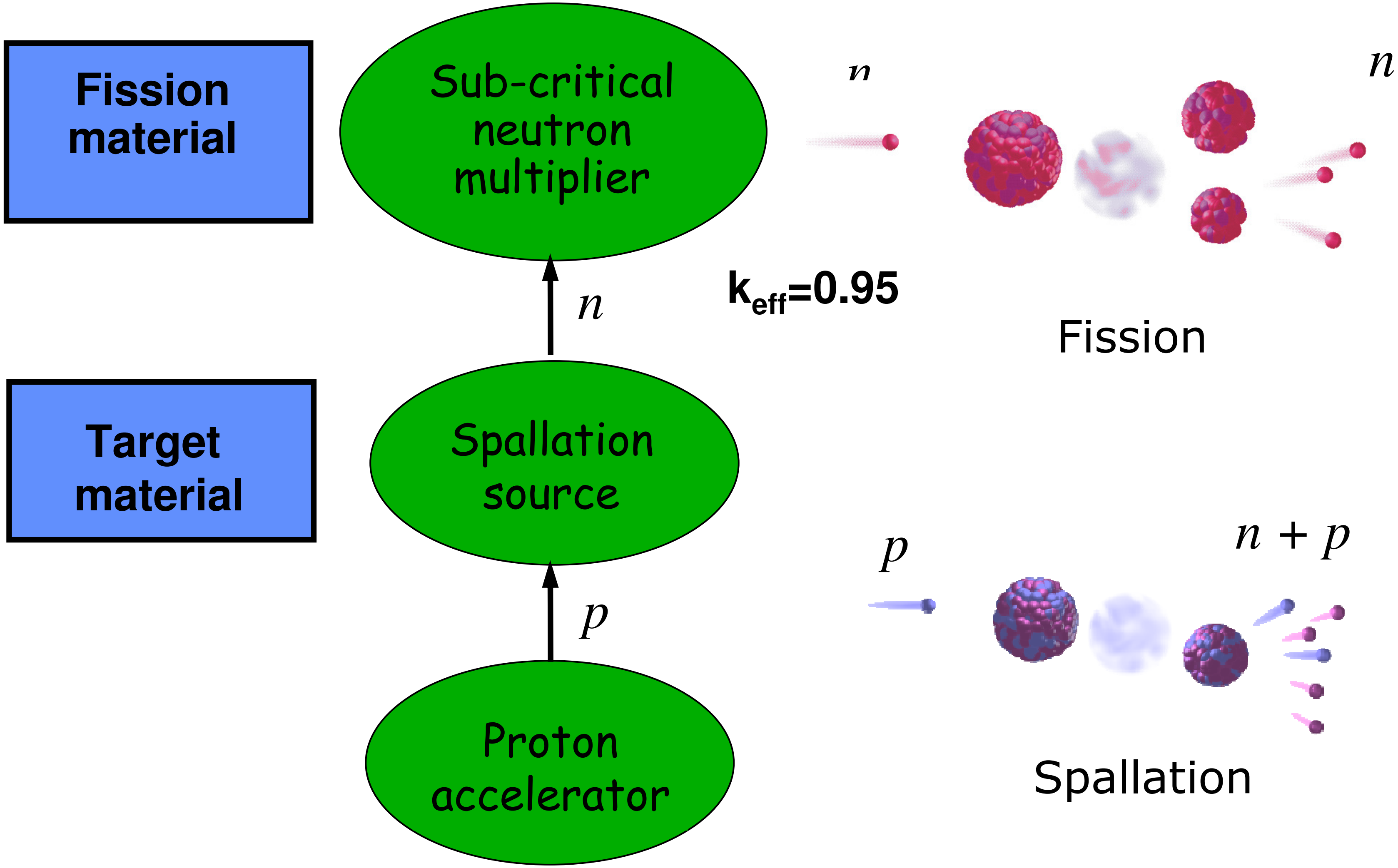
Minimise technological risks	Accelerator	x	Spallation target	x	Sub-critical reactor
Secure the licensing	**PDP** preliminary dismantling plan		**PSAR** preliminary safety assessment		**EIAR** environmental impact assessment
Implement a sound management structure	Central Project Team		Owner Consortium Group		Owner Engineering Team

→ **FEED** (Front End Engineering Design)

Updated project schedule 2010 - 2024



Accelerator driven system : concept

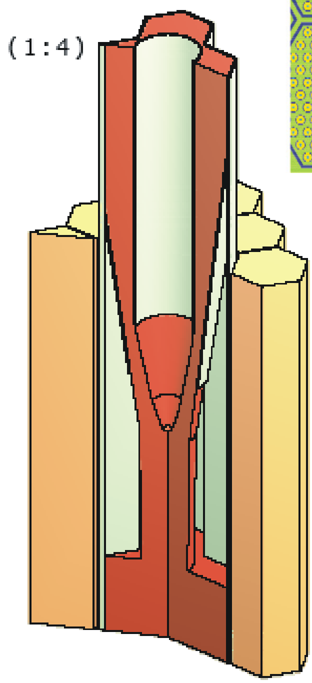


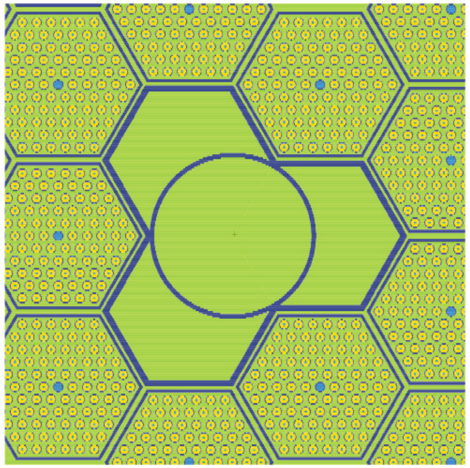
Spallation target for an experimental ADS

- Produce enough neutrons to feed subcritical core @ k_{eff}=0.95
  - Irradiation performance of ADS
- Accept megawatt proton beam
  - 600 MeV, 2.5-3.5 mA $\Rightarrow$ ≈1-1.3 MW heat
- Fit inside hole in subcritical core
  - compact target
- Allow for exploitation of MYRRHA as experimental irradiation machine
  - flexible remote handling
  - Shadow above core
- Safety & economy
  - Reliability & lifetime

Spallation target concept properties

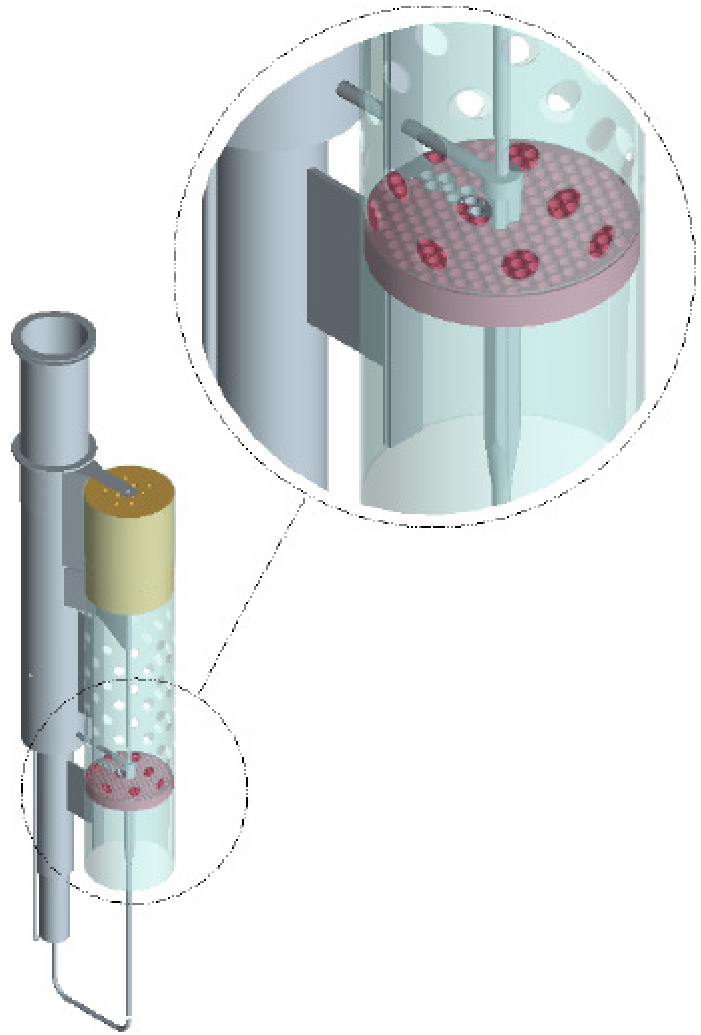
- Produce enough neutrons to feed subcritical core
  - LBE as target material
    - Low temperature possible
    - Low vapour pressure
- Fit inside hole in subcritical core
  - Windowless target
    - Avoid most loaded part of system
    - Beam current density
    - Precautions in case of window failure to be taken anyway
  - Vertical coaxial confluent LBE flow





