From MYRRHA to XT-ADS

Development of LBE cooled ADS and perspective of Implementation in Europe at Mol

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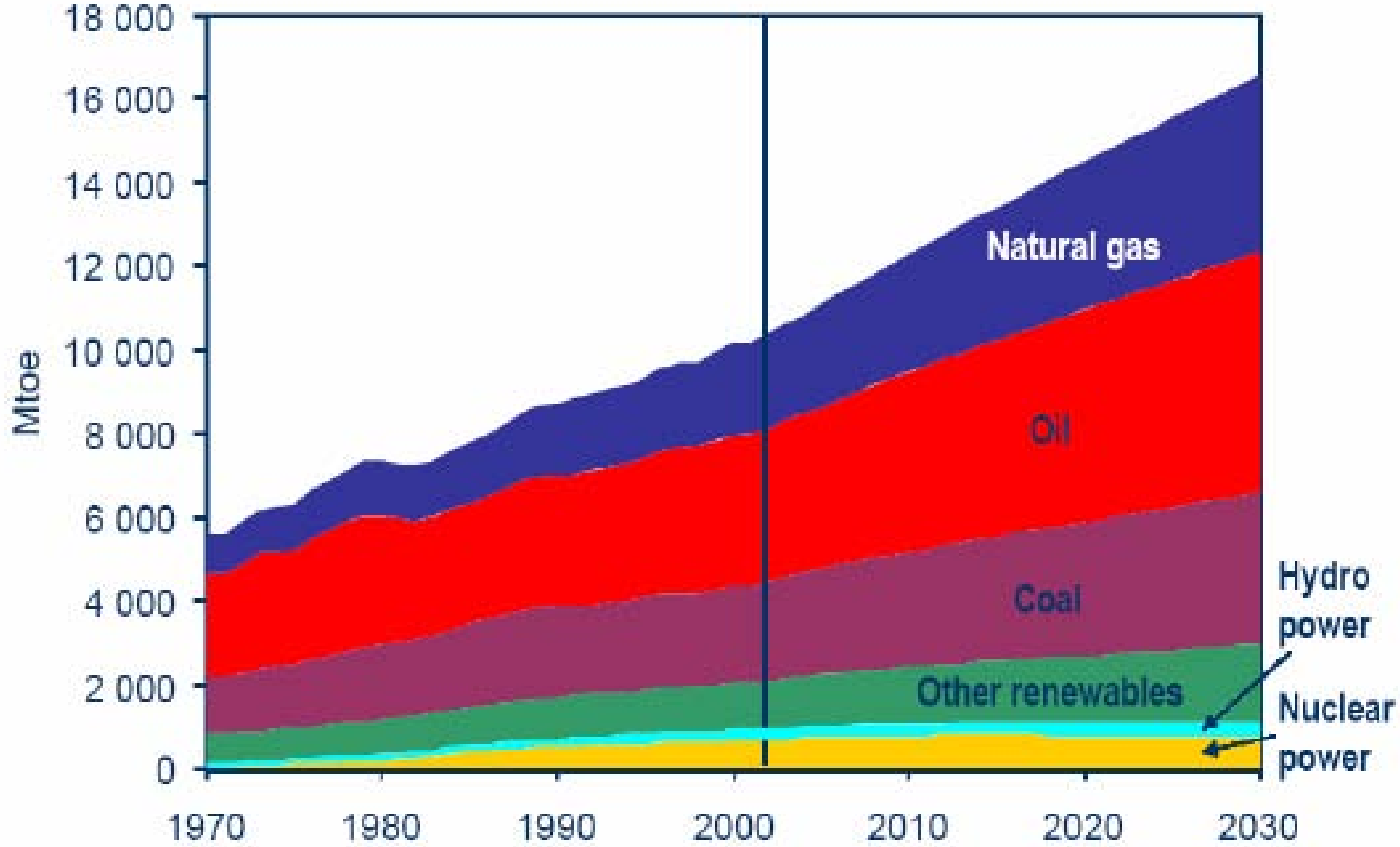
Summary

- Introduction
- MYRRHA Components
- Perspectives for implementation
  1. SCK-CEN Commitment
  2. Opening to Europe
  3. Fast Spectrum Irradiation Facility
  4. Link ADS/Gen. IV LFR
  5. Comprehensive Support R&D
- Roadmap for deployment
- Conclusion

World Primary Energy Demand until 2030, according to IEA



Fossil fuels will continue to dominate the global energy mix, while oil remains the leading fuel

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Cumulated CO_2 emissions from different means of electricity production

Production Mode	grams CO_2 /kWh
• Hydro-electricity	4
• Nuclear	6
• Wind	3-22
• Photovoltaic	60-150
• Combined-cycle gas turbine	427
• Natural gas direct-cycle	883
• Oil	891
• Coal	978

Range reflects the assumption on how the large amount of energy for making the systems are generated!!

Source: SFEN, ACV-DRD Study

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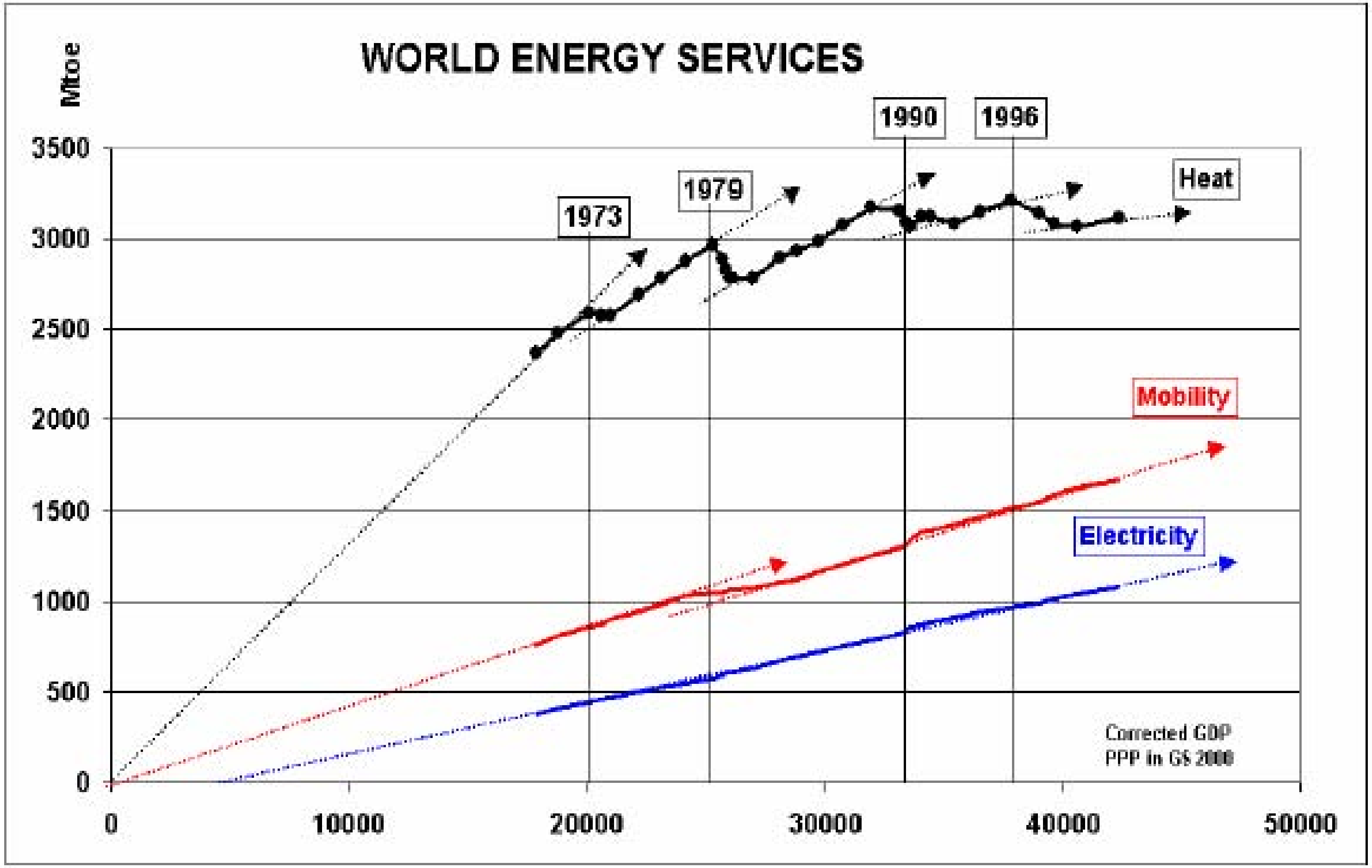
After the oil shock, global energy intensity has dropped down only in stationary uses of heat



Source: WEC, Drivers of the Energy Scene, Dec. 2003

Introduction of Nuclear Power and Reduction of CO_2-emission

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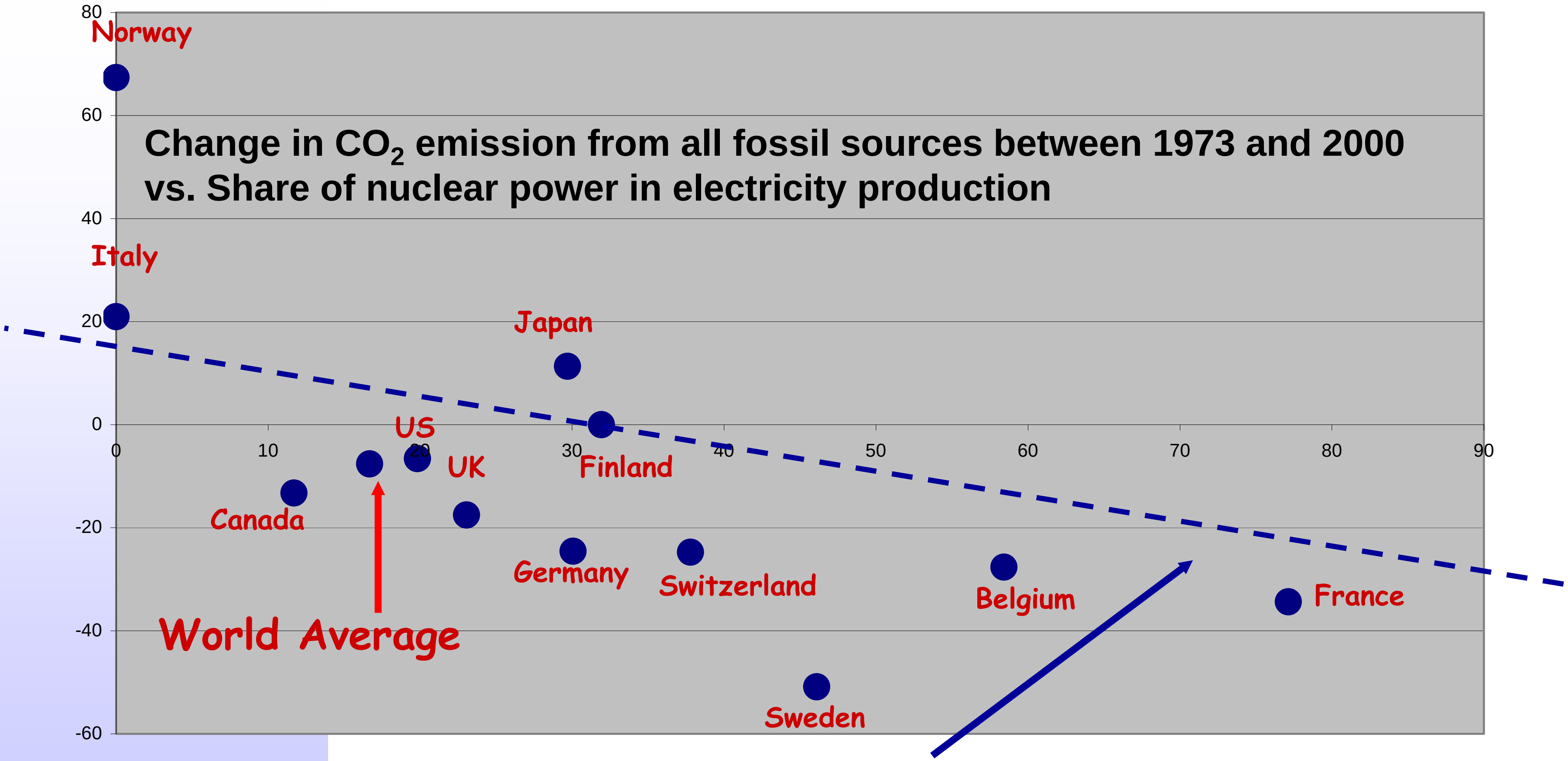
Data: Change from ORNL, Marland et al.
Nuclear Share from EIA, DOE



Is this trend only suggestive or a reality ?

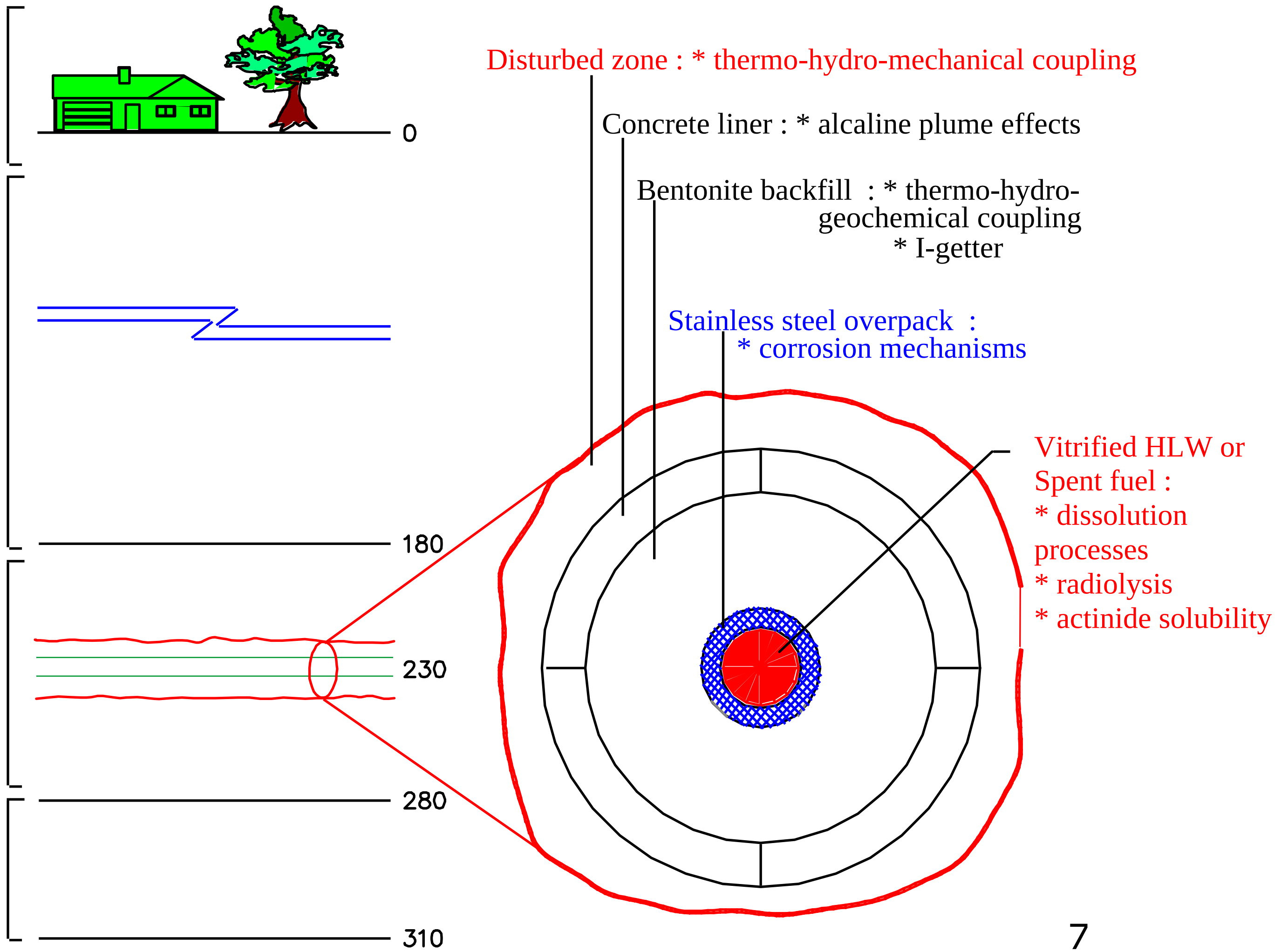
Is there a Solution for HLW?
YES

Biosphere :
* water-soil-plant transfer

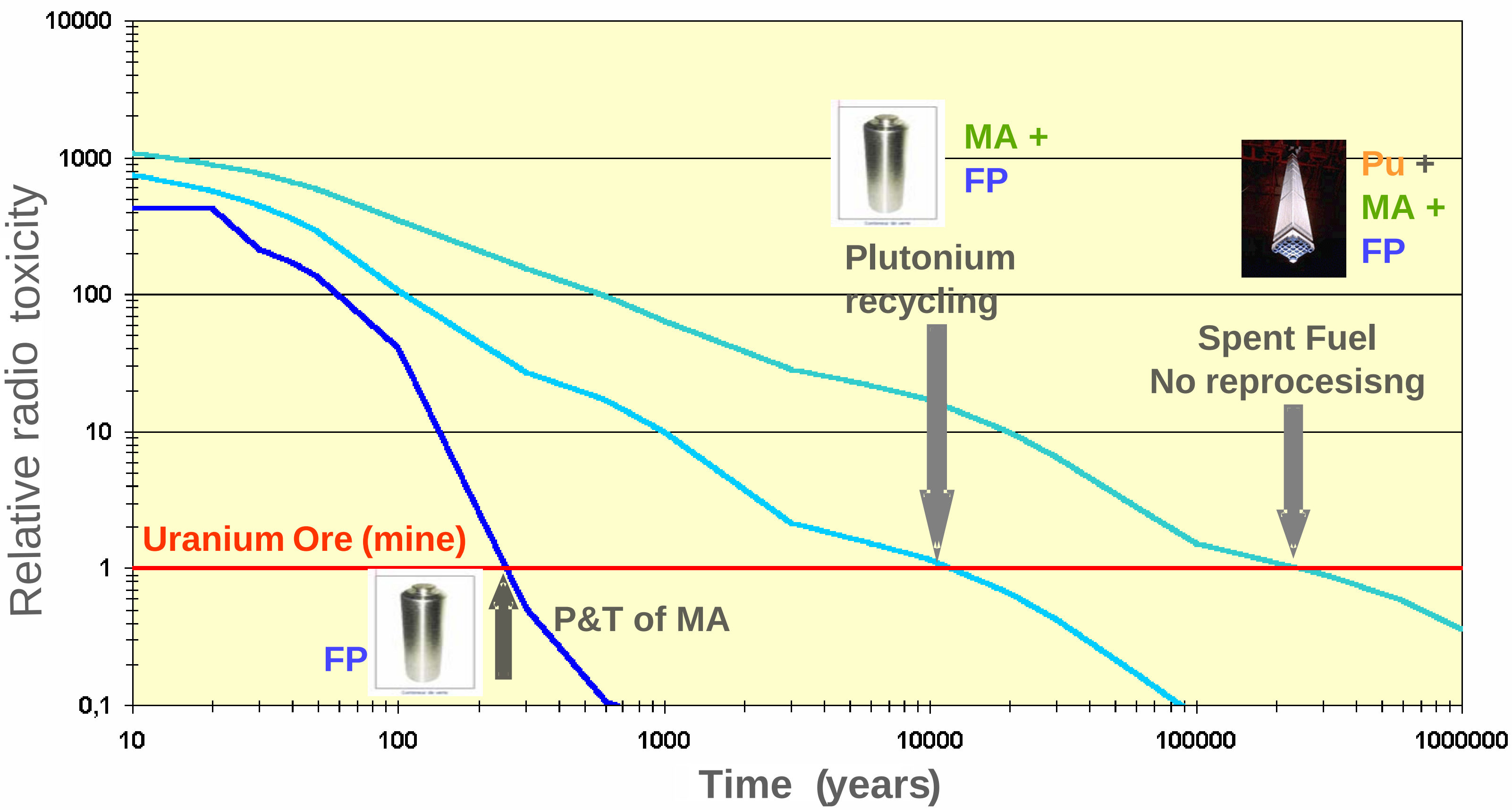
Overlying aquifer :
* paleohydrogeology
* computer code development

Boom Clay :
* radionuclide sorption mechanisms
* organic complexation
* natural trace elements (U, Th, REE) geochemistry
* long term stability i.e. diagenesis, tectonics

Underlying aquifer :
* regional scale hydrogeology



The Problem is the Public acceptance



Estimation Of Amount of Waste Form: Japanese Case study

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(1) "Reference" case

- Conventional reprocessing by PUREX process
- Recovery efficiency of U and Pu : 99.5 %.
- Conventional glass waste form was assumed as the HLW.