Spallation target concept properties

- Allow for exploitation of MYRRHA as experimental irradiation machine
- Safety & economy
  - Off axis unit for loop
    - ➢ Loop away from high radiation zone
    - ➢ Leave core free for experiments & fuel
  - LBE flow & cooling
    - ➢ Forced convection
    - ➢ HEX to main coolant of reactor
  - Service by remote handling
    - ➢ Replaceable loop & components



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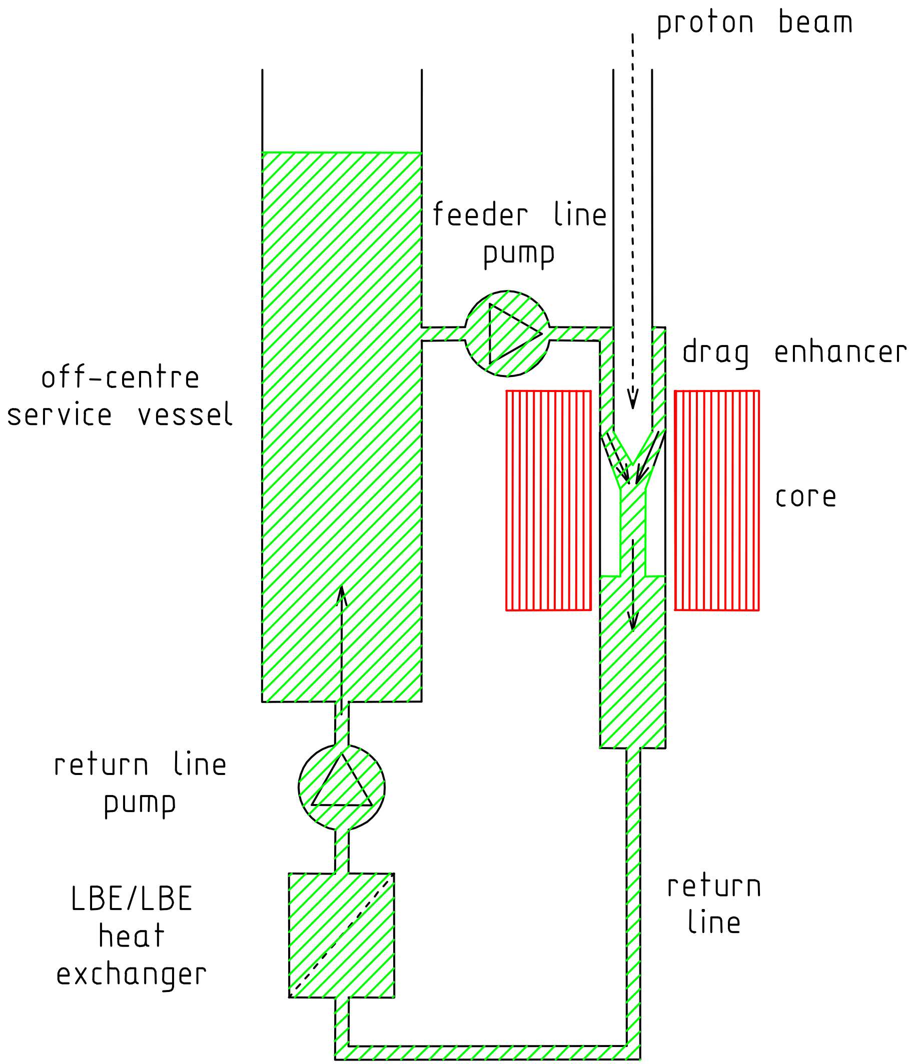
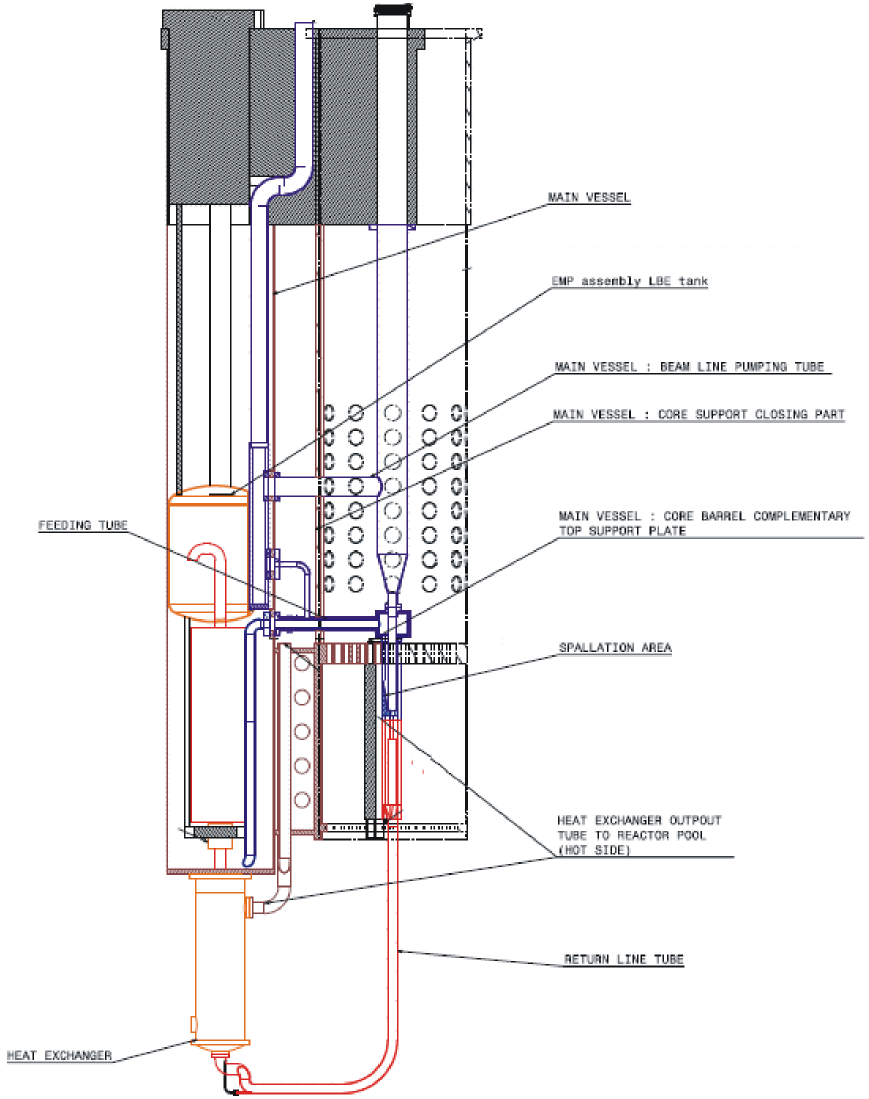
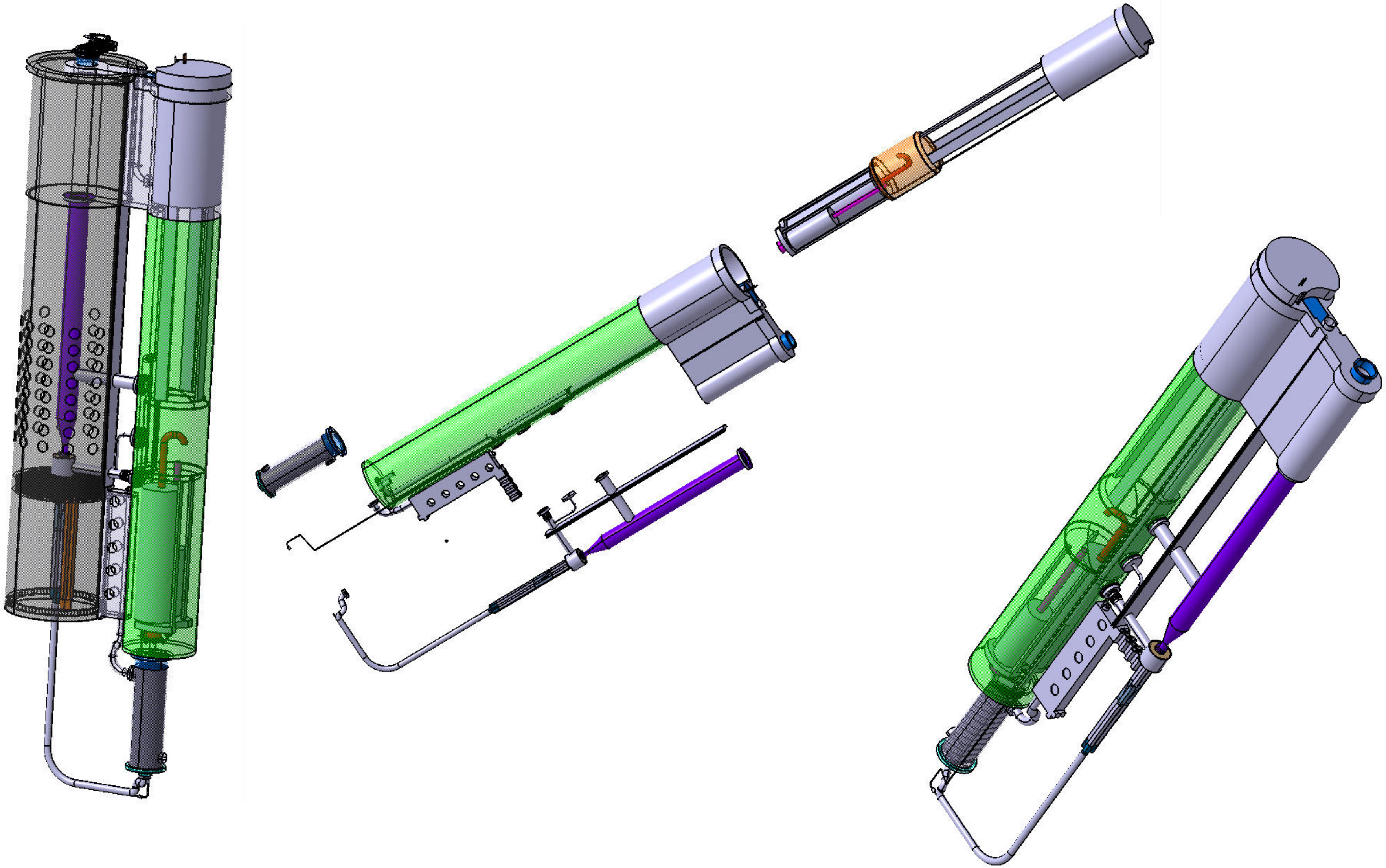
Spallation target loop layout