(2) "MA recycle" case

- MA was recovered and recycled with Pu.
- Recovery efficiency of MA: 99%
- Recovery efficiency of U and Pu : 99.5 %.
- Glass waste form containing FP and small amount of MA was assumed as the HLW.

(3) "MA+FP P&T" case

- HLW from "Reference case" were divided into 7 categories by partitioning.

Estimation of Reduction of Total Repository Area

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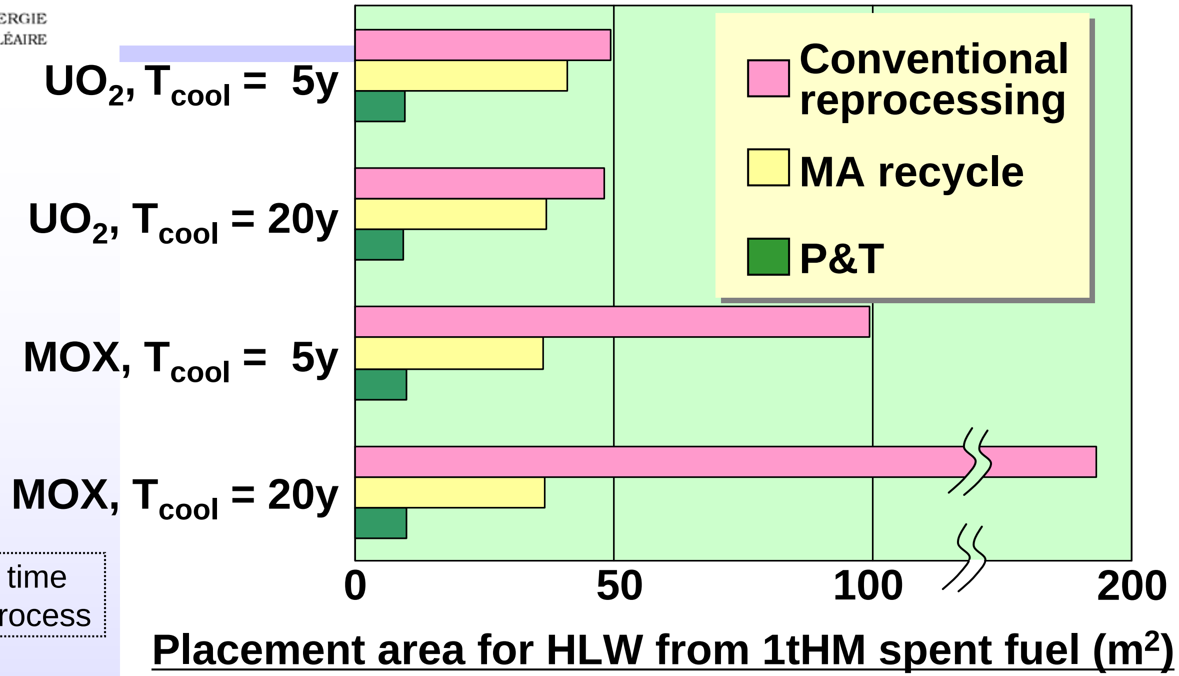

T_{cool} : Cooling time before process

- The area for "MA+FP P&T" case is dominated by Cs and Sr.
- The total area for "MA+FP P&T" case is 1/5 - 1/26 of the "Reference" case and about 1/4 of the "MA recycle" case, even if Tc-PGM is disposed.
- The extension of the repository life-time or capacity is expected. For example, one deep underground repository of 2 km^2, can be effective for 200 years in "MA+FP P&T ", assuming a reprocessing plant of 1,000tHM/y, while one site would be necessary in every 40 years in the conventional case.

Estimation of Repository Area: Results of Total Area

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MYRRHA

Placement area of deep underground repository for HLW from 1 tHM of spent fuel (Unit: m^2)

Fuel	Cooling period	Reference	MA recycle	MA+FP P&T					
		HLW	HLW	(b) Tc-PGM	(c) Cs	(d) Sr	(e) Precipitate	(f) Others	Total a)
		Glass 44m^2/piece	Glass 44m^2/piece	Alloy 0.5m^2/piece	Calcined 4.4m^2/piece	Calcined 4.4m^2/piece	Glass 2.5m^2/piece	Glass 11m^2/piece	
UO_2	5 y	49.3	40.9	(1.04)	3.77	3.05	0.48	1.18	8.47 (9.51)
	10 y	49.1	37.0	(1.04)	3.60	3.14	0.48	1.18	8.40 (9.43)
	20 y	48.2	37.0	(1.04)	3.35	3.26	0.48	1.18	8.27 (9.30)
	50 y	51.9	37.1	(1.04)	2.87	3.49	0.48	1.18	8.02 (9.05)
MOX	5 y	99.4	36.4	(1.46)	4.09	2.89	0.44	1.10	8.52 (9.98)
	10 y	139.0	36.4	(1.46)	3.92	3.01	0.44	1.10	8.47 (9.93)
	20 y	193.2	36.5	(1.46)	3.66	3.18	0.44	1.10	8.39 (9.85)
	50 y	251.7	36.5	(1.46)	3.17	3.50	0.44	1.10	8.22 (9.68)

a) Areas in parentheses are including the areas for Tc-PGM group which may be reused or transmuted.

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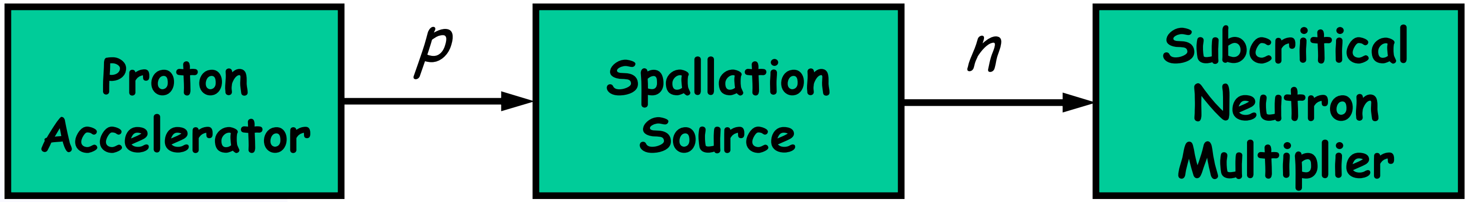
The ADS Concept

MYRRHA



ADS systems are presently studied for nuclear waste transmutation because of the β (delayed neutron fraction which let the reactor control):

^{235}U	650 pcm	^{238}U	1480 pcm
^{238}Pu	120 pcm	^{239}Pu	210 pcm
^{240}Pu	270 pcm	^{241}Pu	490 pcm
^{242}Pu	573 pcm	^{237}Np	334 pcm
^{241}Am	113 pcm	^{243}Am	208 pcm
^{242}Cm	33 pcm	^{244}Cm	100 pcm

Therefore if one wants to load large quantities of MAs in the Waste burner it should be a subcritical machine

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The ADS Principle

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SCK•CEN Competencies

- SCK•CEN core competencies: design, realisation and operation of large nuclear research facilities (BR1, BR2, BR3, VENUS reactors, Pu-Lab, LHMA Hot cells, HADES URL for waste Mgt).
- BR2, a 100 MW MTR, will soon be 45 years old, like other major MTRs in Europe (OSIRIS, HFR, R2).
- SCK•CEN and IBA have been associated to develop the ADONIS project during the 1995-97 period. ADONIS was a ~1.5 MW ADS with 0.15 to 0.3 MW low energy proton beam power (1 to 2 mA * 150 MeV) for Radioisotopes production

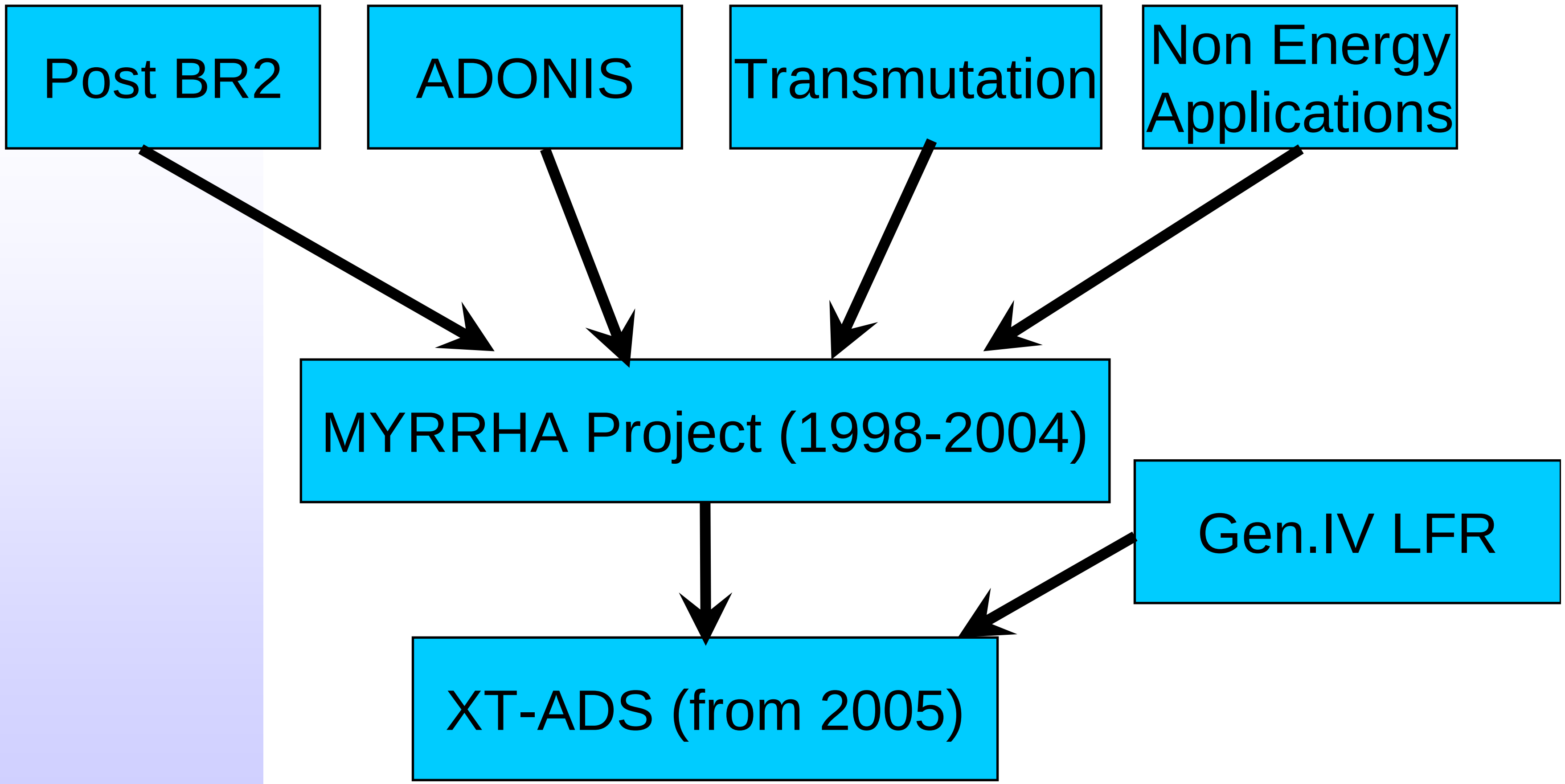
MYRRHA in a European scene

- the RJH (F) project, a thermal spectrum MTR, is the only planned testing reactor for the moment

- MYRRHA would be the natural fast spectrum complementary facility.

- This will put Europe in a strong position towards the support of Gen. III and development of Gen. IV reactors.

MYRRHA Genesis & Evolution towards XT-ADS



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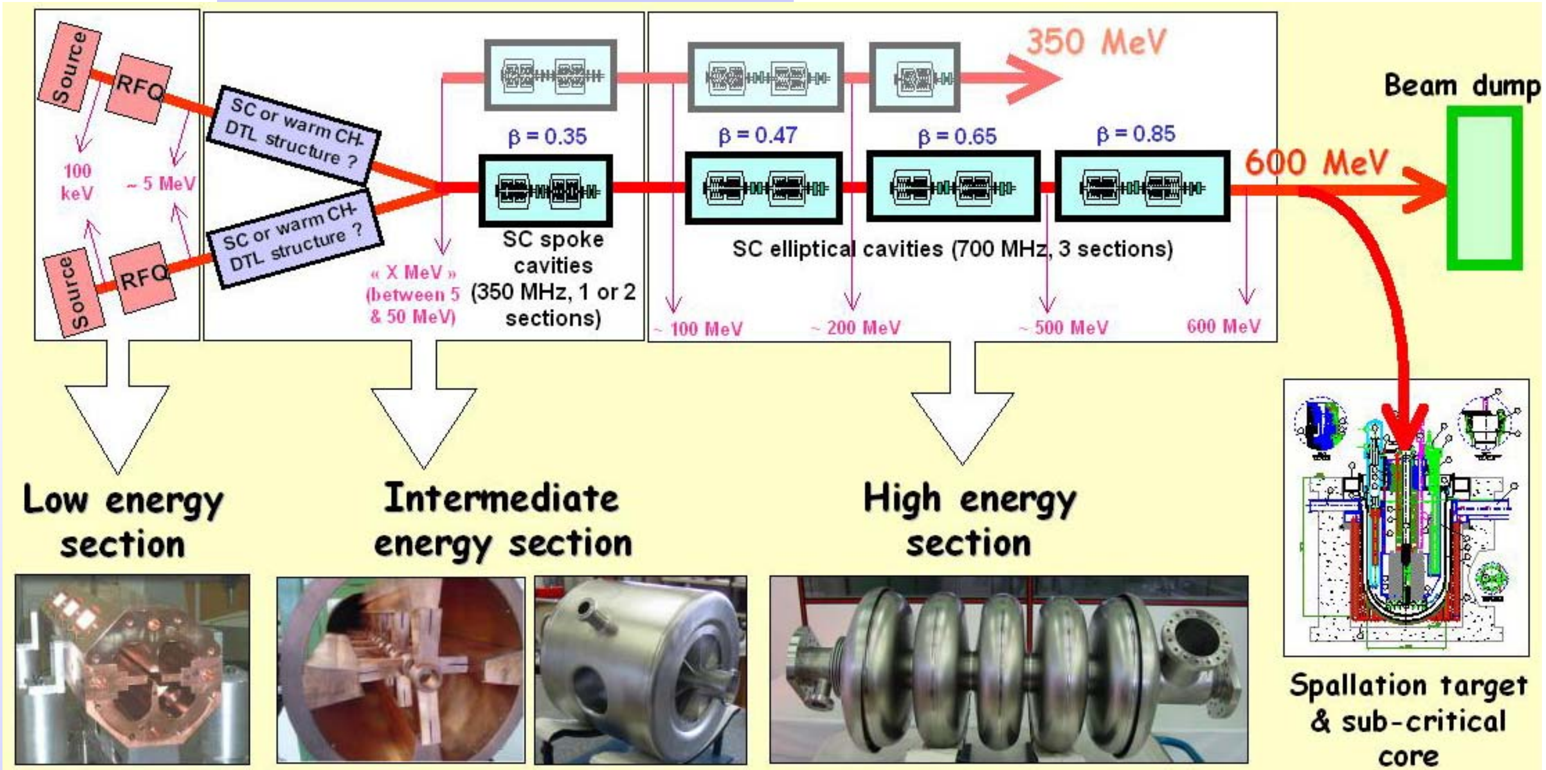
The Applications catalogue: MYRRHA/XT-ADS is to be:

- A full step ADS demo facility
- A P&T testing facility
- A flexible irradiation testing facility in replacement of the SCK•CEN MTR BR2 (100 MW)
- An attractive fast spectrum testing facility in Europe, beyond 2015 complementary to RJH (F)
- HLM Technological prototype as test bench for LFR
- An attractive tool for education and training of young scientists and engineers
- A medical radioisotope production facility

MYRRHA/XT-ADS Components

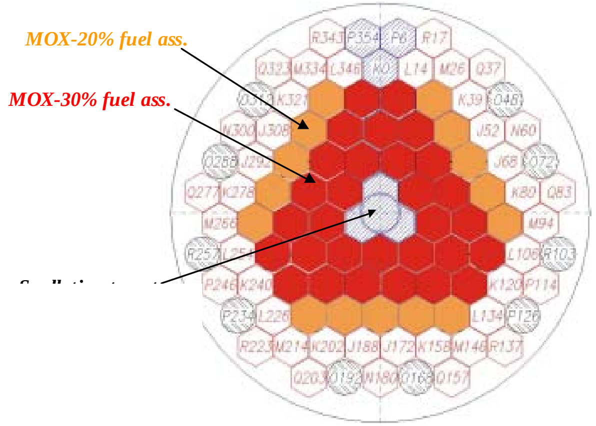
- ACCELERATOR
- SPALLATION SOURCE
- SUB-CRITICAL REACTOR
- REMOTE HANDLING & IN-SERVICE INSPECTION

MYRRHA/XT-ADS Accelerator: the LINAC solution

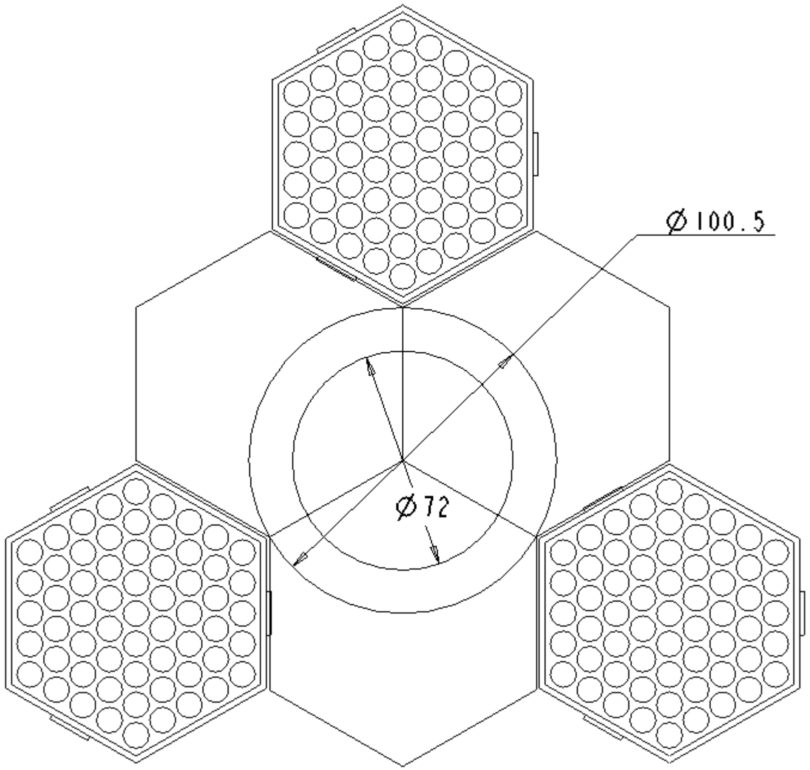


Strong R&D & construction programs for SC linacs are underway worldwide for many applications (Spallation Sources for Neutron Science, Radioactive Ions & Neutrino Beam Facilities, Irradiation Facilities)

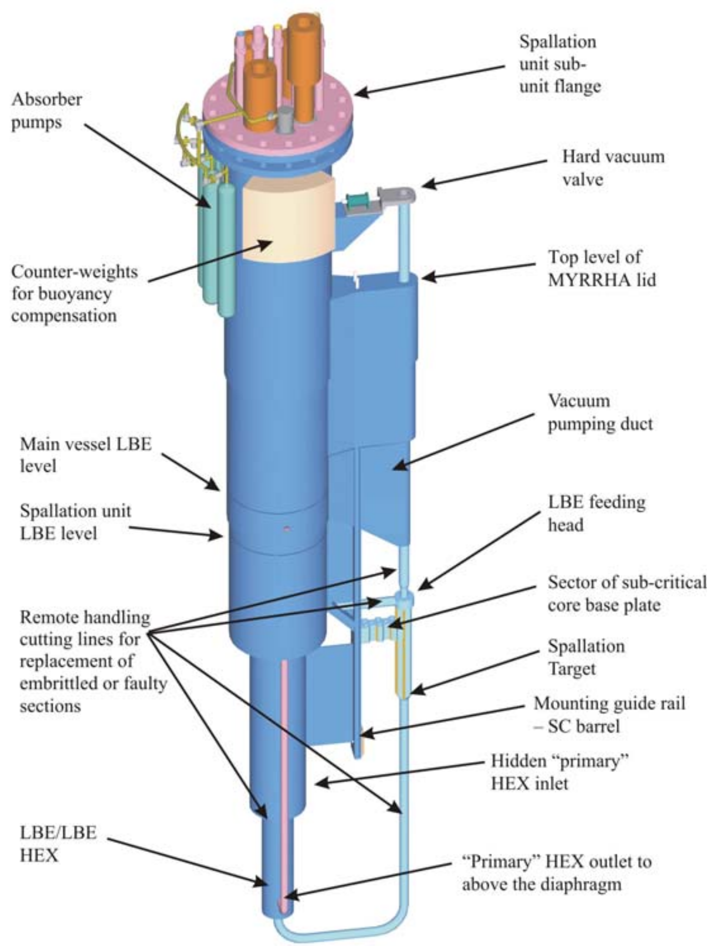
Spallation Target: Radial Geometrical Constraints

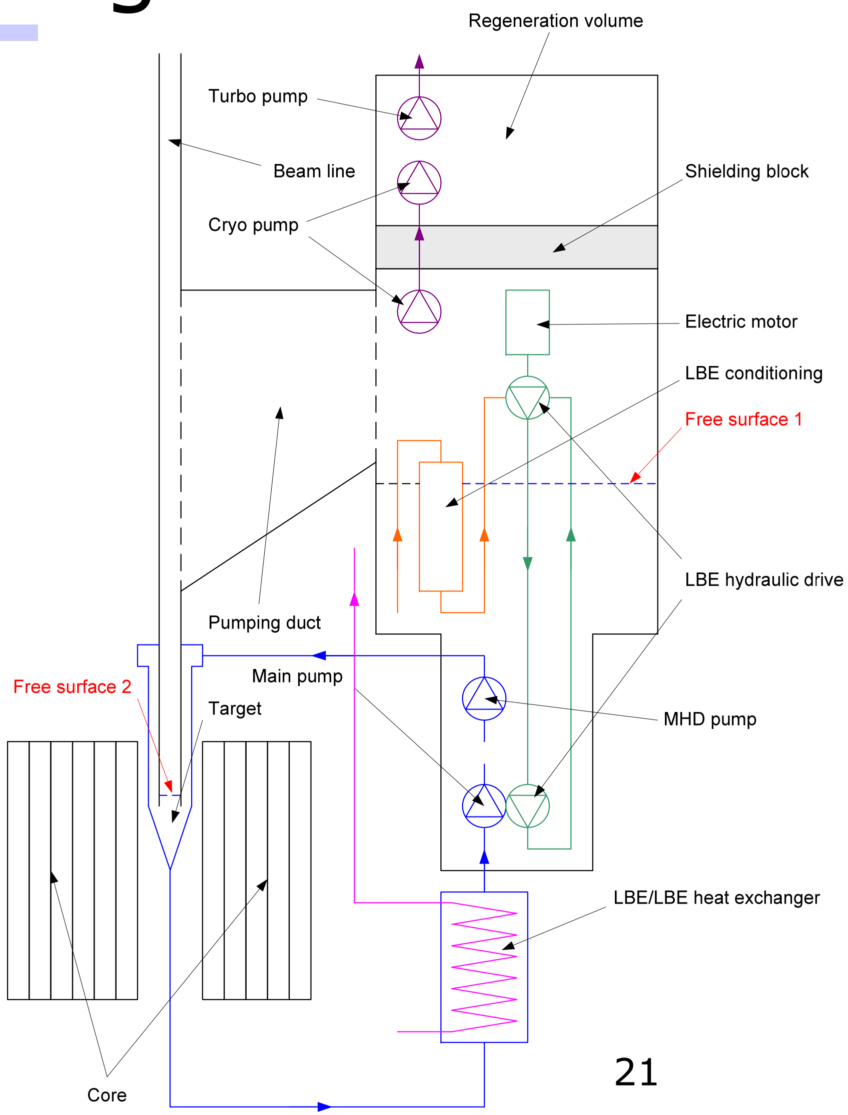


- Due to the high performances desired in the core, we limited drastically the central hole in the core for housing the spallation source



MYRRHA/XT-ADS Spallation Target





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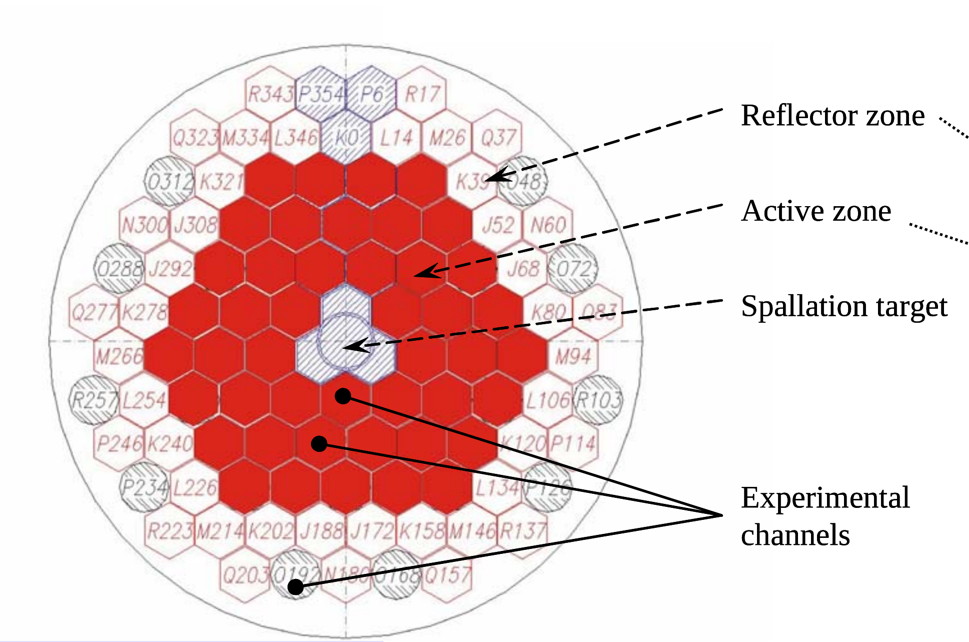
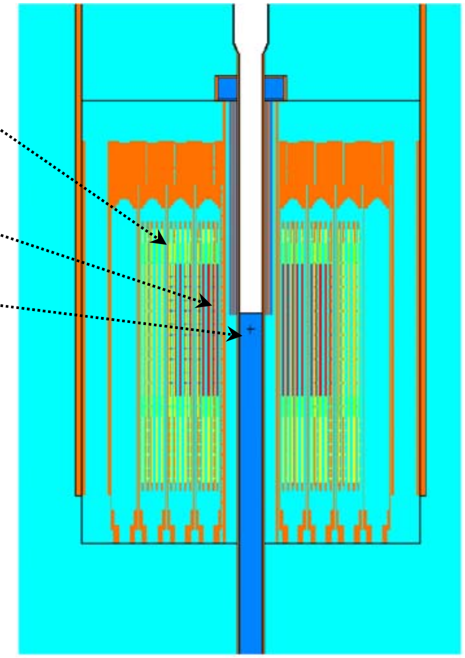
Sub-Critical Reactor
Pb-Bi: benefits and drawbacks

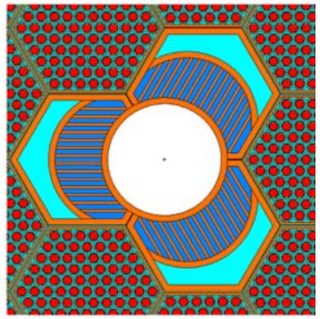
MYRRHA

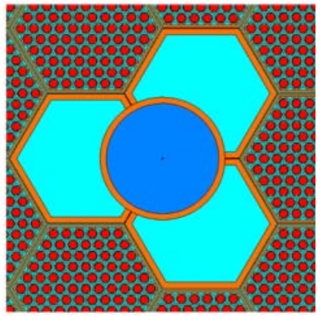
- ☺Undergoes spallation
- ☺Reasonable melting temperature (123 °C)
- ☺Water can be used for the secondary cooling
- ☹High coolant density (steel and fuel float)
- ☹Opaque: blind fuel handling
- ☹Possible problems in case of variation of the eutectic composition (deposits of high melting point phases)
- ☹Bi activates into Po
- ☹The compatibility of Pb-Bi with structural and cladding materials is to be addressed by design

MYRRHA Core configuration
Under updating for XT-ADS





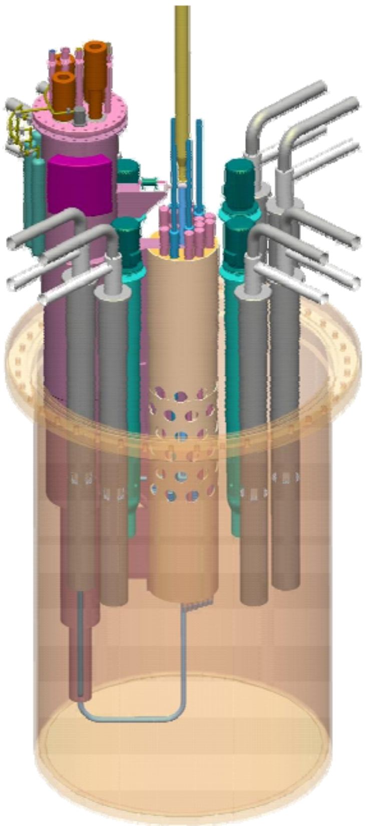




- 99 + 3 hexagonal cells (“macro-cells”)
- Target-block hole is made by 3 removed FA in the central region
- Surrounding active zone composed of 45 (or more) FA
- Outer reflector zone composed of 54 (or less) reflector assemblies

MYRRHA design description
Primary cooling system

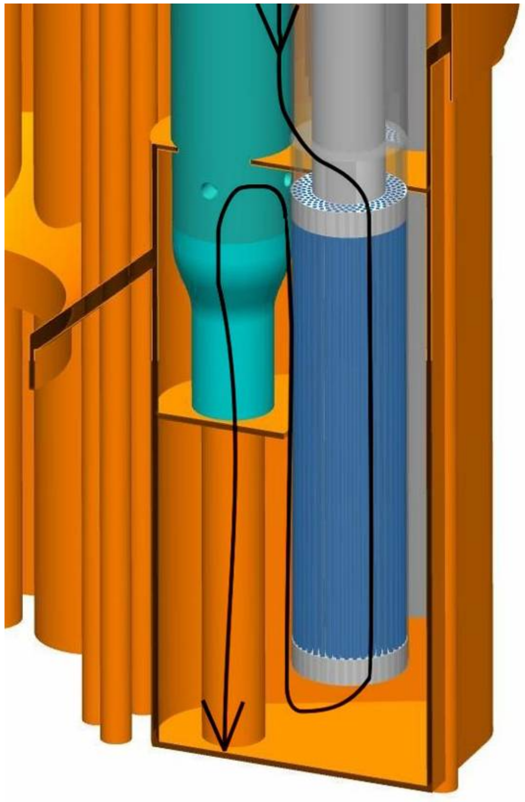
- The cooling system is *designed* for *60 MW_{th}*
- The total heat production in the vessel is the sum of the nominal *core* heat production (50 MW_{th}) and *other* heat sources (1.8 MW)
- Two options were studied : pressurized and boiling water heat exchangers



- *Four groups* with each one pump and two LBE/water heat exchangers are installed at the periphery of the vessel = 4 pumps and 8 heat exchangers.
- The system is capable to evacuate the total heat production even in the case of the *failure of one pump*

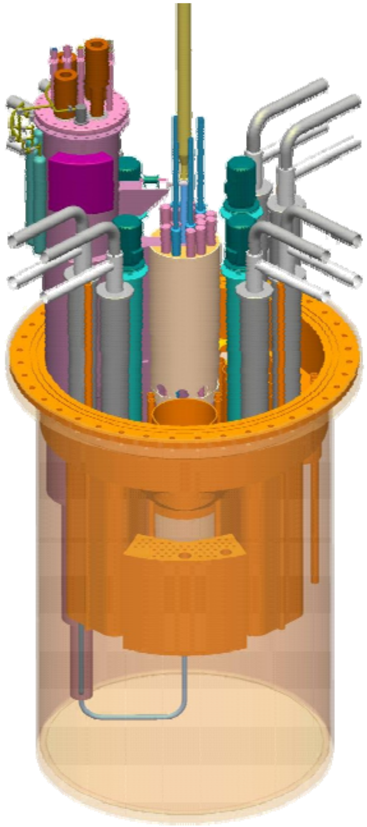
MYRRHA design description
Primary cooling system

- Each HX/PP group is placed in its casing in such a way that the flow path describes a vertical *chicane* which should help to *avoid water ingress* in the core by providing the separation of water/ vapour and Pb-Bi in case of a tube rupture.
- A *leak detection system* on each HX/pump casing is foreseen. It detects the presence of steam or water at the high point of the chicane.



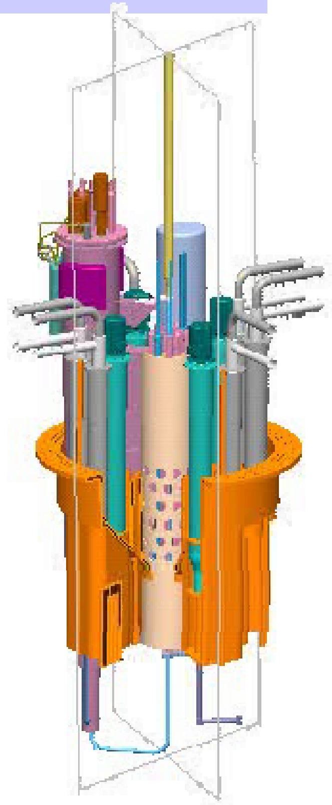
MYRRHA design description
Diaphragm

- forces the coolant *flow path* through the core, separating the lower part (200°C, high pressure) of the Pb-Bi from the upper part (337°C, low pressure);
- supports the two in-vessel *fuel storages* (which are foreseen to avoid excessive delay between operation cycles);



- has *4 casings* containing the pumps and heat exchangers;
- has numerous *penetrations* for the large components (spallation loop, core, pumps, heat exchan-gers, handling machines) and for the smaller irradiation devices.