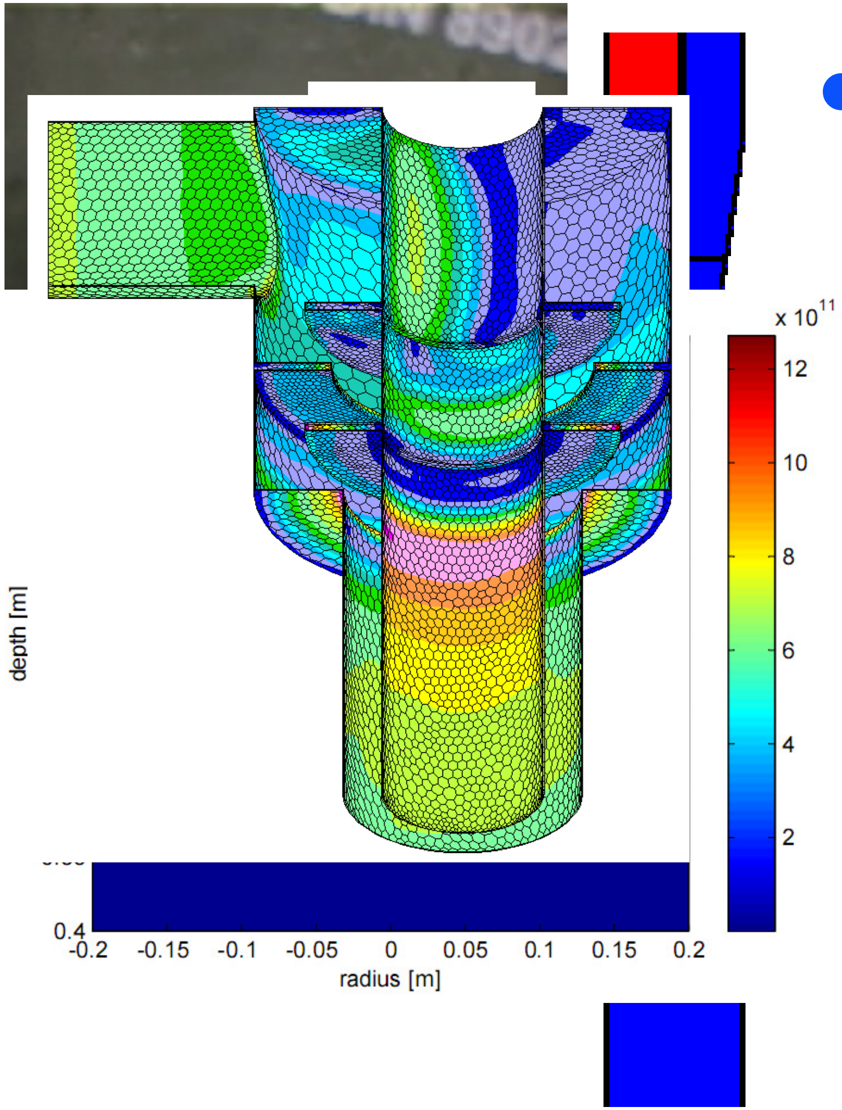




Spallation target loop layout

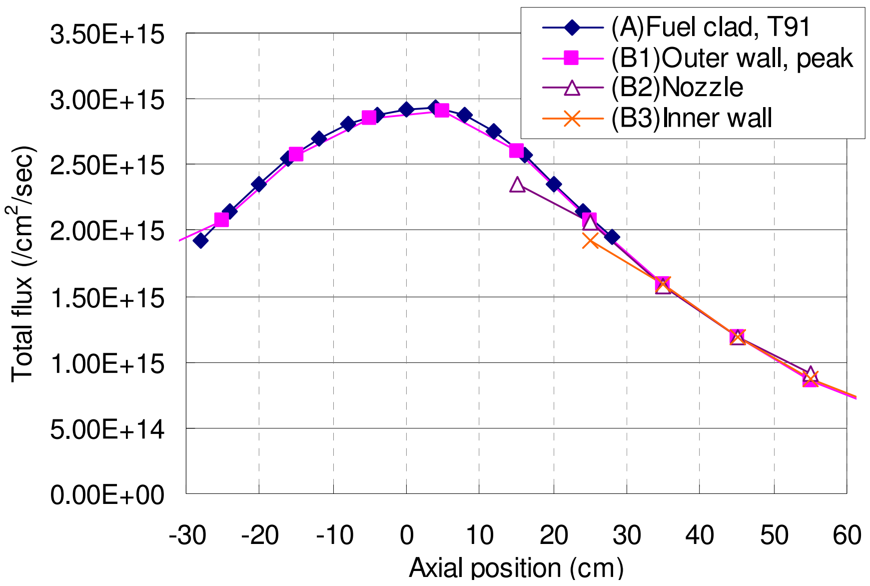


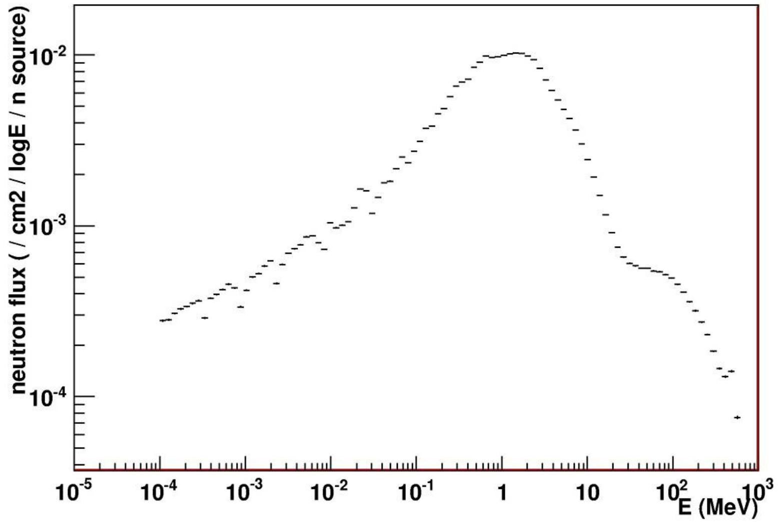
Spallation target thermalhydraulics

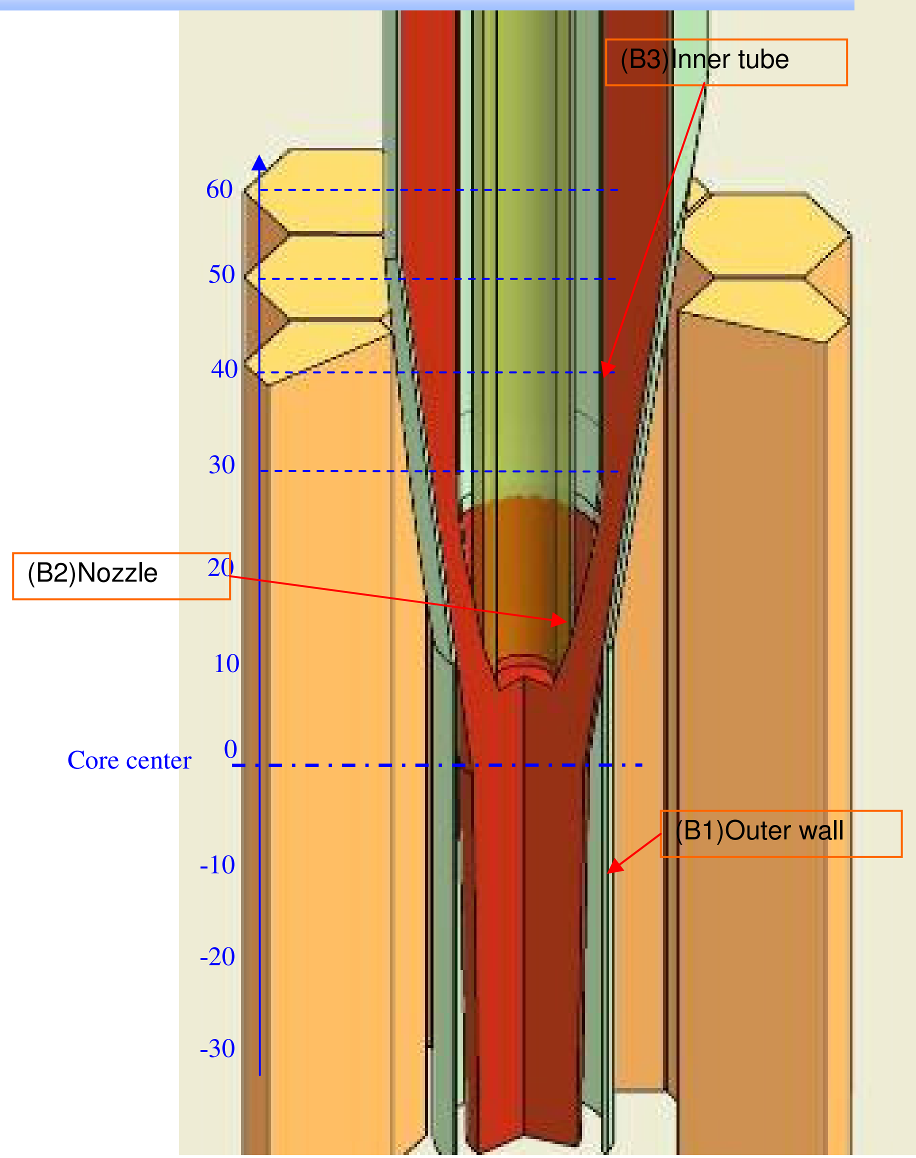


- Formation of target free surface
  - Feeder head
  - Drag enhancer
  - Target nozzle
  - Forced detachment
    - Decoupled inlet-outlet flow
    - Buffer during beam transient
  - Flow feedback
  - Recirculation zone
  - Proton beam distribution

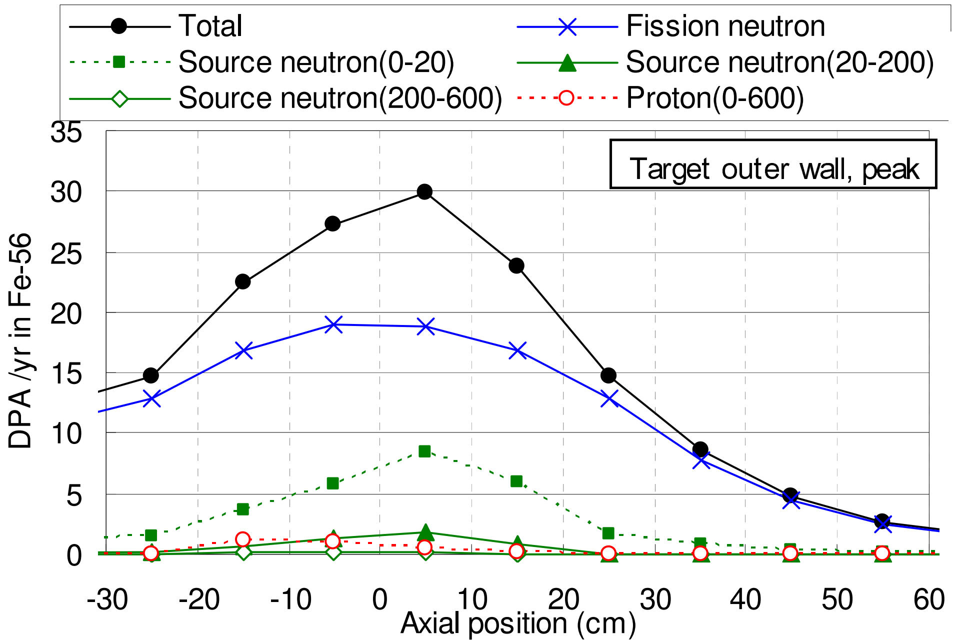
Spallation target : radiation damage

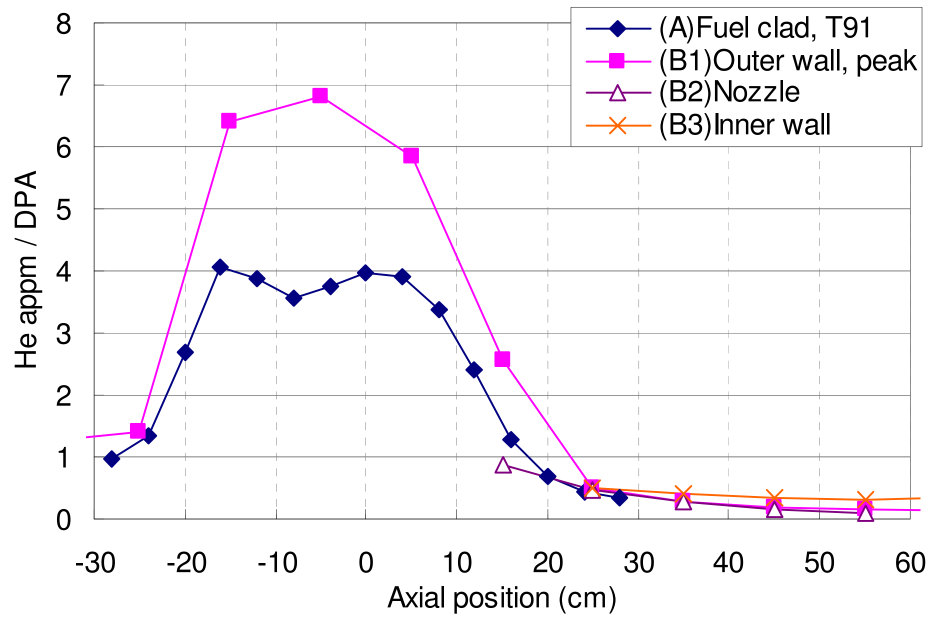




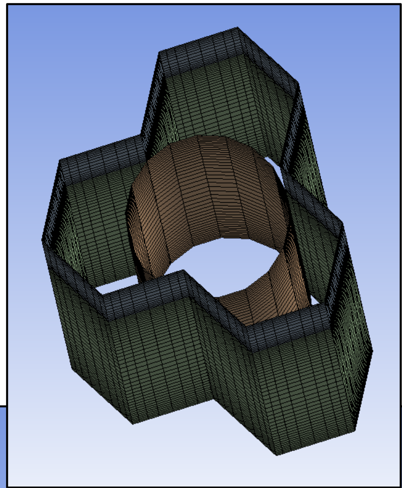


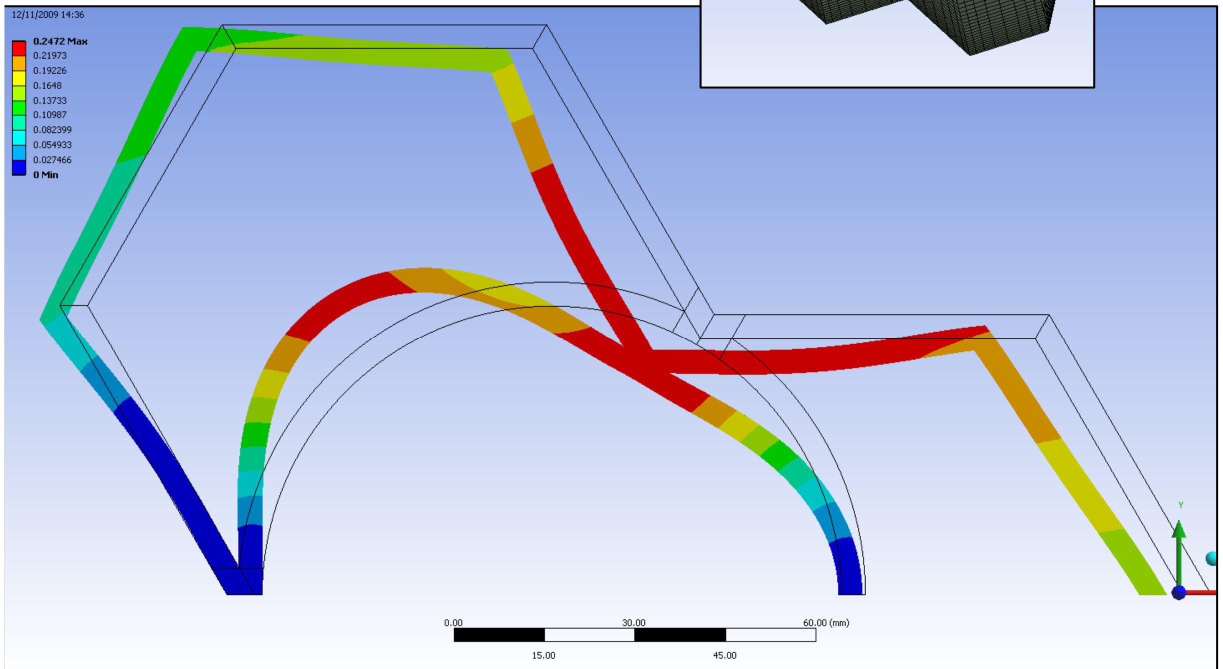
Spallation target : radiation damage





Spallation target : mechanical analyses



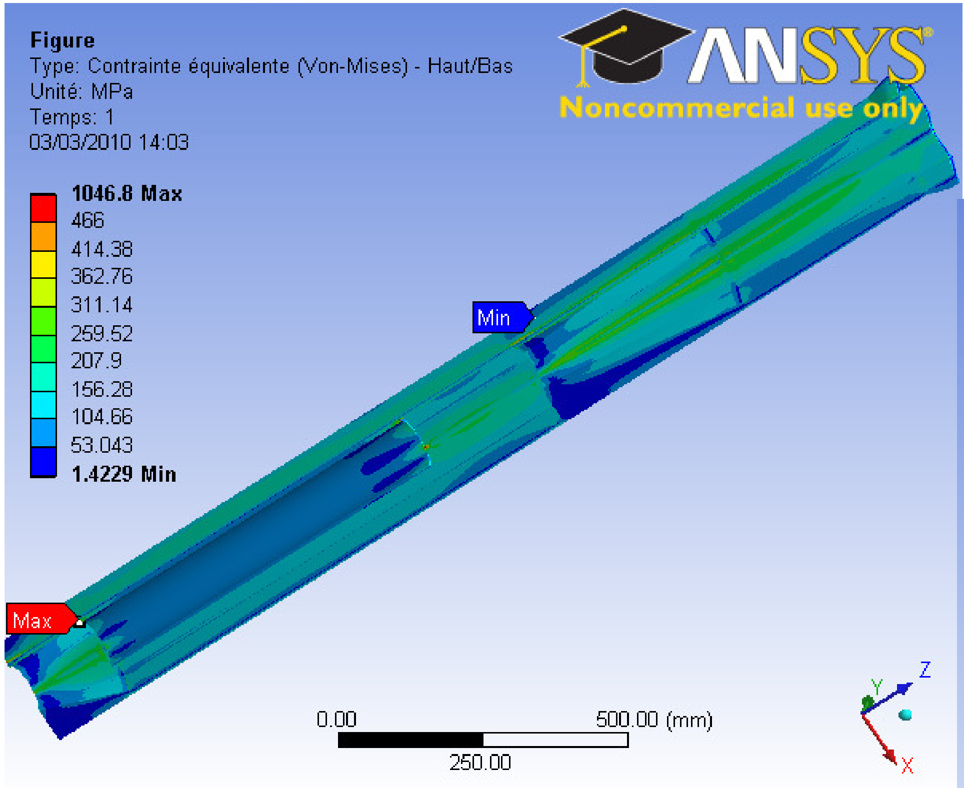


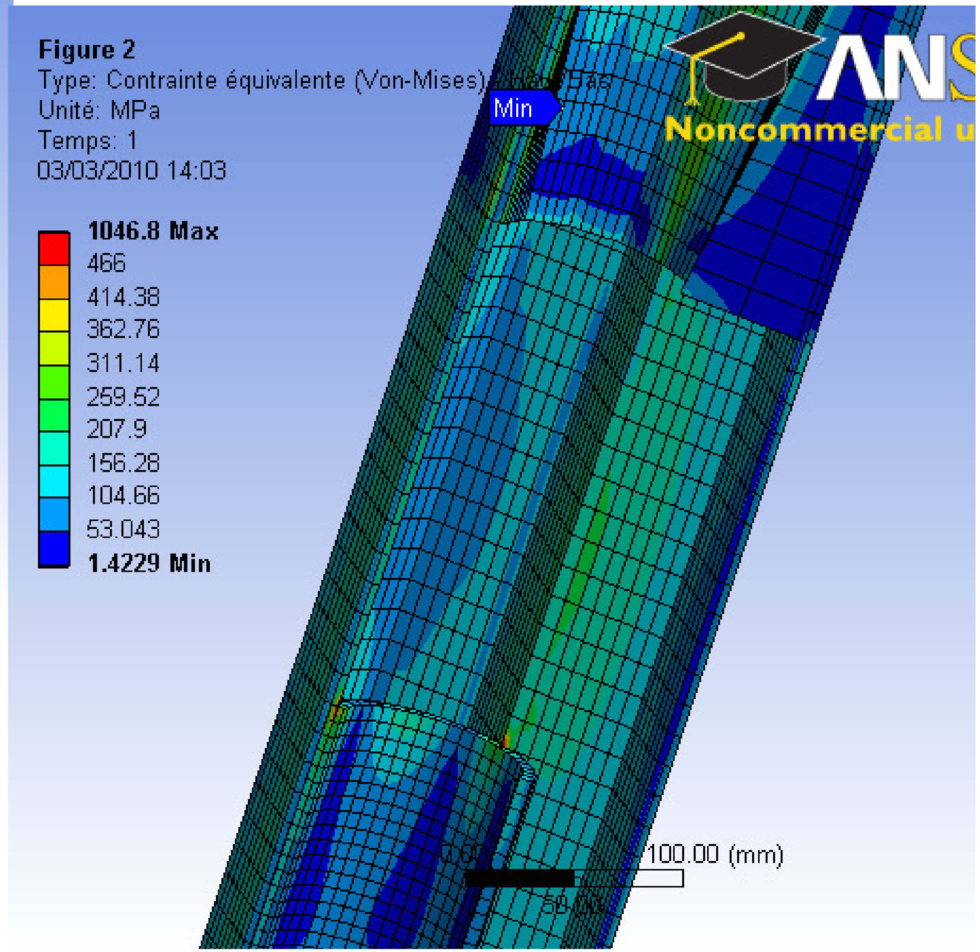
1 MP external pressure, 4mm wall thickness

- Analyses critical due to shape of target tube
  - 3 lobed structure
  - Inner tube needed
  - Sufficient wall thickness in high stress paces
  - T91 or similar required (strength)
  - Max deflection <0.25 mm
  - VM stress ≤ 466 MP

Spallation target : mechanical analyses

0.5 MP external pressure 100K ΔT , 4mm wall thickness





- Thermal mechanical stress
  - Optimisation internal structure
  - Remove stress points