MYRRHA design description
Diaphragm



MYRRHA design description
In-vessel fuel manipulators

- The fuel handling is performed *underneath* the core:
  - because the *irradiation devices* (inside the core and in the periphery of the core as well) will stay several cycles in the reactor and because their handling will be a difficult process, it is wished to keep them into location while reloading the core – this makes fuel manipulation above the core very impractically;
  - the room situated directly above the compact core will be *occupied* by instrumentation, the beam tube and partially by the spallation loop, with which the fuel handling would interfere if performed from the top of the core,
  - the *interlinking* of the spallation loop with the core makes some fuel assembly positions inaccessible from above,
- The fuel assemblies rest by *buoyancy* force under the support plate.

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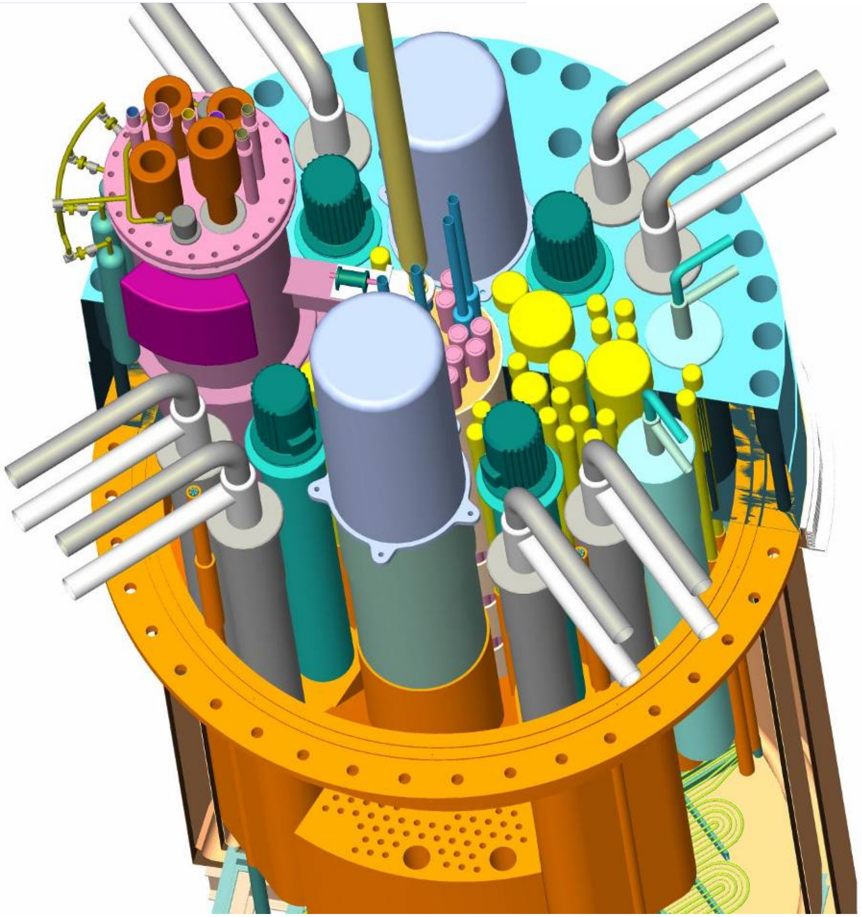
MYRRHA design description
In-vessel fuel manipulators



MYRRHA design description
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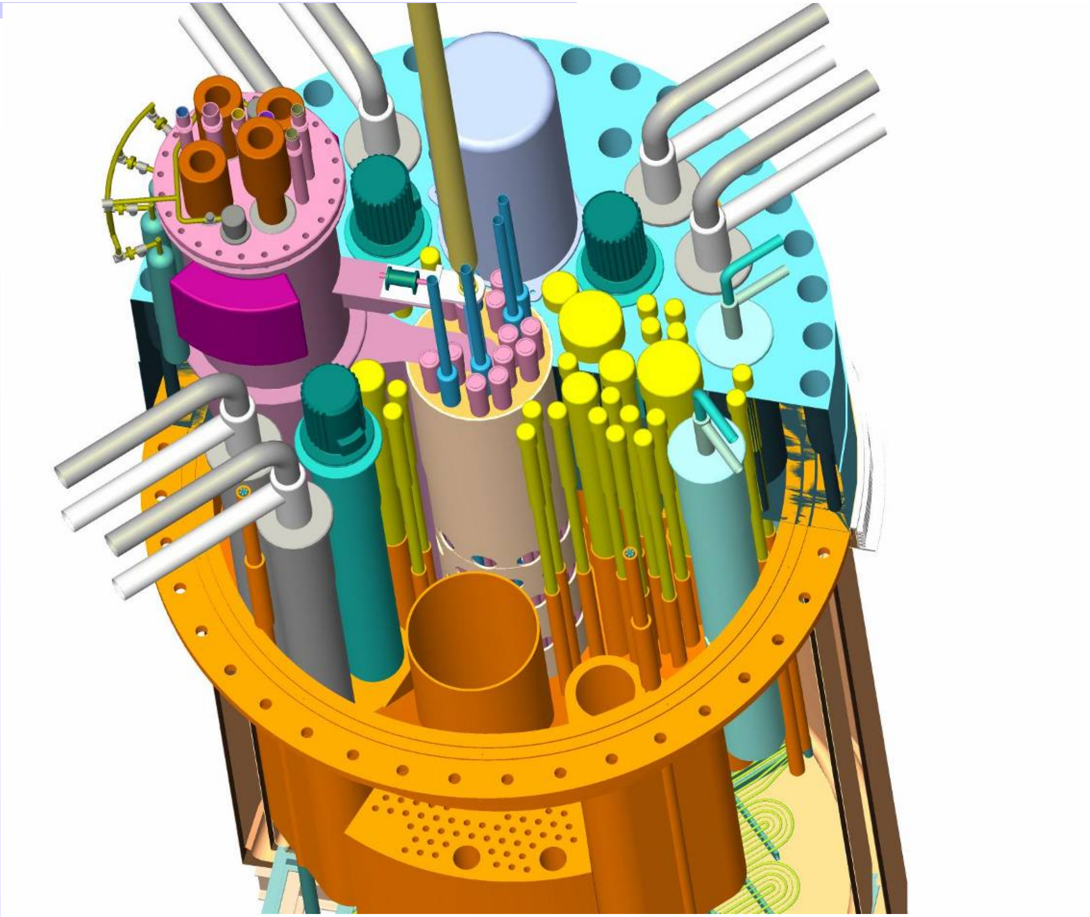

MYRRHA design description
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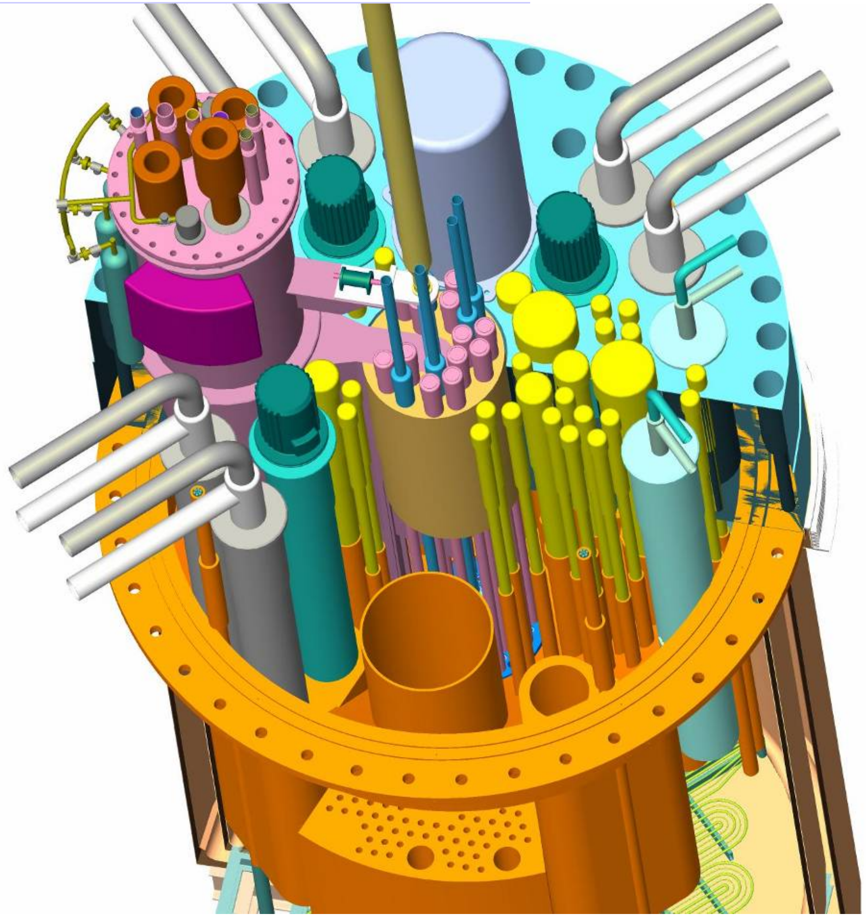
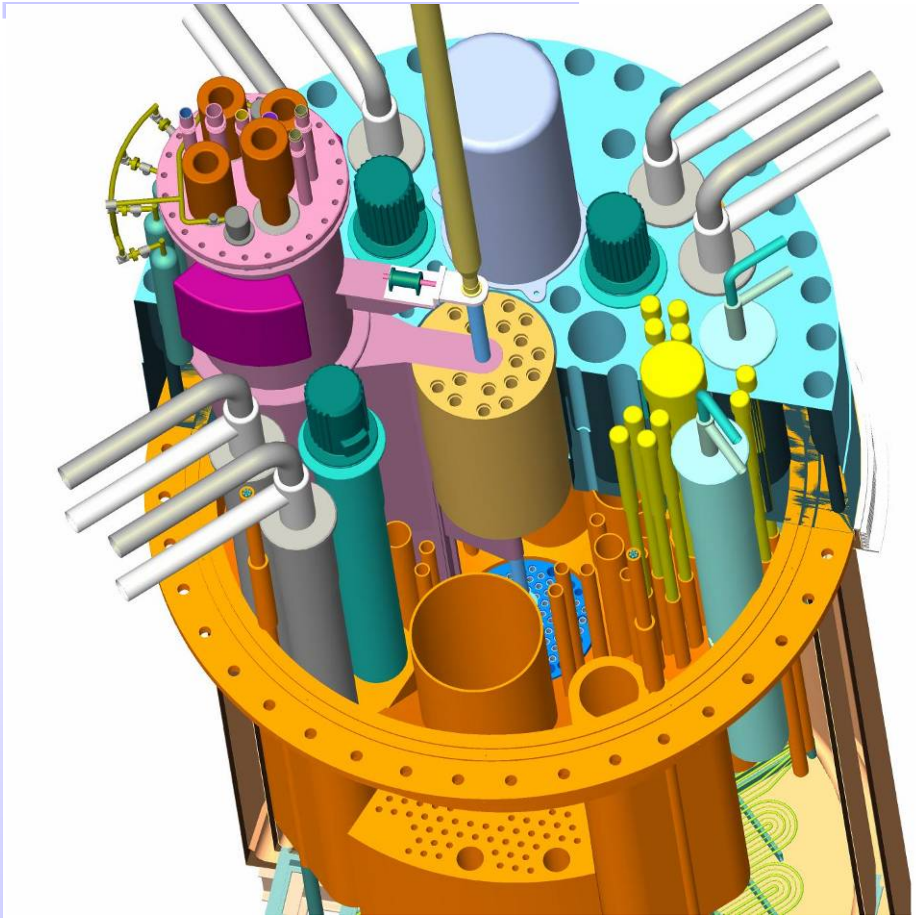
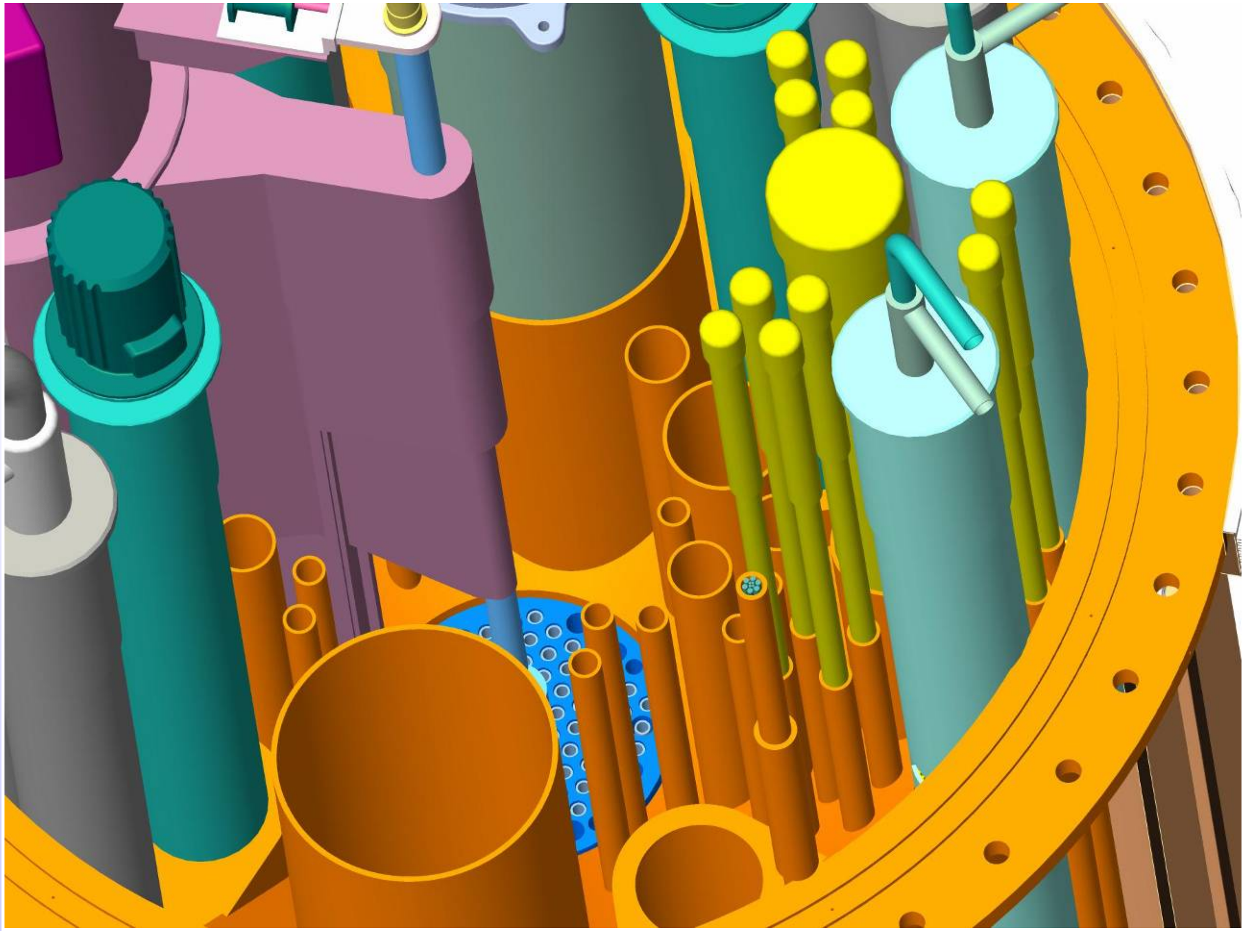


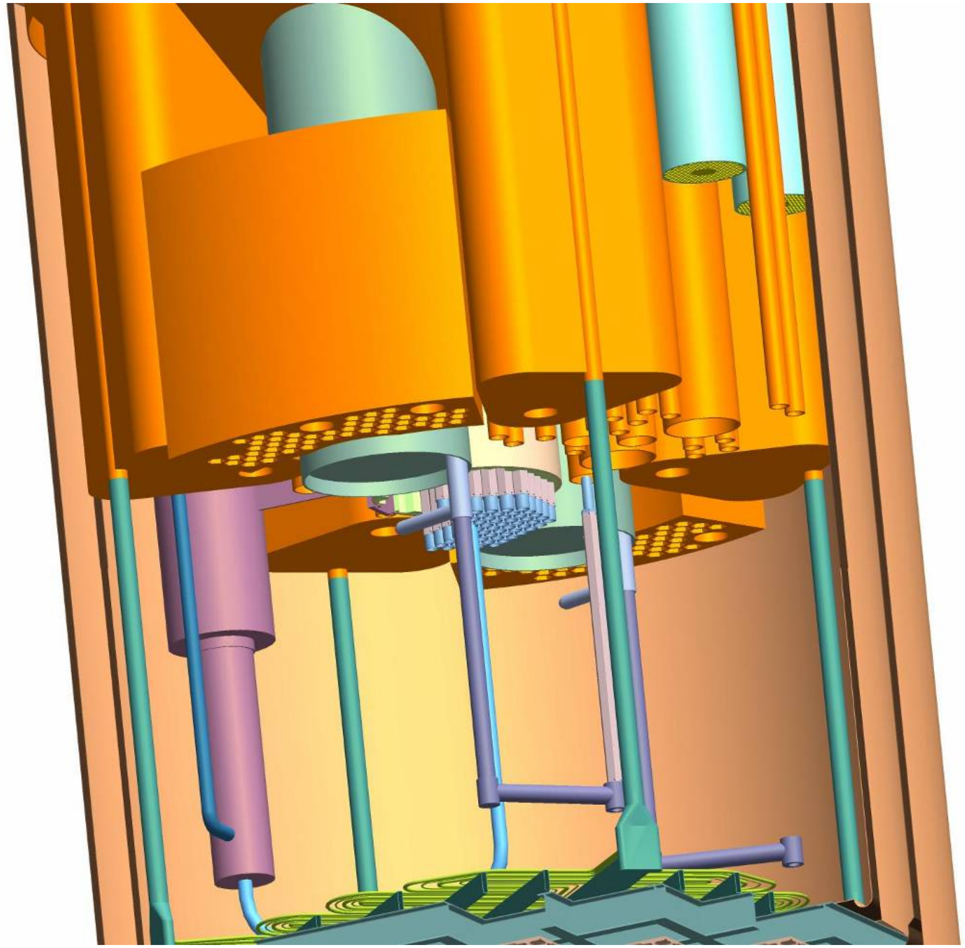
MYRRHA design description
In-vessel fuel manipulators