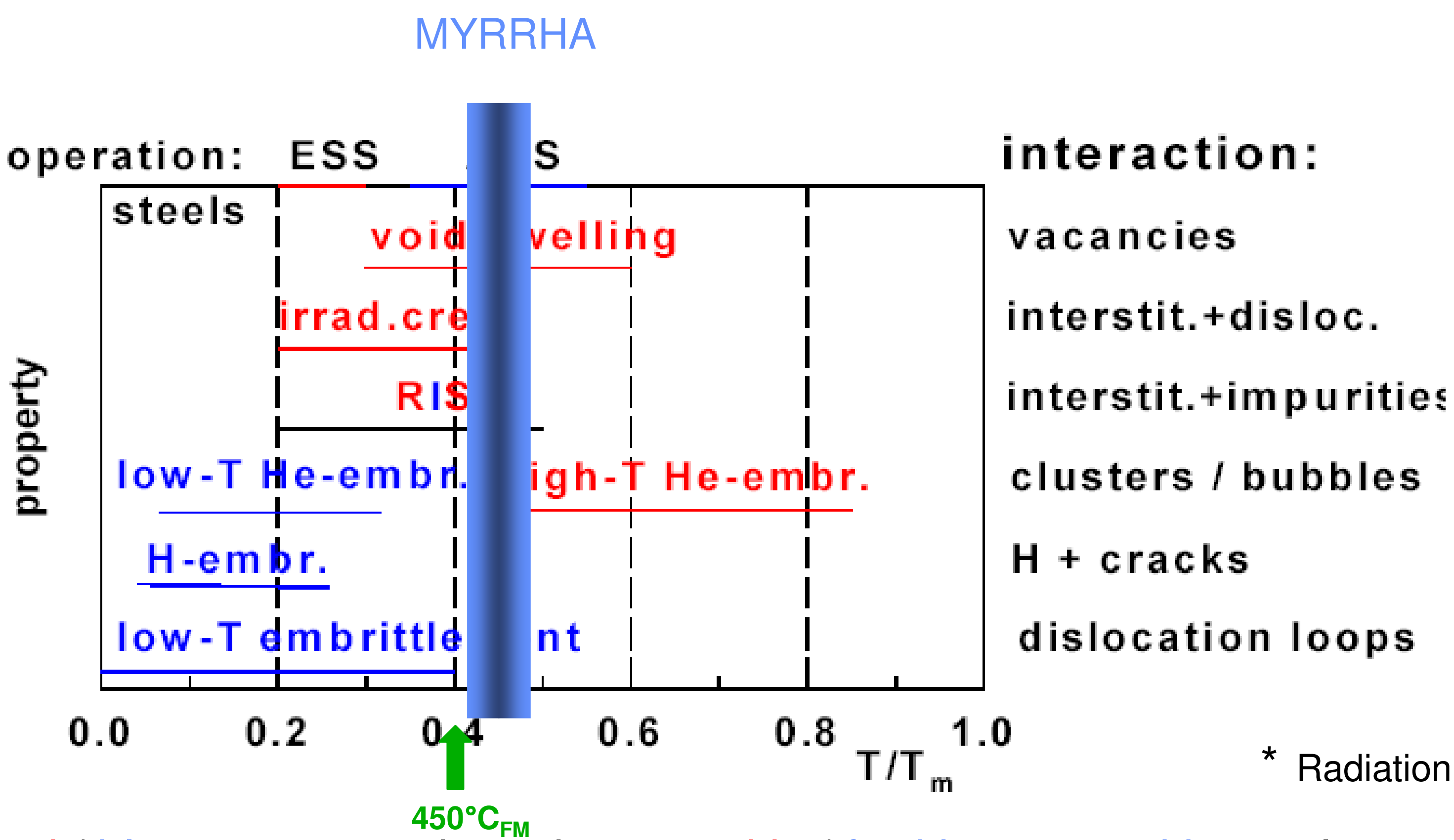
Summary

- Design of MYRRHA spallation target loop
- Fundamental properties
  - No target window
  - Compact vertical confluent flow
  - Detached flow in target nozzle
  - Off axis servicing
  - Active pump in feeder line
  - Vacuum & cover gas system, Oxygen control unit
- R&D support
  - Thermal hydraulics
  - Vacuum interface
  - Beam target interaction
  - Mechanical analyses
  - Safety analyses
- Windowless spallation target feasible for MYRRHA

What about a window target for MYRRHA ?

- Beam energy increase since initial choice for windowless target
  - 350 MeV, 5 mA → 600 MeV, 3 mA
  - Damage per proton
  - Current density
  - He production vs dpa damage
- Target window
  - Material choice
  - Operation temperature
  - Cooling
  - Replacement scheme
  - Safety issues

Effects of irradiation on target window
Ferritic-Martensitic steel T91

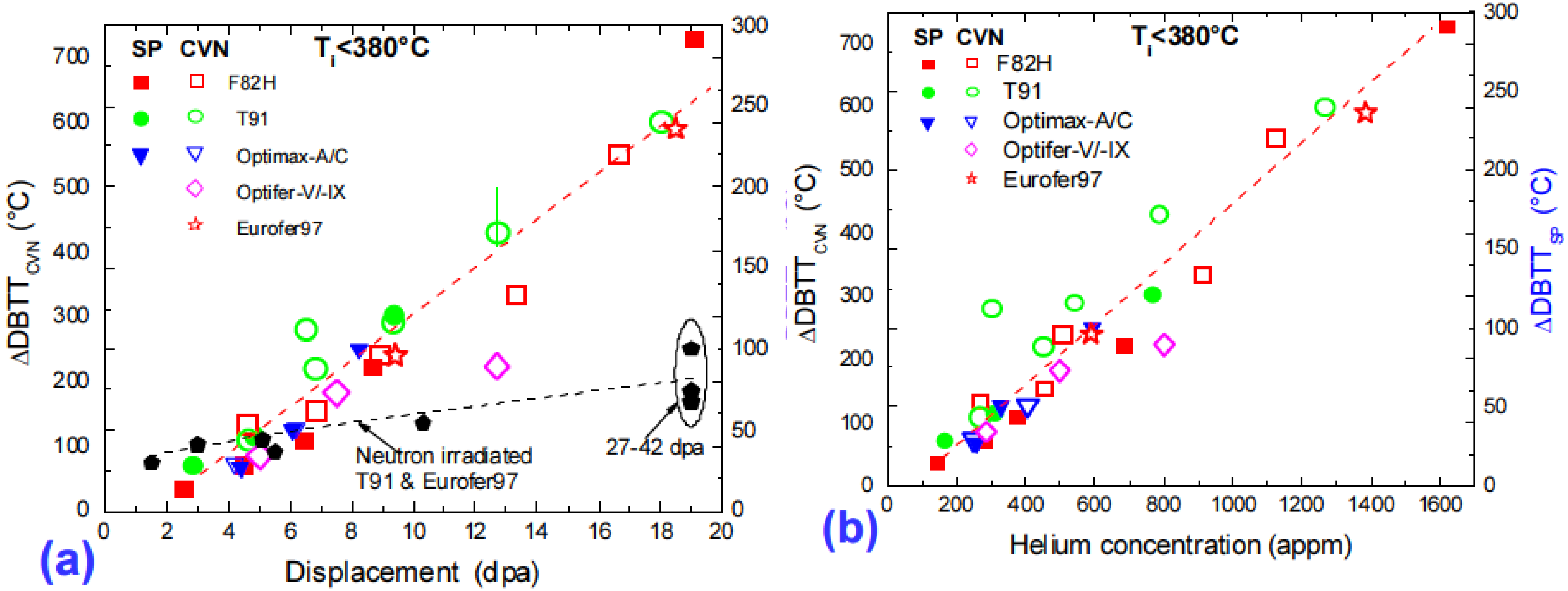


T_M(a) ca 1700K
T_M(f) ca 1800K

* Radiation induced segregation

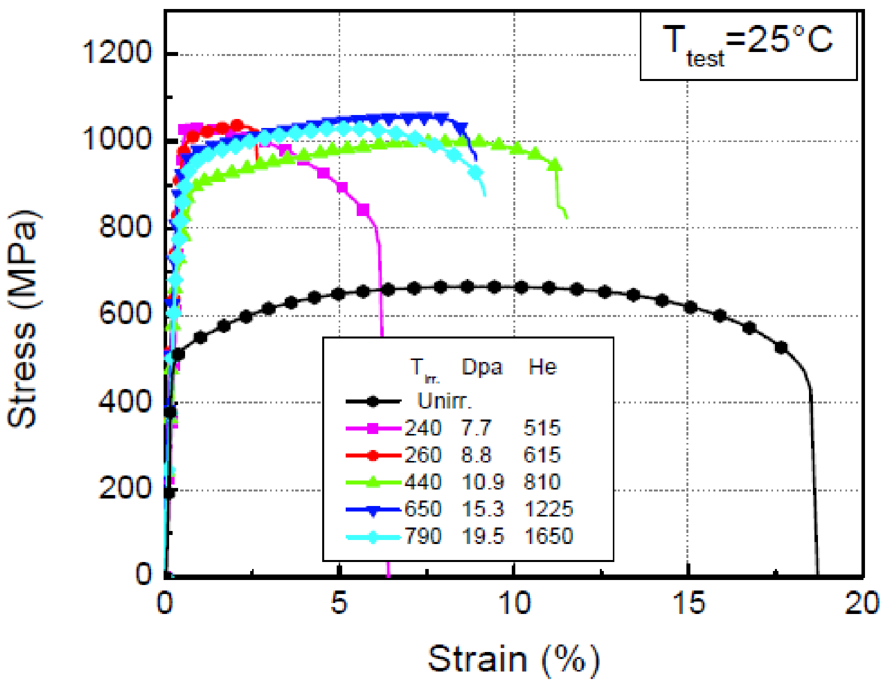
Red / blue: most prominent in austenitic / ferritic-martensitic steel

DBTT shift Ferritic-Martensitic steel

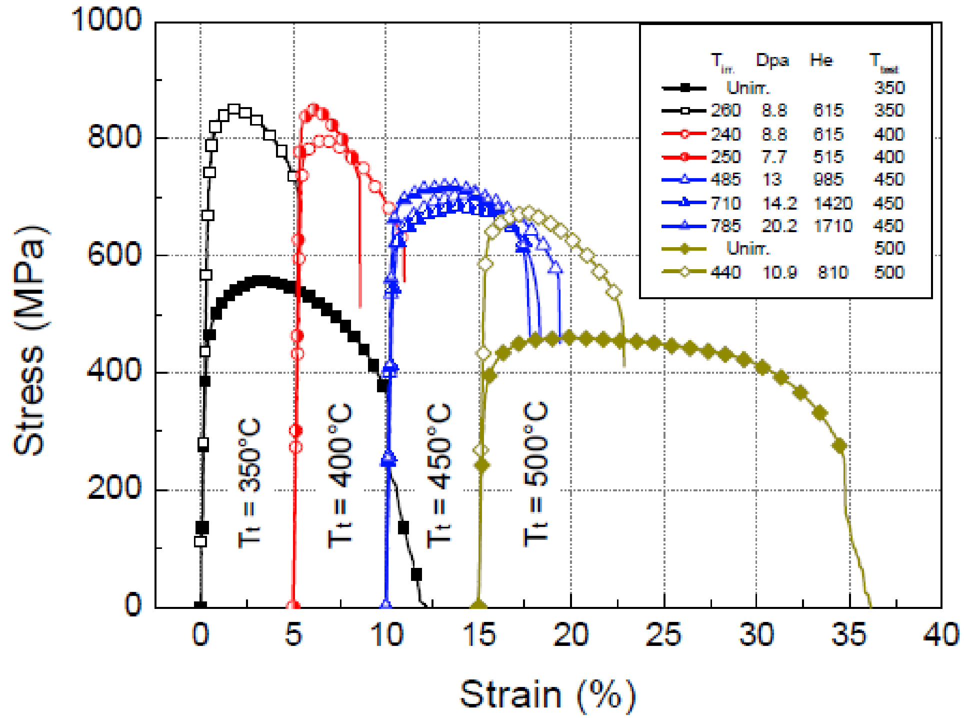


- DBTT shift linear with dose
- Data for irradiations below 380°C

DBTT shift Ferritic-Martensitic steel

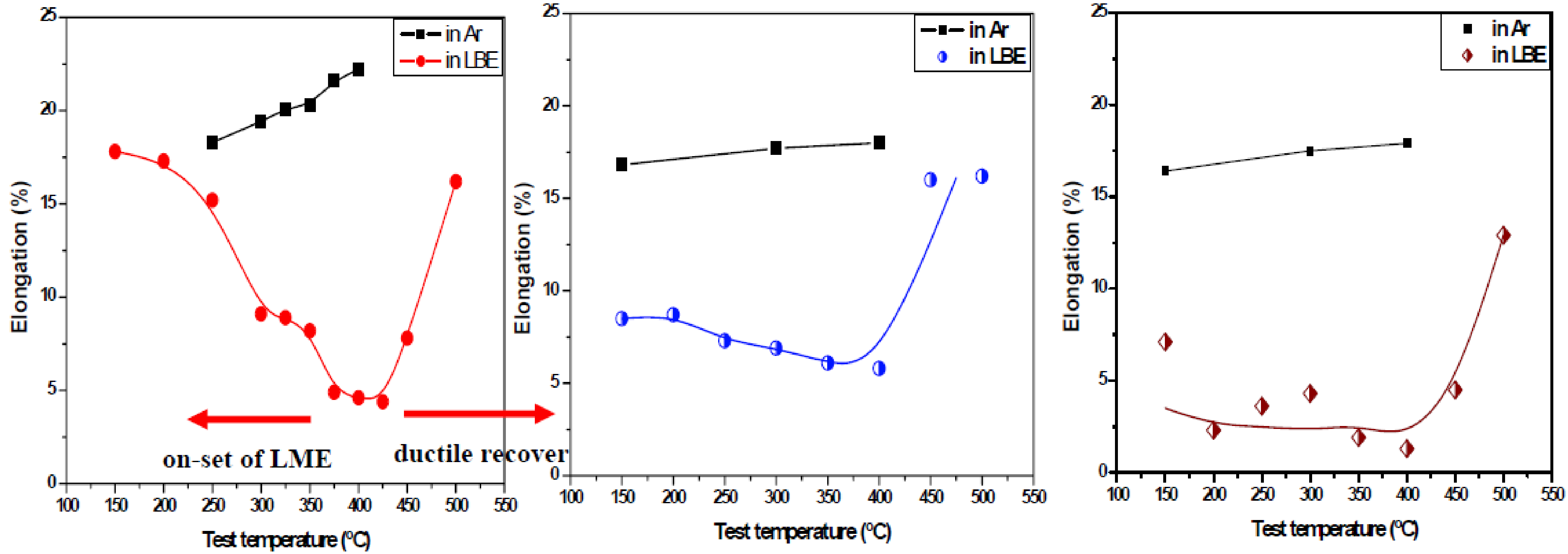


STIP-III irradiation data of T-91 steel at different irradiation temperatures.
Tensile test at 25°C



STIP-III irradiation data of T-91 steel at different temperatures.
Tensile test at elevated temperatures