MYRRHA design description
In-vessel fuel manipulators

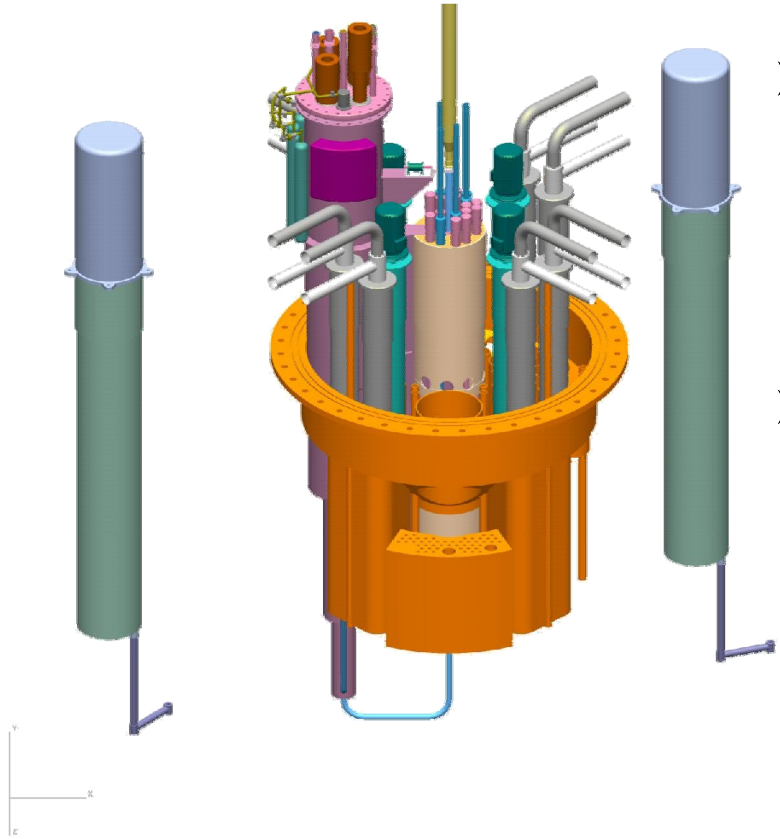


MYRRHA design description
In-vessel fuel manipulators



3. MYRRHA design description
In-vessel fuel manipulators

- *Two* handling systems are inserted in a penetration of the reactor cover on opposite sides of the core.
- Each system has a *rotating plug*, with an *offset arm*.



- The arm can rotate in the rotating plug, and so has *access to half of the core*.
- The arm can move up and down by about 2 m to extract the assemblies from the core.

MYRRHA design description
In-vessel fuel manipulators

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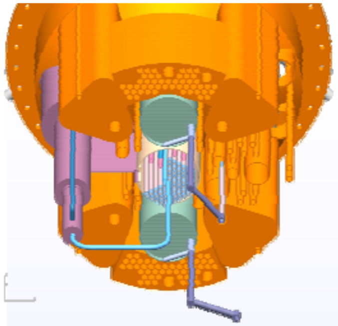
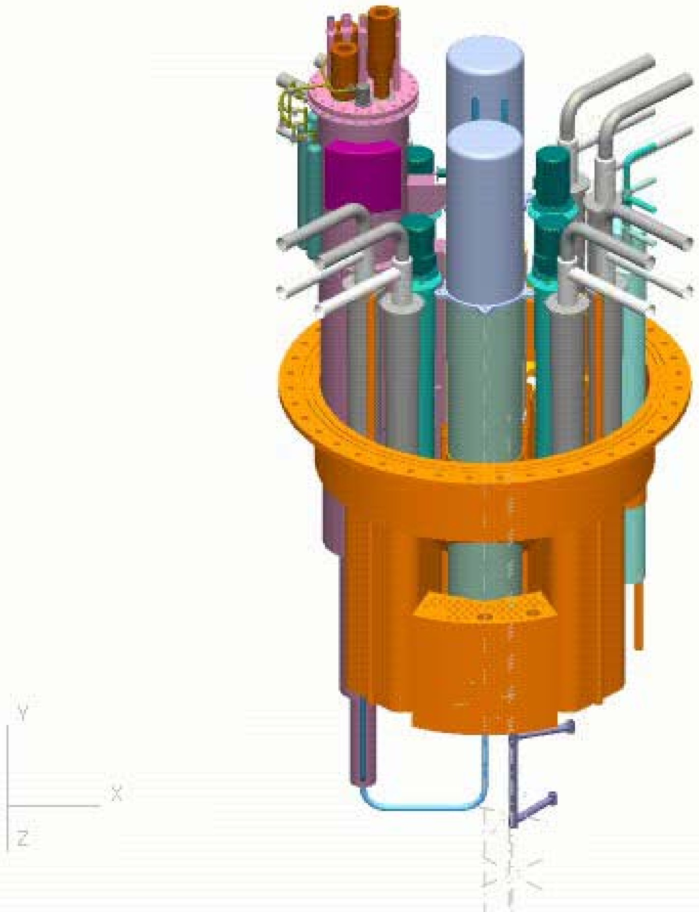
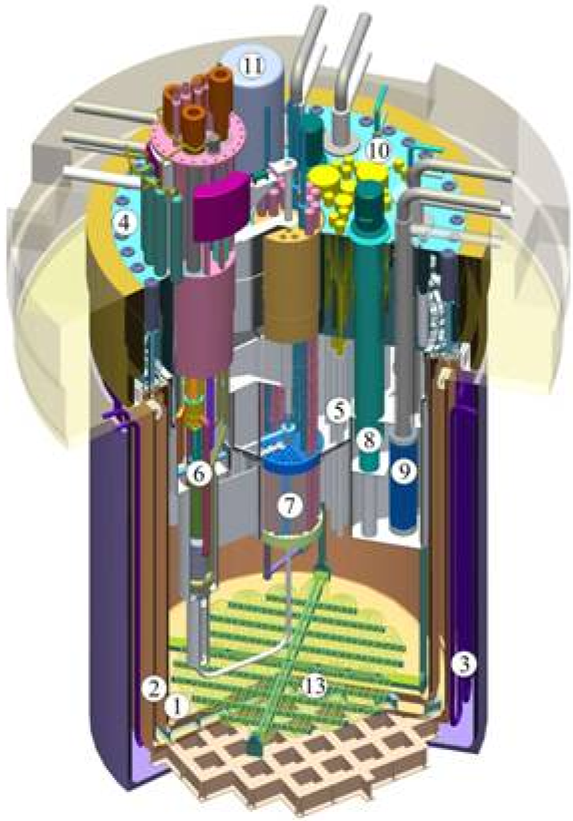




Design of MYRRHA Overall configuration

Under updating for XT-ADS

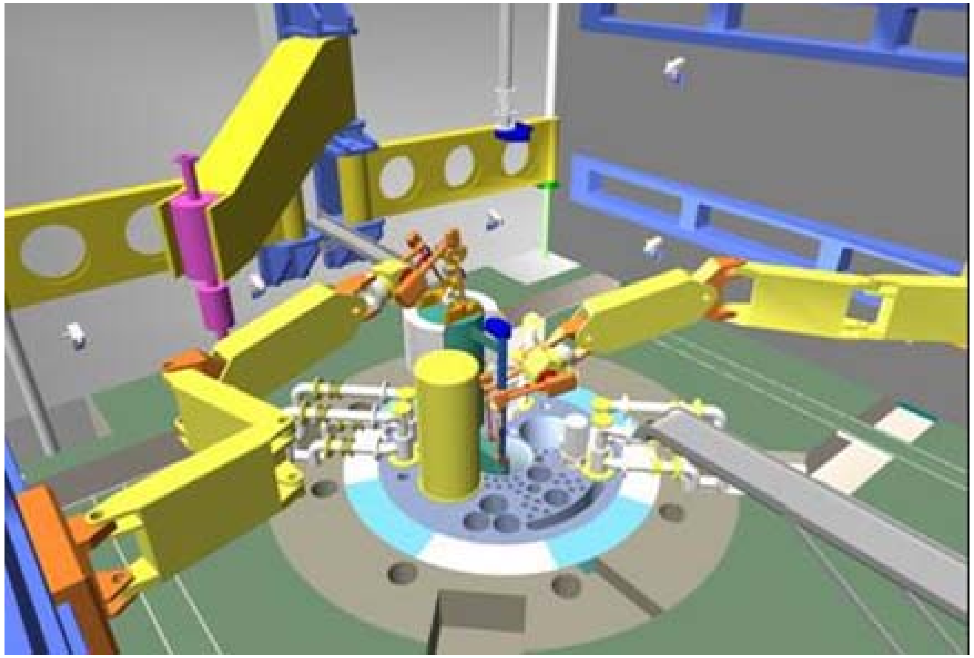


1. inner vessel
2. guard vessel
3. cooling tubes
4. cover
5. diaphragm
6. spallation loop
7. sub-critical core
8. primary pumps
9. primary heat exchangers
10. emergency heat exchangers
11. in-vessel fuel transfer machine
12. in-vessel fuel storage
13. coolant conditioning system

Design of MYRRHA: Remote handling

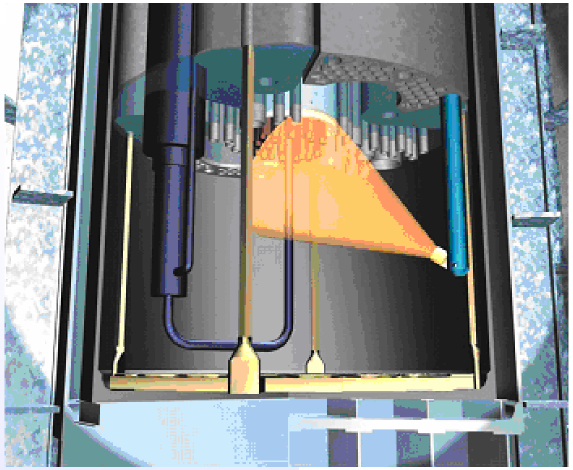
All MYRRHA maintenance & operation on the machine primary systems and associated equipment are performed by remote handling, which is based on the *Man-In-The-Loop principle*:

- force reflecting servomanipulators
- Master-Slave mode: the slave servo-manipulators are commanded by remote operators using kinematically identical master manipulators
- supported with closed-cycle TV (CCTV) feedback

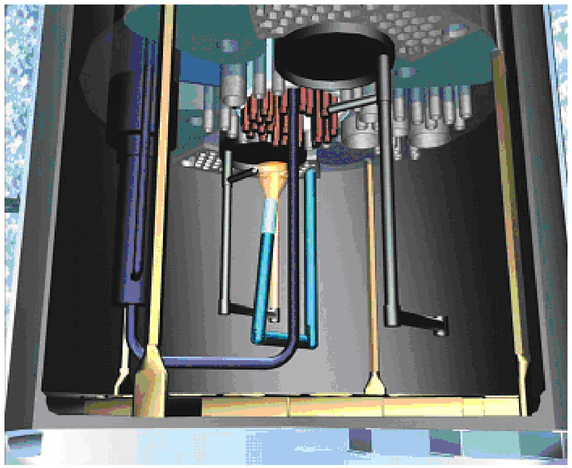


OTL concludes positive on the feasibility of the proposed RH approach.

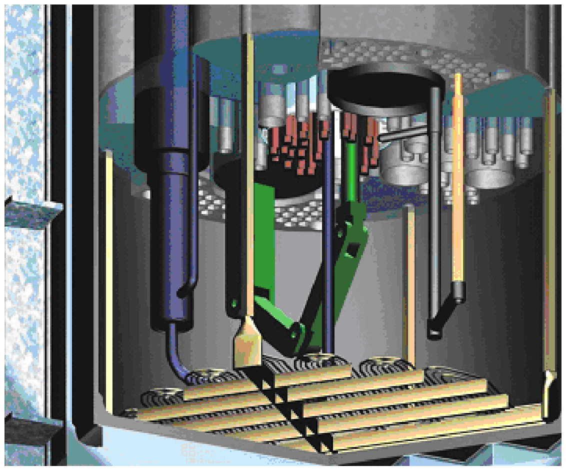
Design of MYRRHA: In-service inspection and repair



Two permanently installed *inspection* manipulators with US camera to provide a general *overview*. (periscope type device with three degrees of freedom)



The second *inspection* manipulator positions the camera close to critical components for *detailed* inspection. (anthropomorphic type device with five degrees of freedom)



The *repair* manipulator recovers debris or deploys specialised tooling for repair. (anthropomorphic type device with eight degrees of freedom)

OTL concludes positive on the feasibility of the proposed RH approach.

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Perspectives for Implementation

1-SCK•CEN Commitment

- SCK•CEN Mgt has declared its readiness to welcome a fast spectrum irradiation facility at its technical site in Mol
- SCK•CEN has finished the preparation of a business plan and a funding plan that has been made available to the Belgian Government in May 2007 and will be presented to potential partners by autumn 2007
- Bilateral discussions with some potential partners are already going on (CNRS, CEA, CIEMAT, …)

2-Opening MYRRHA to Europe => XT-ADS

- MYRRHA Draft-2 has been made available to the EUROTRANS Community
- SCK•CEN is studying in collaboration with EUROTRANS partners the modifications needed to achieve the XT-ADS objectives
- Considering Joint Undertaking for setting up the frame for the realisation at European level

2. XT-ADS design description
Reference architecture

- The reference architecture of the primary system as decided during Eurotrans DCC_2 meeting (Lyon 10/2006):
- Modifications with respect to MYRRHA (*between brackets*)
  - primary system capable to extract 70 MW_{th} total heat power (*60 MW_{th}*)
  - core inlet and outlet LBE cooling temperatures : 300°C – 400°C (*200°C – 340°C*)
  - improved natural convection in case of PLOH by:
    - ✓ core pressure drop Δp limited to 1000 mbar
    - ✓ increased elevation between PHX & core to 2 m
  - simplified flat diaphragm
  - reduced number of primary components to 2 groups to reduce costs (*4 groups*)

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2. XT-ADS design description
Reference architecture

- Modifications with respect to MYRRHA (cont'd)
  - reduced number of possible IPS in the core to 8 possible positions
    (*19 positions*)
  - no test rigs positions outside the core
    (*many positions outside the core*)
  - boiling water heat exchangers at lowest possible pressure
  - decay heat removal (DHR) through PHX/secondary loops + vault cooling system (RVACS)
    (*emergency heat exchangers*)
  - hanging vessel with elliptical bottom head
    (*standing vessel with flat bottom*)
  - LBE cold plenum has free level (0.5 m underneath vessel top)
  - LBE hot free level is 1 m underneath cold free level (= Δp core)

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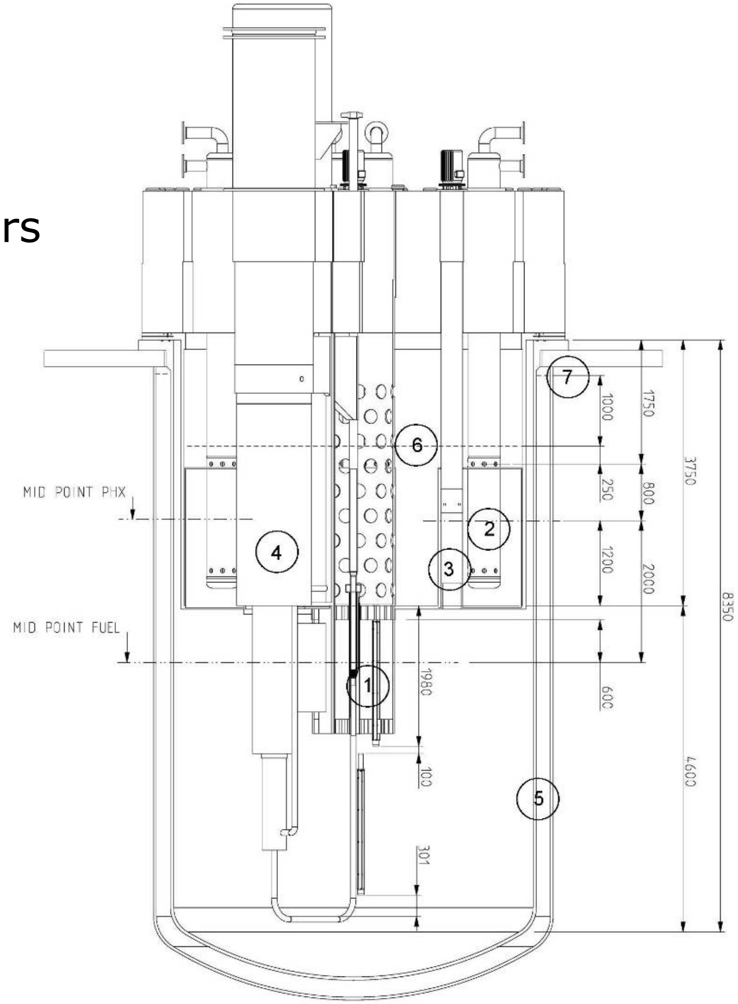
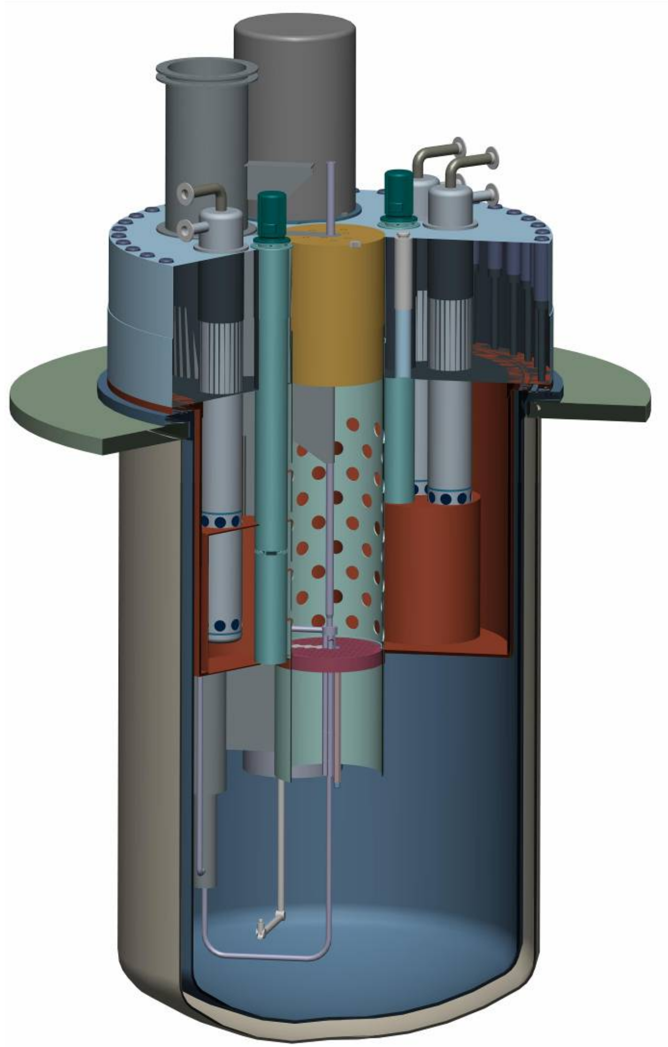
2. XT-ADS design description
XT-ADS overall configuration