Liquid metal embrittlement

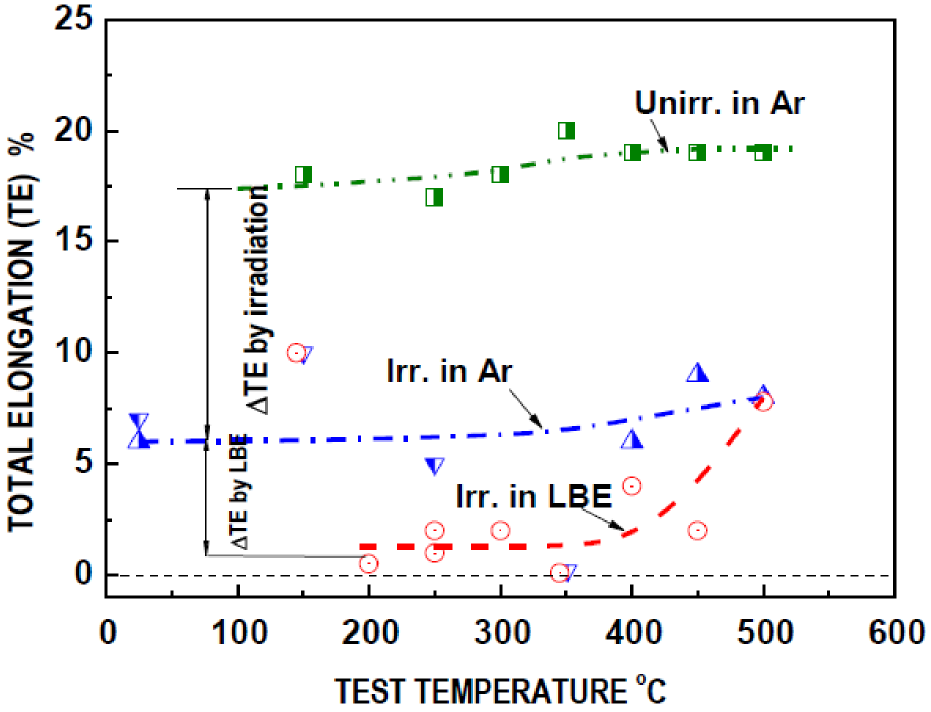


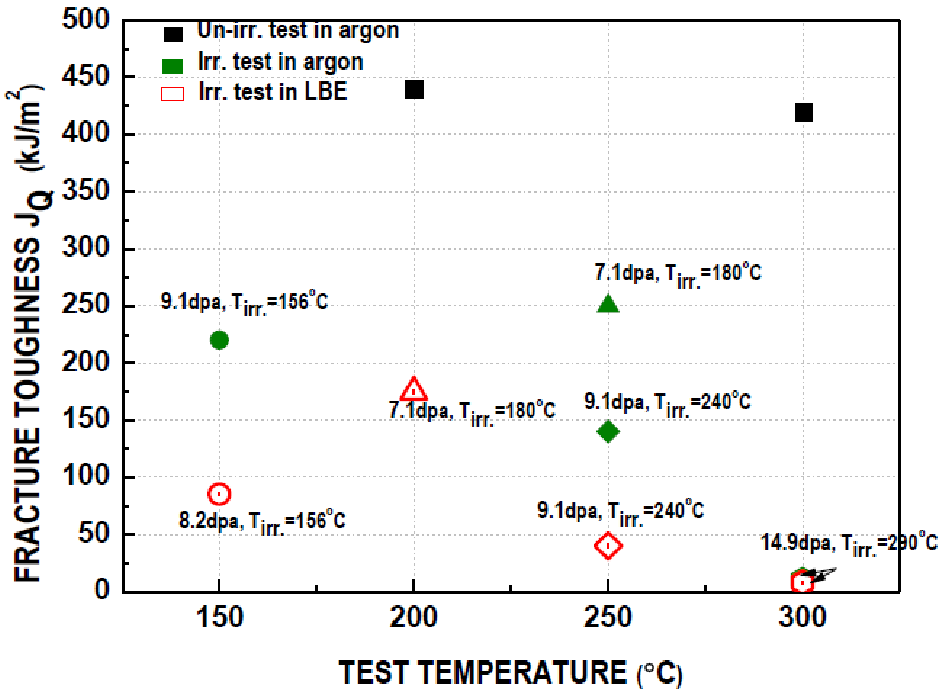
HT750 **HT600** **HT500**

- Heat treatment 1h
- Test in Ar & LBE

- LME
  - Samples with cracks
  - Plastic deformation at high stress

Ductility and fracture toughness



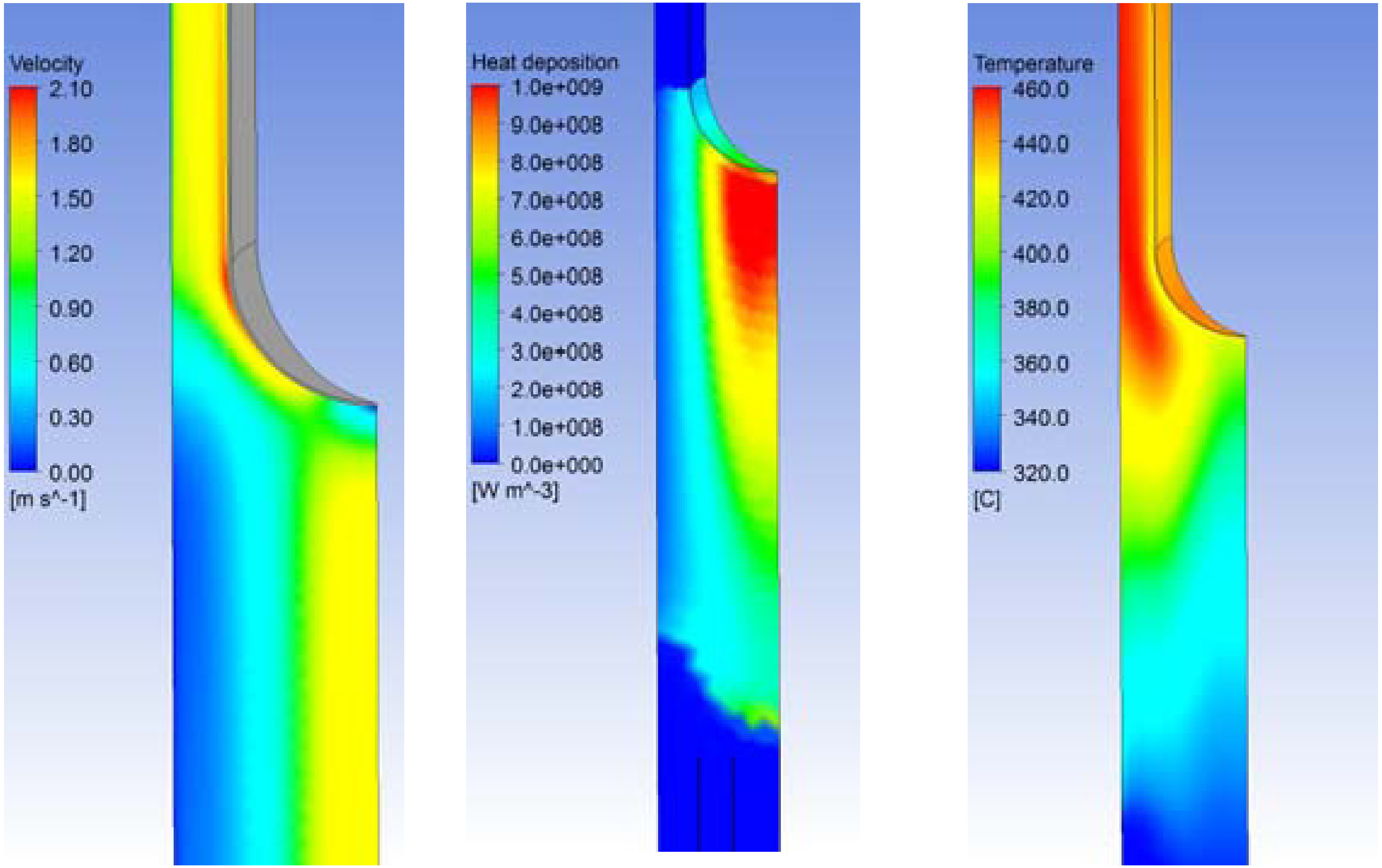


- Elongation reduction below 450°C
- Partial recovery above 500°C
- LBE lowers ductility further but less so at high T

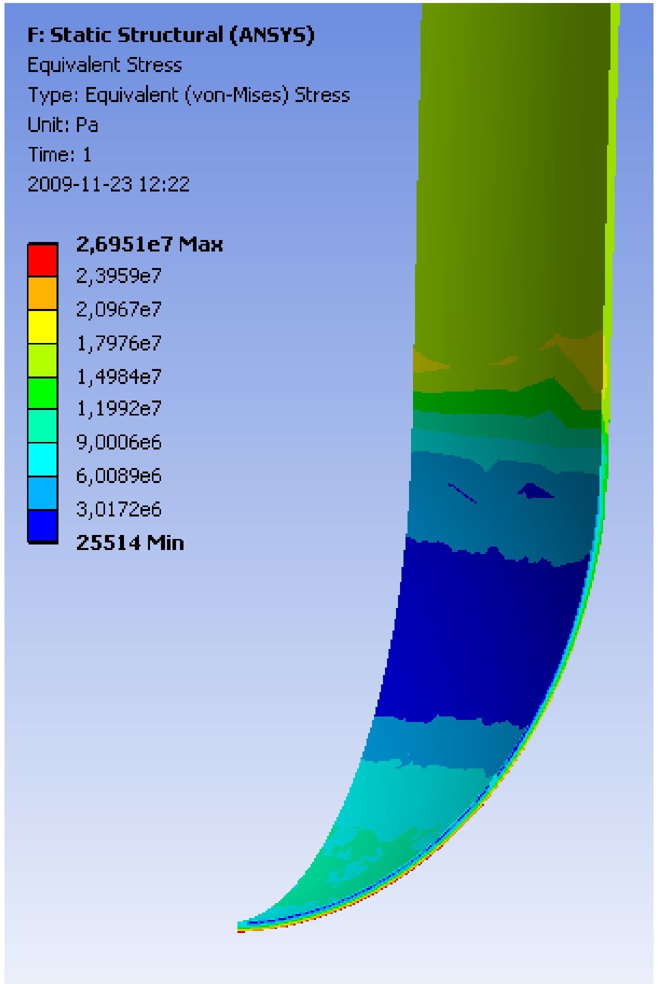
Design efforts target window

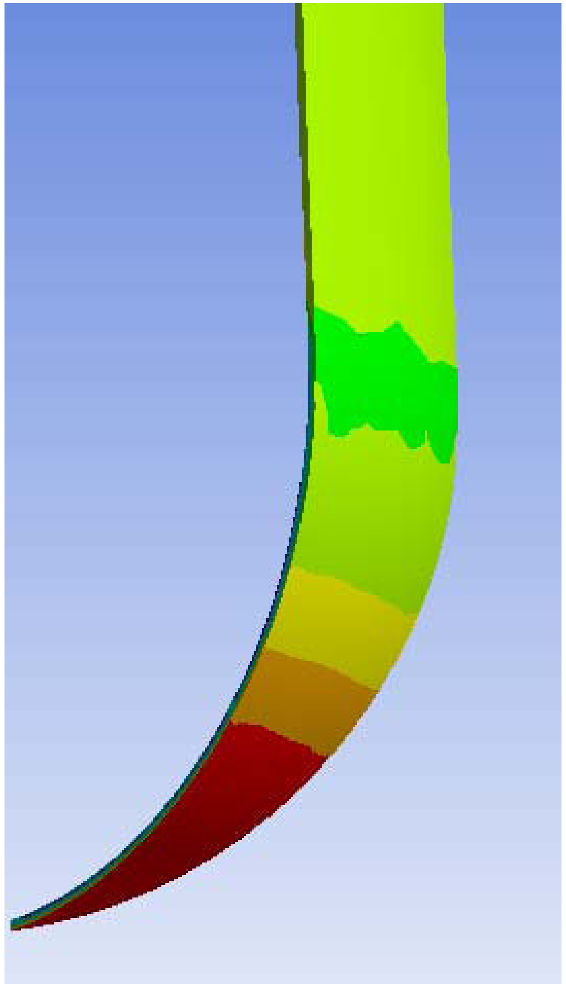
- Target window possible in FM steel (T91) ?
- As low as possible current density
- Operation temperature around 500°C
  - Corrosion ok for short lifetime (min 90 days)
- Stress as low as possible

Design efforts target window



Design efforts target window





Design efforts target window

- To be continued…..

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Thank you !

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