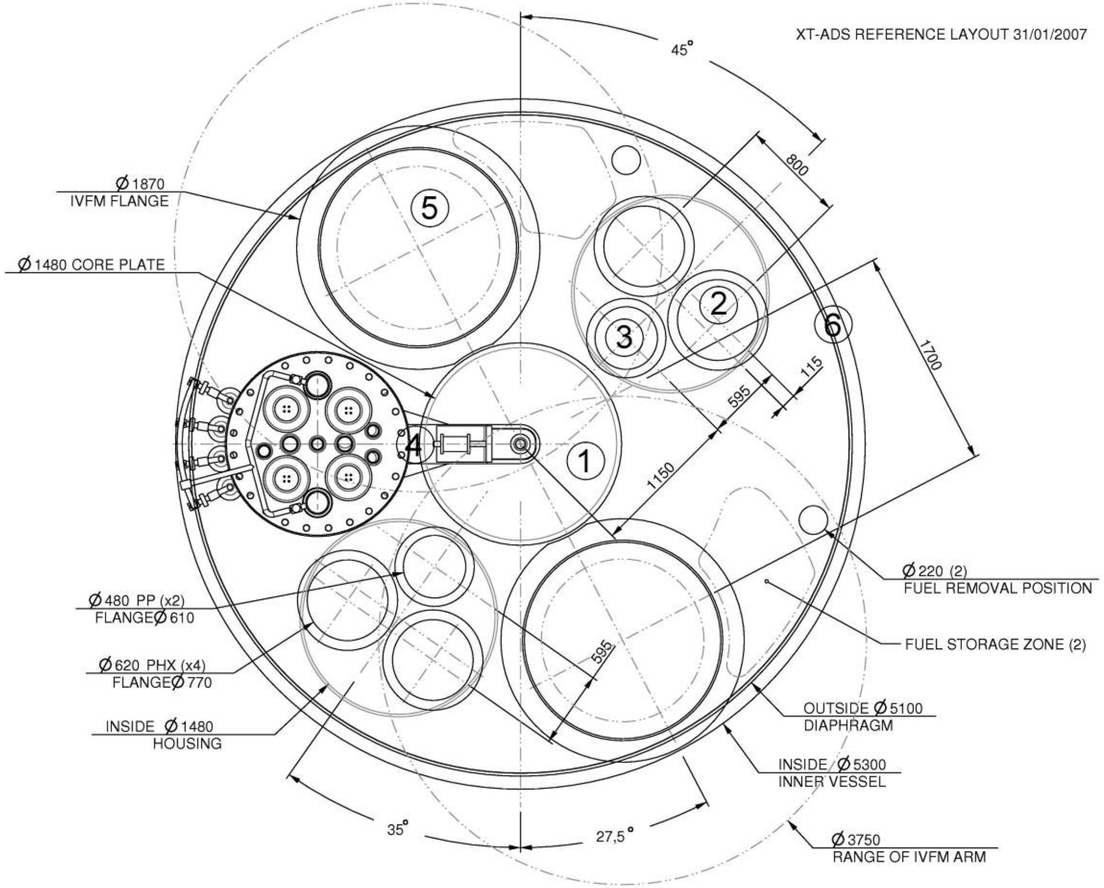
1. Core
2. Heat exchangers (2 x 2)
3. Pumps (2 x 1)
4. Spallation loop
5. Vessels
6. LBE hot level
7. LBE cold level



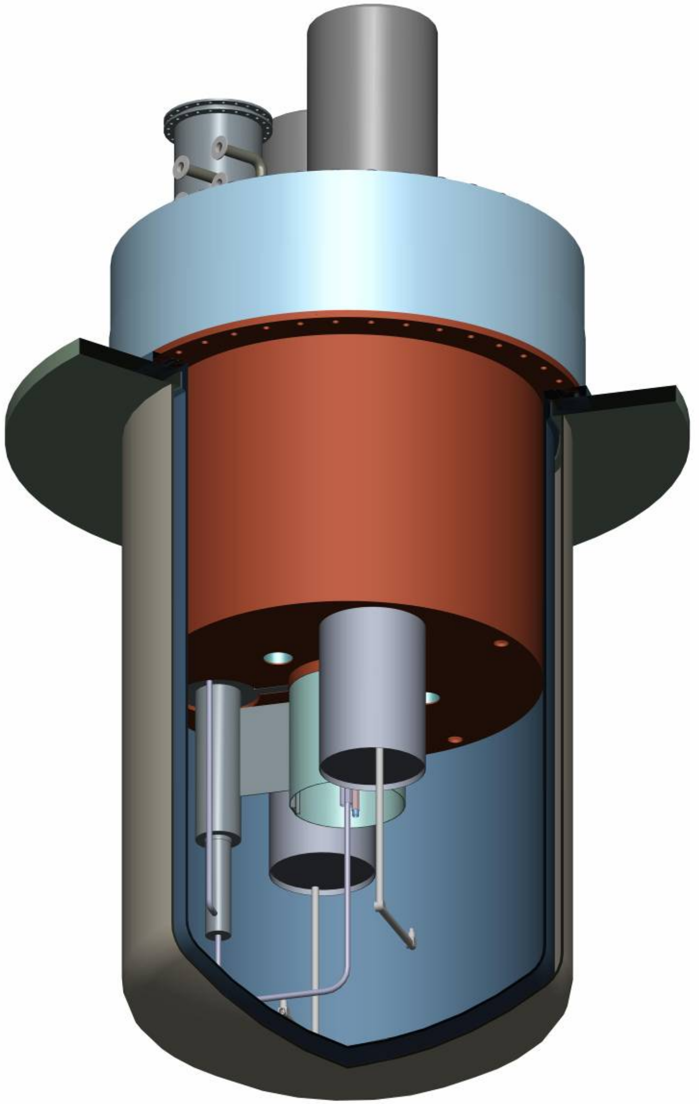


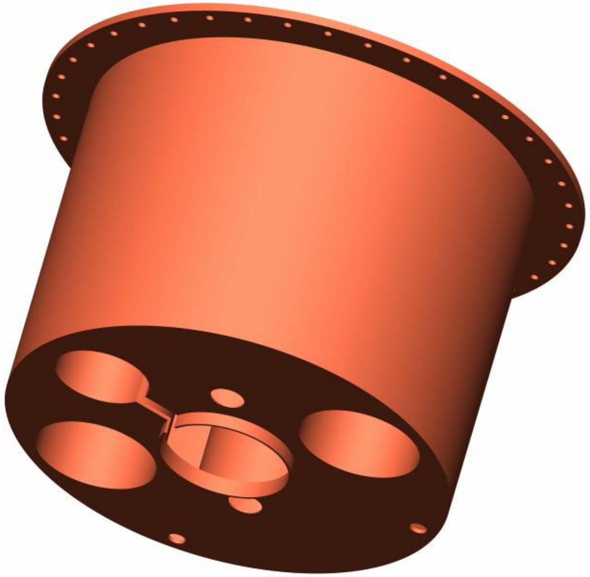
2. XT-ADS design description
XT-ADS overall configuration

1. Core
2. Heat exchangers (2 x 2)
3. Pumps (2 x 1)
4. Spallation loop
5. Fuel manipulators (2 units)
6. Vessel



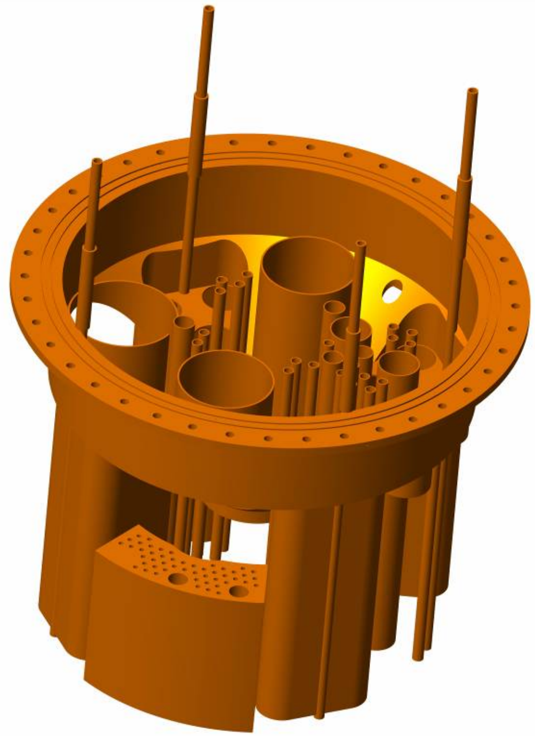
2. XT-ADS design description
Simplified diaphragm





XT-ADS

MYRRHA

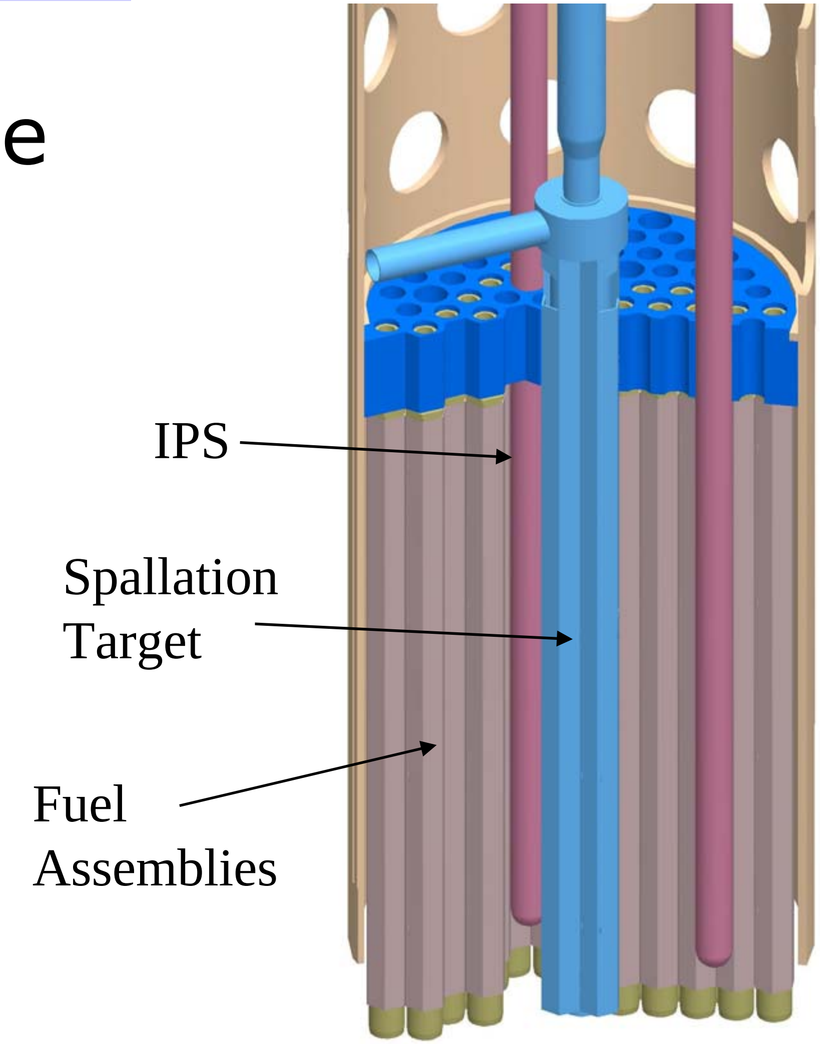


3. Holding the objective of Fast irradiation facility

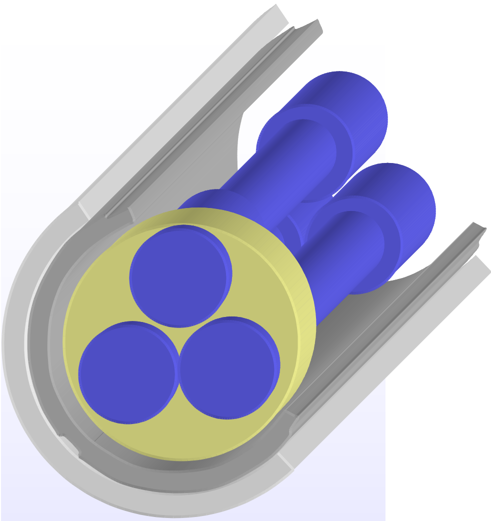
- Multi-irradiation channels available
- High performance levels
- Multiple irradiation conditions secured to the user

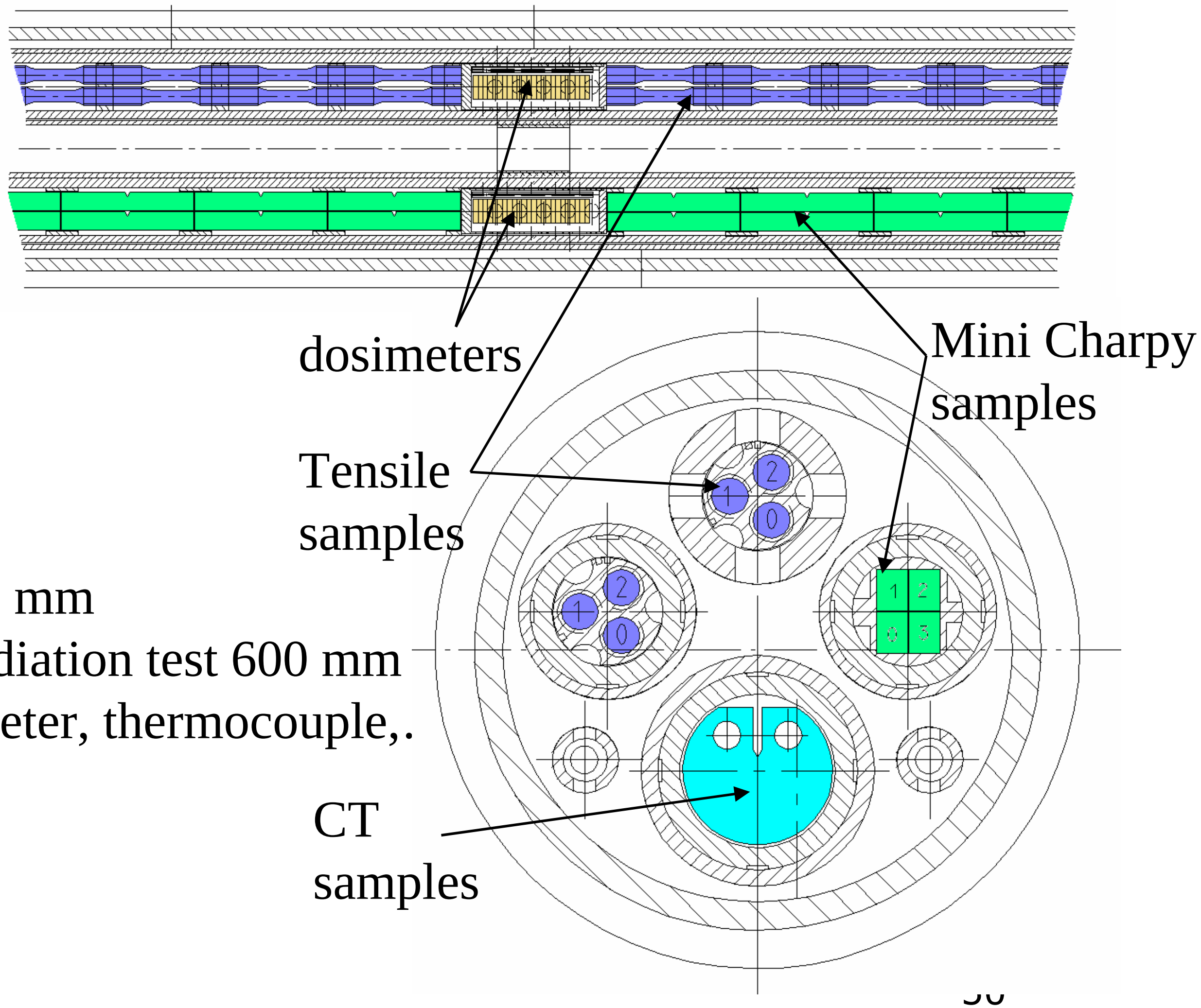
3. Material Irradiation in MYRRHA

- IPS Location in the core



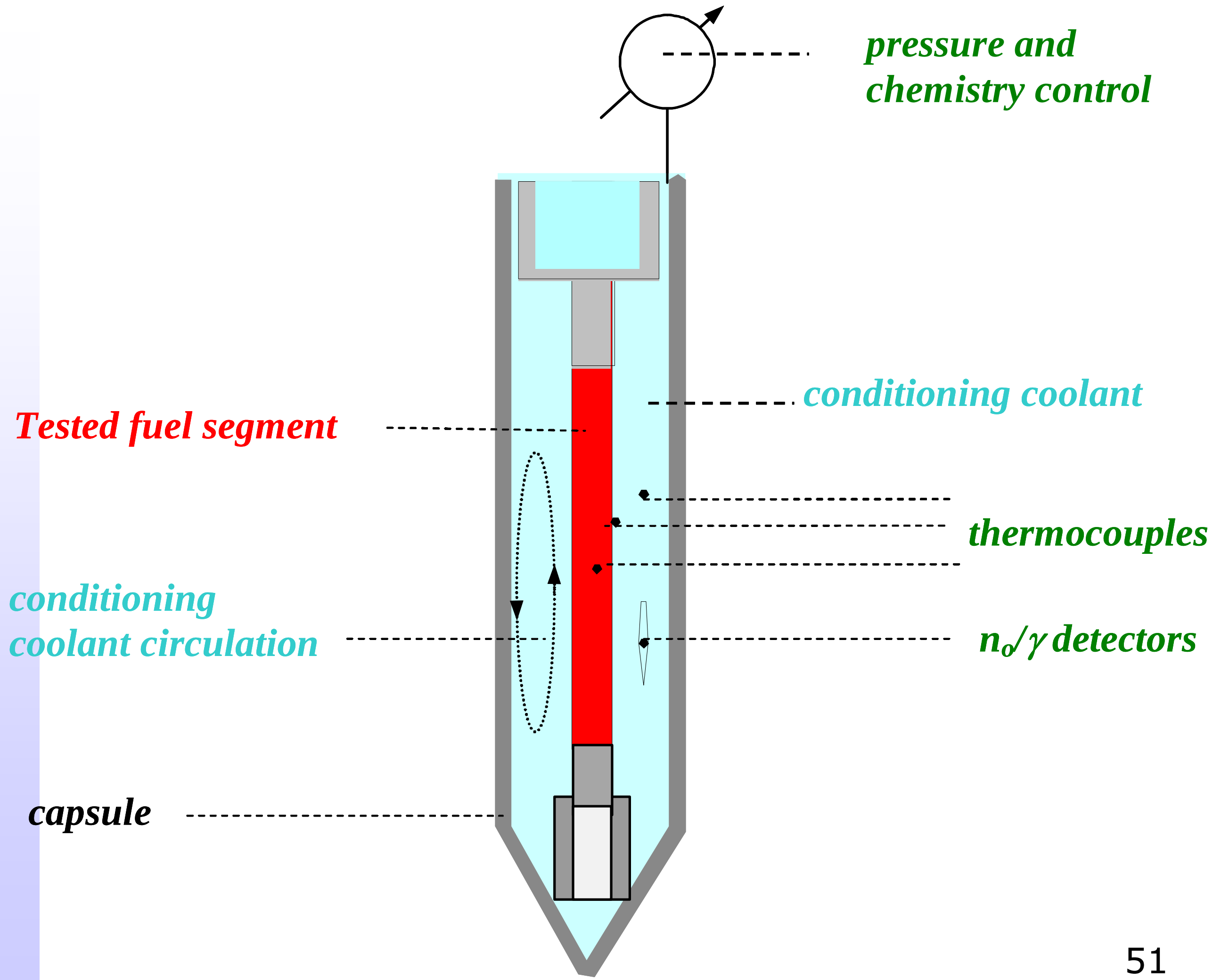
3. IPS Material Testing typical Layout



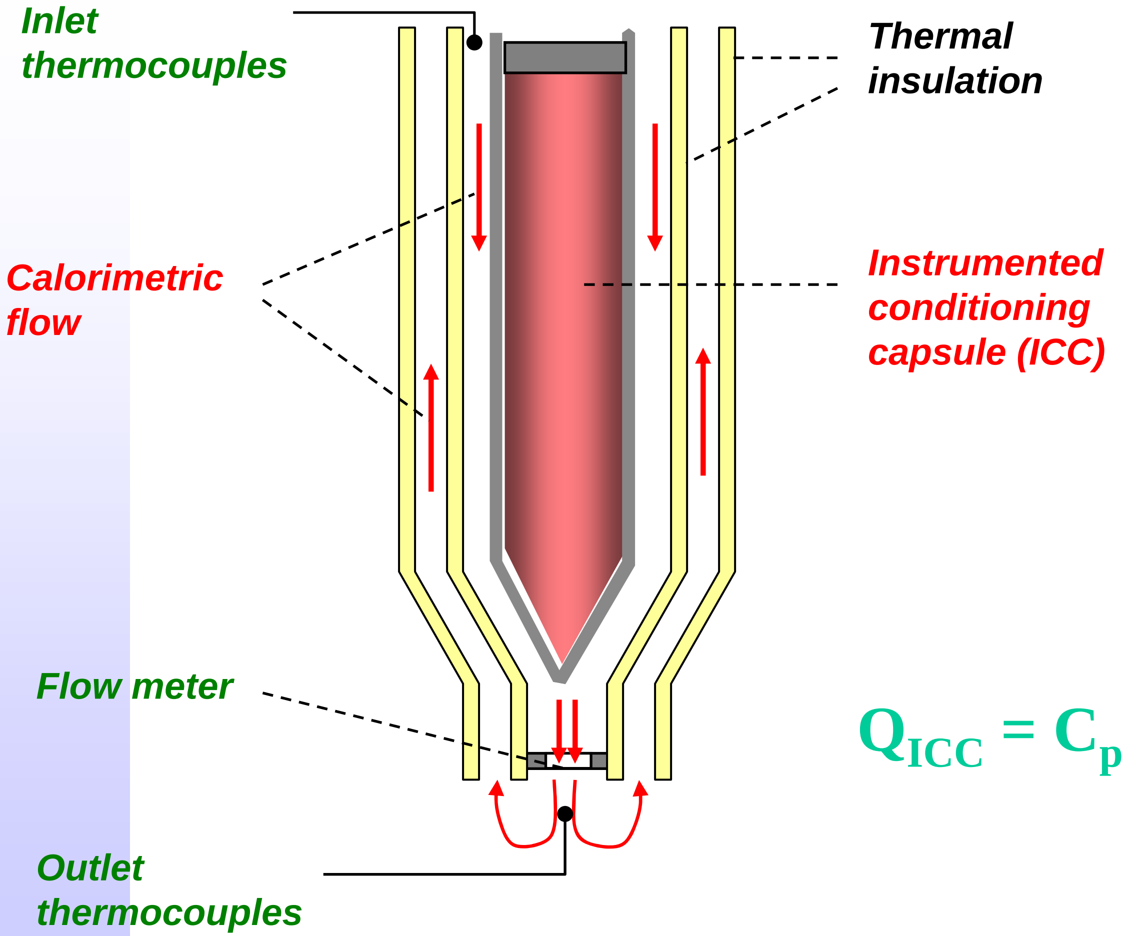


IPS outside diameter 80 mm
Relevant length for irradiation test 600 mm
Instrumentation : dosimeter, thermocouple,.

3. Fuel Irradiation in MYRRHA Instrumented and Conditioned Capsule (ICC)



3. Fuel Irradiation in MYRRHA Calorimetric Calibration Device (CCD)



$$Q_{ICC} = C_{p\ cool} \cdot G_{\ cool} \cdot \Delta T$$

3. Fuel Irradiation in MYRRHA Instrumented and Conditioned Capsule in Calorimetric Calibration Device (ICC-CCD)

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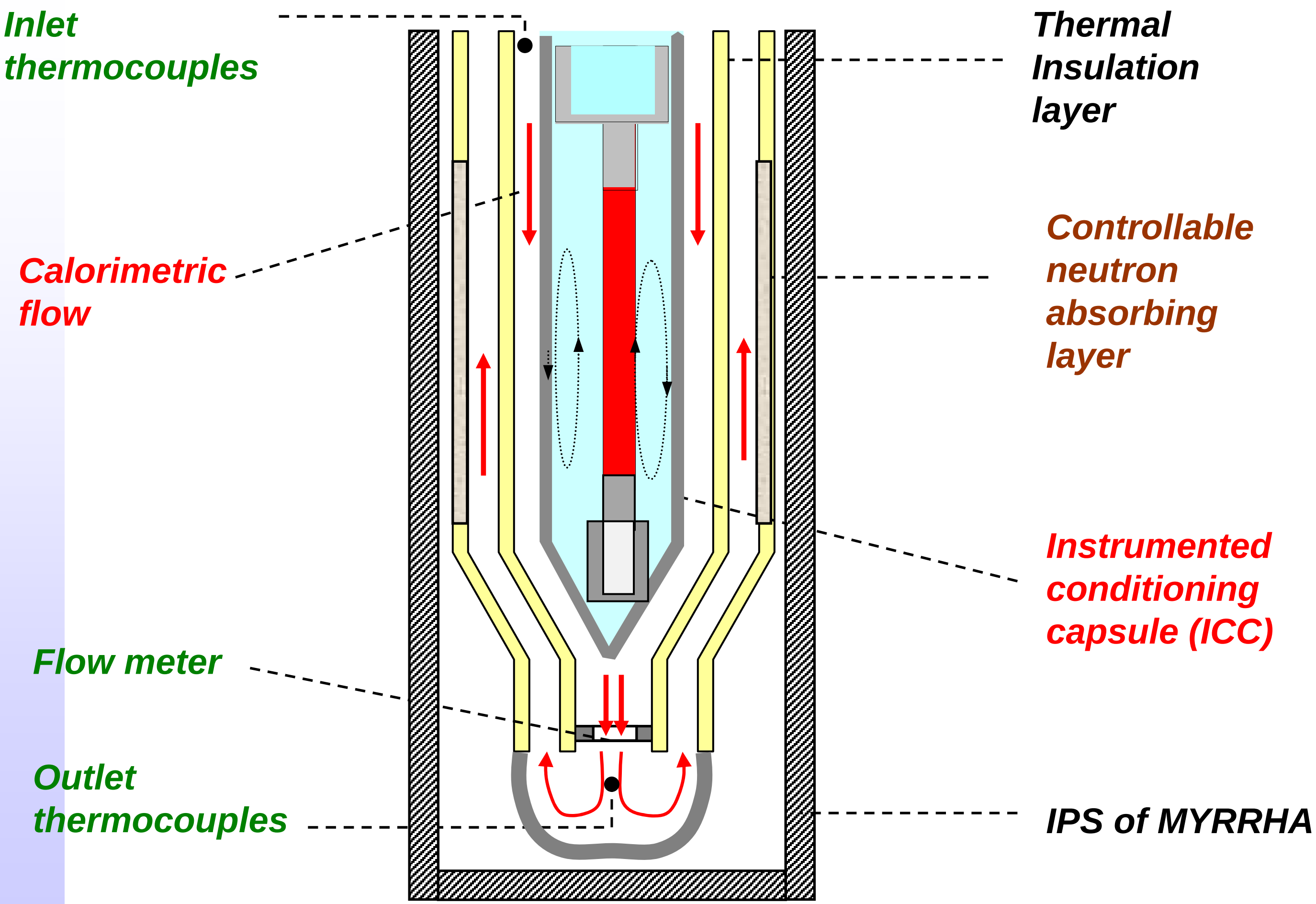
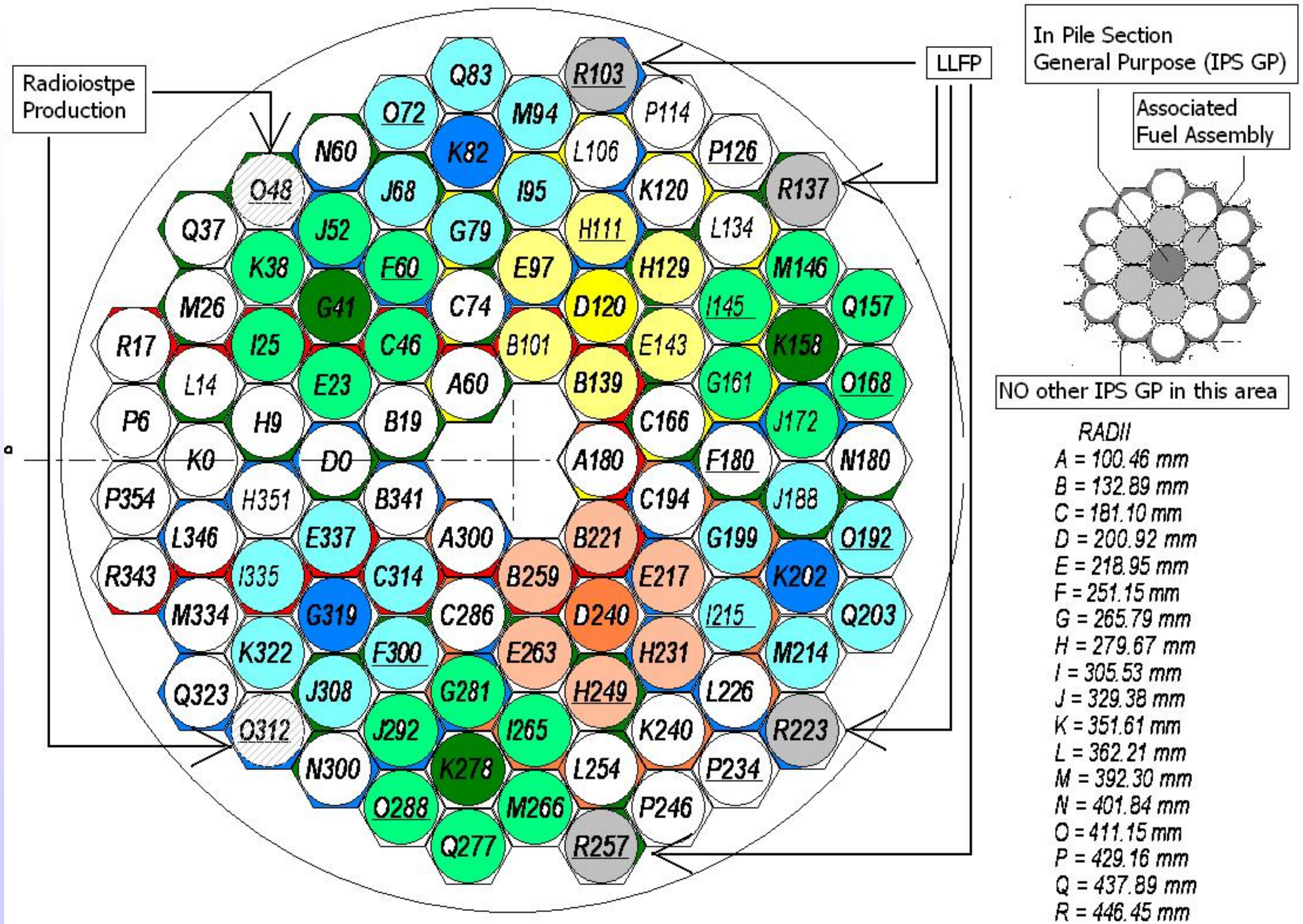
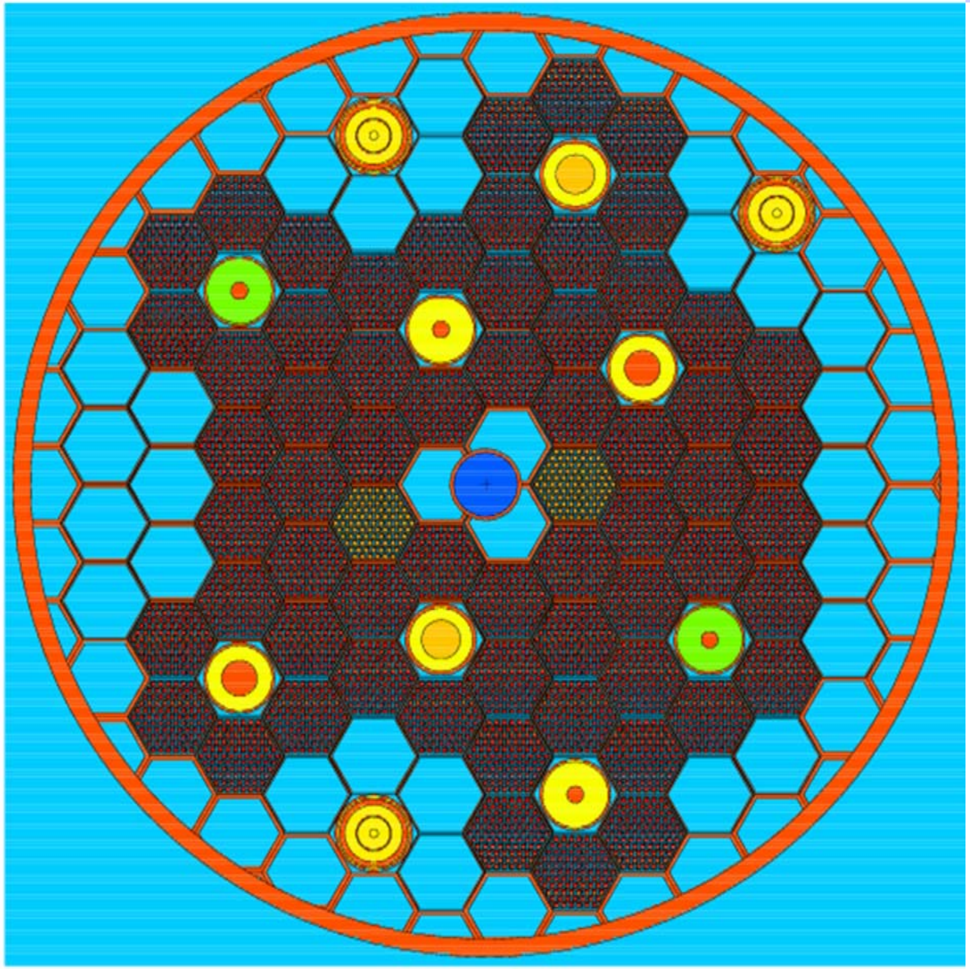


3. Accessible channels in MYRRHA Core for exp. rigs under reviewing for XT-ADS

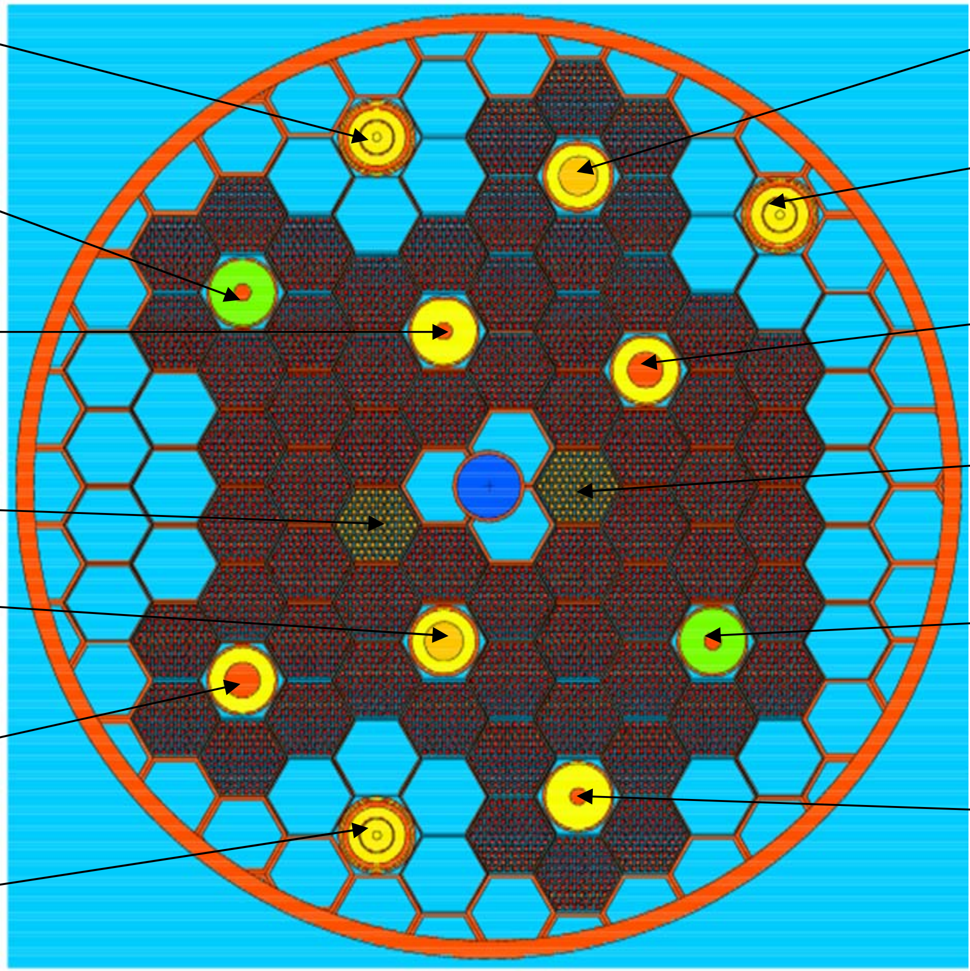


3. Typical MYRRHA core configuration with exp. rigs

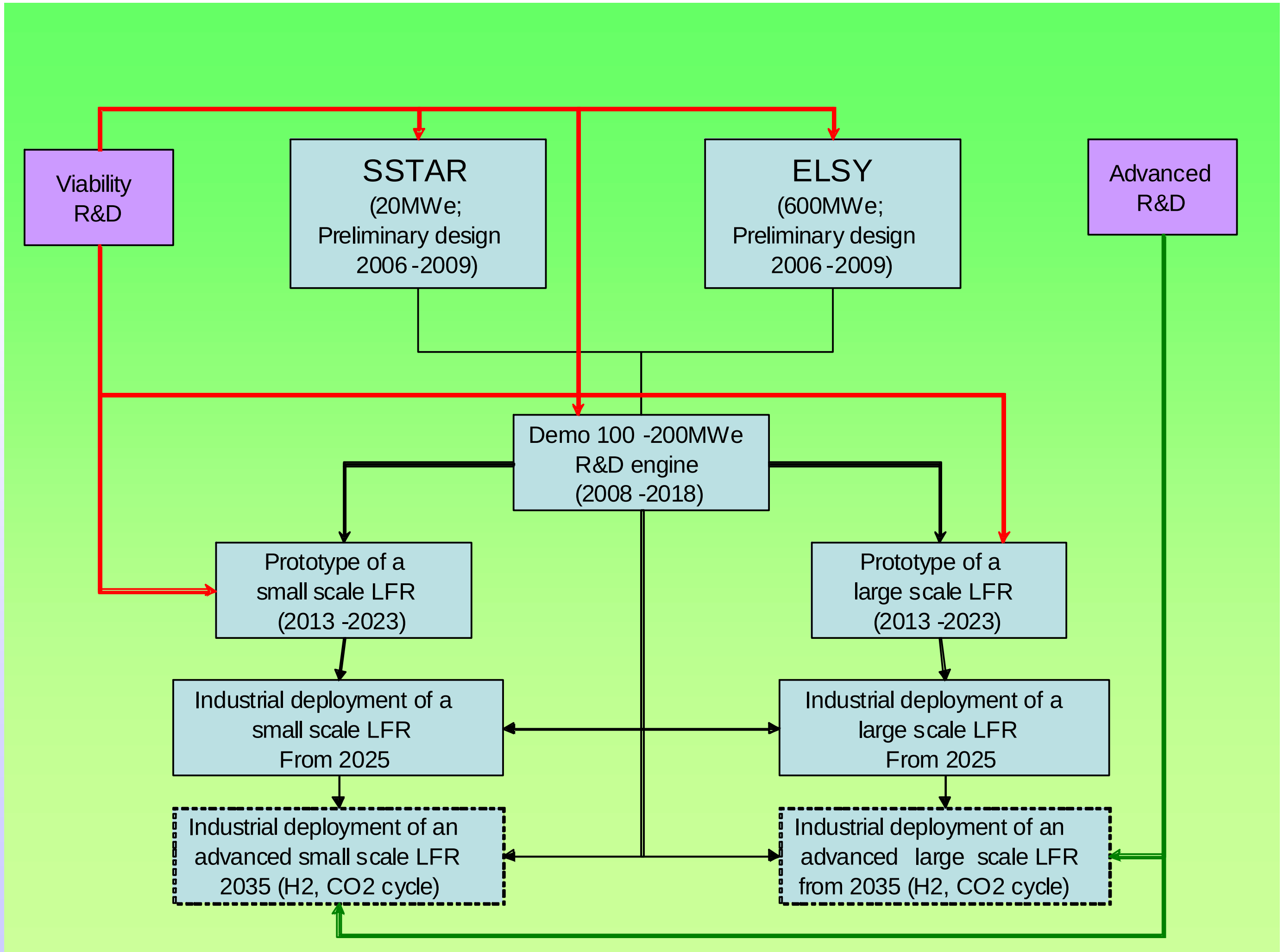


- 61 MOX-fuel assemblies
- 2 U-free MA (MgO matrix) assemblies
- 6 rigs with Steel samples
  - 2x2 He-cooled
  - 2 lead-cooled
- 2 rigs with SiC samples
- 3 H2O-moderated IPS
- Keff= 0.95181 ± 0.00025
- Ks = 0.95960
- Power : 52.3 MW

3. Fluxes and Cumulated DPA-damage (DPA/yr ; yr=365 EFPDs)



4. Link ADS – Gen. IV LFR



5-Well established and design driven support R&D Programme

- Pluri-annual R&D support programme established around the MYRRHA project inside SCK•CEN
- A bilateral collaboration network of quality
- The support R&D programme enhanced thanks to EUROTRANS

5. The MYRRHA R&D Programme

- Since the beginning of the MYRRHA project, we decided to accompany the project by a comprehensive support R&D programme including:
  - Windowless spallation target thermal-hydraulic design.
  - Vacuum Interface compatibility,
  - LBE technology: Po migration, visibility under LBE through ultrasonic cameras,
  - Material Corrosion & erosion and their mitigation,
  - LBE conditioning and monitoring,
  - Material embrittlement due to irradiation and LME,
  - MOX fuel qualification under LBE and irradiation up to high targeted burn up (100 GWd/t) and high dpa (100) and also under representative transient conditions,
  - Instrumentation development: O_2-meters (< 200°C), HLM free surface monitoring, sub-criticality monitoring, ultrasonic visualisation
  - Robotics : development of a robot arm to be deployed under LBE for testing and qualification

5. MYRRHA Collaboration Network (1/3)

- **IBA**, Belgium: cyclotron design and/or Intermediate energy section of the LINAC (normal conducting);
- **ENEA**, Italy: spallation source thermal-hydraulics design, core dynamics;
- **UCL**, Belgium: spallation source design water experiment, CFD modelling, Advanced CFD development;
- **FZR**, Germany: instrumentation for the spallation target;
- **FZK**, Germany: windowless spallation source testing with Pb-Bi in KALLA, Material Corrosion studies, Neutronics of sub-critical systems;
- **NRG**, The Netherlands: Spallation Source CFD modelling and system safety assessment;

5. MYRRHA Collaboration Network (2/3)

- **CEA**, France: subcritical core design, MUSE experiments;
- **CNRS/IN2P3**, France: LINAC development and components design, Windowless Spallation Target design, T91 structural material research, sub-critical core physics,
- **PSI**, Switzerland: basic spallation data, MEGAPIE;
- **IPUL**, Latvia: windowless spallation source testing with Hg,
- **Belgonucléaire**, Belgium: MOX Fuel manufacturer fuel pin and assembly design, fuel loading policy and fuel procurement;
- **CIEMAT**, Spain: Neutronic core design;
- **KTH**, Sweden: development and validation on basis of experimental results of adapted burn up codes for ADS,
- **IPPE**, Russia: design of the MYRRHA sub-critical reactor;

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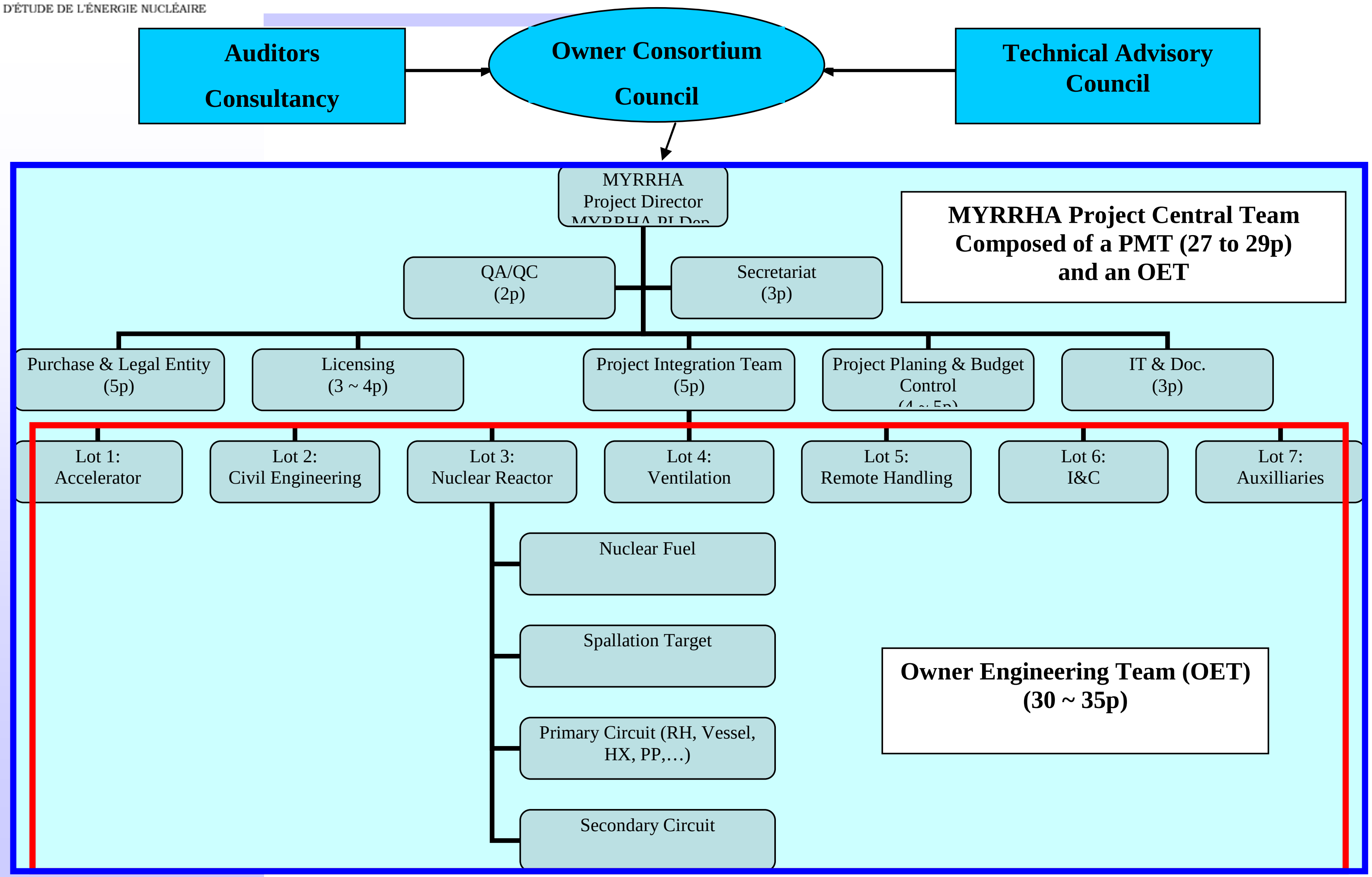
5. MYRRHA Collaboration Network (3/3)

- **Suez-Tractebel,** Belgium: confinement building and auxiliary systems, Safety analysis studies.
- **OTL**, UK: Remote Handling & Robotics design and development;
- **USI_KU**, Lithuania: development of US sensors operational under LBE and aggressive radiation environment, development of associated visualisation camera and signal treatment;
- **AFCN and AVN**, Belgium: Licensing authorities
- **JAEA,** Japan : Material for fuel cladding, LBE technology, ADS Design
- Contacts that may lead to additional collaborations exist with:
  - ISTC: JINR-Dubna, Russia, YALINA-Minsk, Belarus (Through EUROTRANS)
  - DoE and LANL; USA
  - CIAE, China

MYRRHA Project future organisation



Roadmap of an XT-ADS at Mol (I)

- End 2008 ➔ The conceptual design available.
- Informal discussions with the safety authorities ➔ submit end of 2008 Preliminary Decommissioning Plan (PDP) to the waste management authorities – ONDRAF/NIRAS.
- 2009 – 2013 to work in parallel on:
  - 2009 – 2011 : detailed engineering design
  - 2012 – 2013: Drafting of the technical specifications of the different lots, the publication of the call for tenders, and awarding of the manufacturing contracts
  - 2009 – 2011 : In parallel testing of innovative components (for the accelerator and for the reactor);
  - 2009 – 2013 : Licensing and permitting ➔ obtain the authorization of construction at the end of 2013

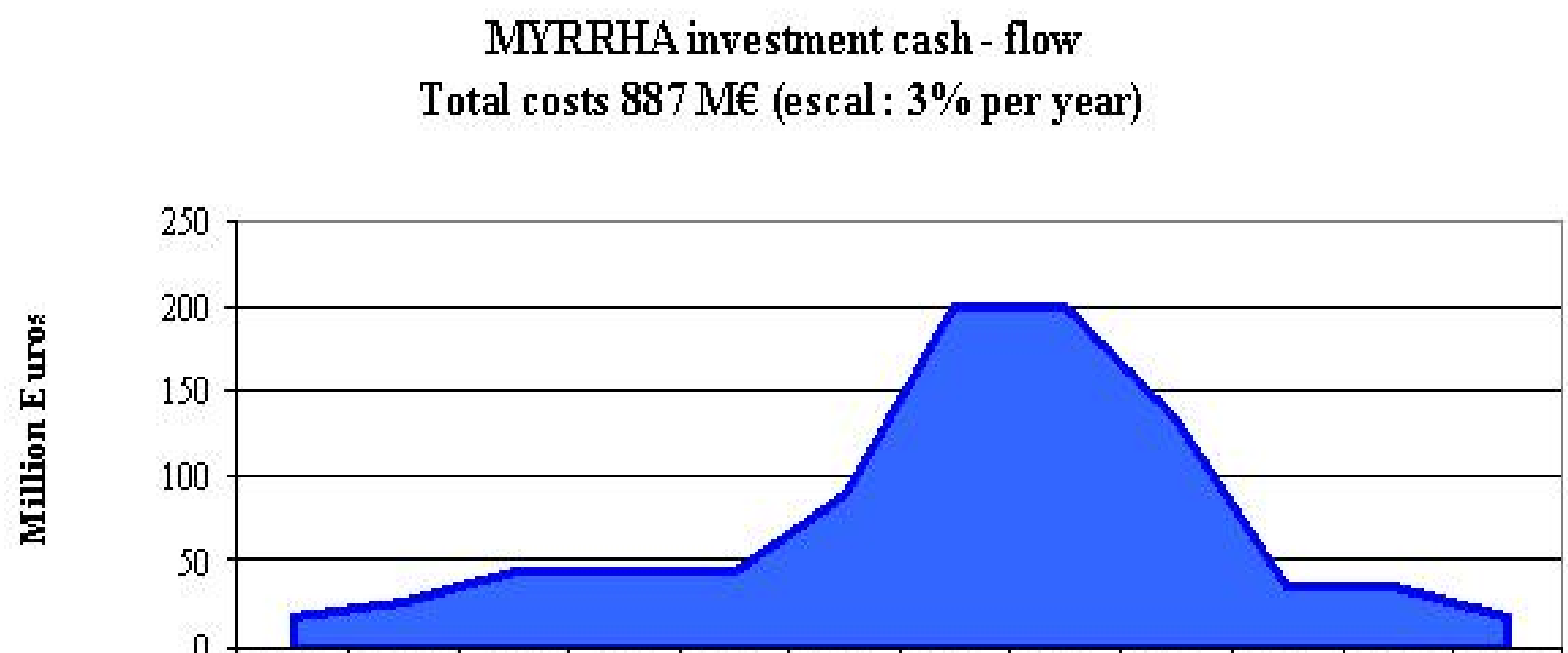
Roadmap of an XT-ADS at Mol (II)

- 2014 – 2016 construction of components and the civil engineering works on the Mol site.
- 2017 Assembling together the different components
- 2018 – 2019 commissioning (at progressive levels of power).
- 2020 MYRRHA/XT-ADS full Power operation

Summary of costs & contingencies:

- The total investment costs expressed in current value (2007) amounts to:
- 570 M€ without contingencies and 700 M€ with contingencies.
- In the 2007 MYRRHA project cost assessment, the project management costs are included.
- MYRRHA Project will be proposed as European open Research Facility for potential partners (Business plan 04.2007) will presented officially soon.
- First we are working for obtaining the Belgian support and commitment (Government, Industries, Universities)

Financial Life Cycle



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Amount	18	27	44	44	44	89	200	200	133	35	35	18

One picture is better than a thousand words, we are in 2017~2020