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School on Physics, Technology and Applications of Accelerator Driven Systems (ADS)

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Engineering Design of the MYRRHA .
Part IV

Didier DE BRUYN

Myrrha Project Coordinator
Nuclear Research Division
SCK CEN
BE-2400 Mol (Belgium)

MYRRHA - Draft 2
Primary System Design

D. Maes & H. Aït Abderrahim

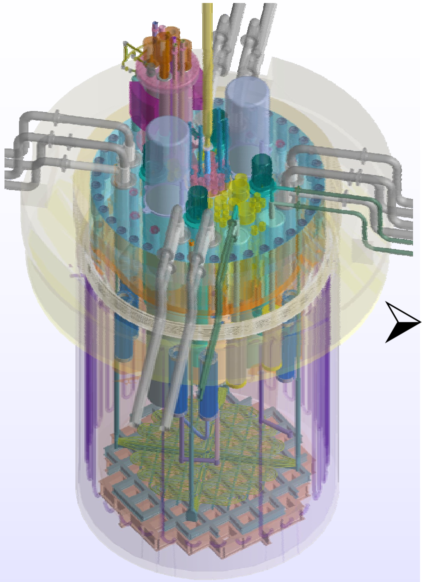
On behalf of MYRRHA team and MYRRHA Support

http://www.sckcen.be/myrrha

Design of the small scale eXperimental ADS: MYRRHA

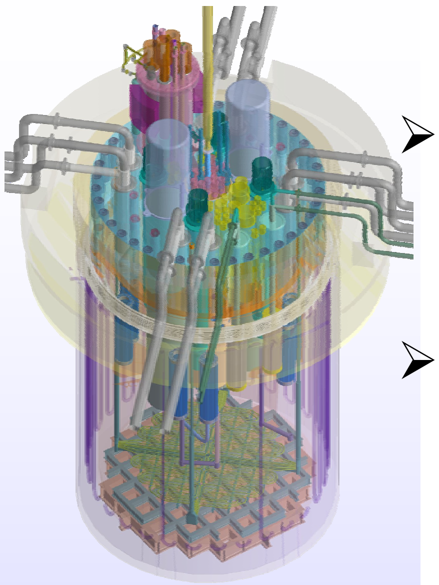
- Introduction
- Design requirements
- Design description
    - overall configuration and general characteristics
    - spallation loop and core interference
    - primary cooling system
    - diaphragm
    - in-vessel fuel manipulators
    - emergency cooling system
    - vessel and reactor cover
    - remote handling
- MYRRHA in the European frame

Design of MYRRHA
Design requirements



- As an irradiation test facility, MYRRHA must have
  - the capability to host experimental *irradiation rigs* in the core and in positions out of the core;
  - *flexible core management* for the fuel assemblies and for the experimental irradiation devices.
- The demonstration of transmutation requires a fast and high n-flux ($\sim 10^{15}$ n/cm^2.s, >0.75 MeV), that in turn implies:
  - a *compact* core;
  - this flux almost mandates *HLM cooling* (LBE);
  - the structure must be sufficiently *resistant* against irradiation, corrosion/erosion in the LBE.
- Direct access in the MYRRHA hall for personnel is highly improbable → ISIR and O&M are performed by *remote handling.*

Design of MYRRHA
Design requirements (cont'd)



- Core *cooling* has to be guaranteed in all conditions in order to prevent damage to the system.
- All in-vessel components can be *removed* and *exchanged* during lifetime of the installation for maintenance.
- A *pool-type* reactor was chosen:
  - for safety reasons (large thermal inertia of several hundreds of tons of LBE);
  - the LBE pool serves as primary coolant for the spallation target and the core;
  - the LBE pool serves as reflector/shielding for the fast neutrons and gamma rays;
  - it provides an extremely flexible core management for the fuel assemblies and the experimental irradiation devices.

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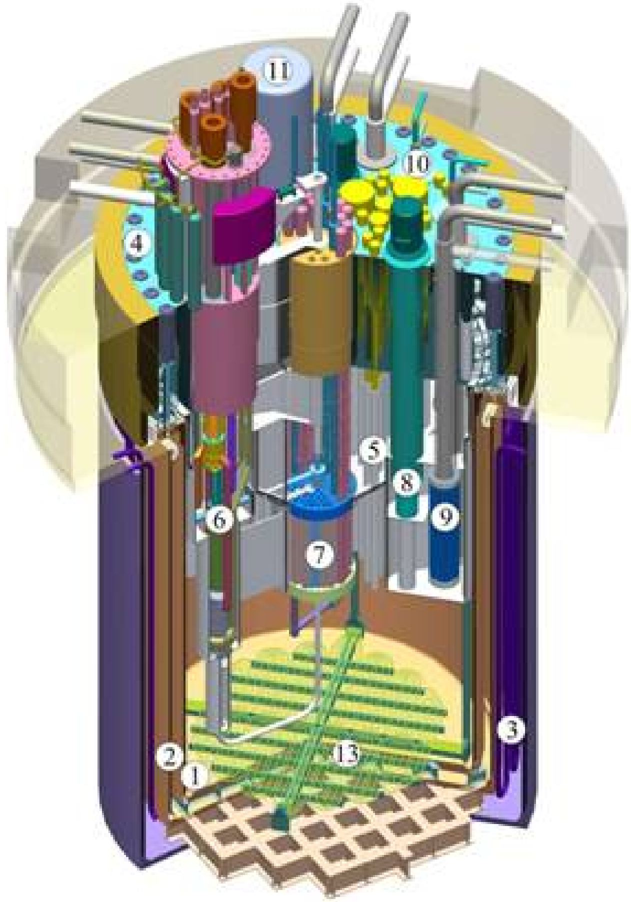
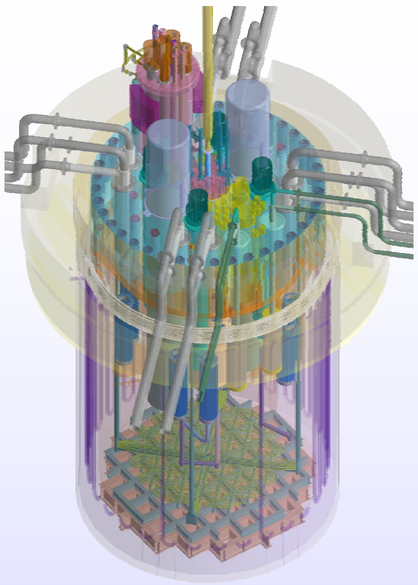
Design of MYRRHA Overall configuration

MYRRHA



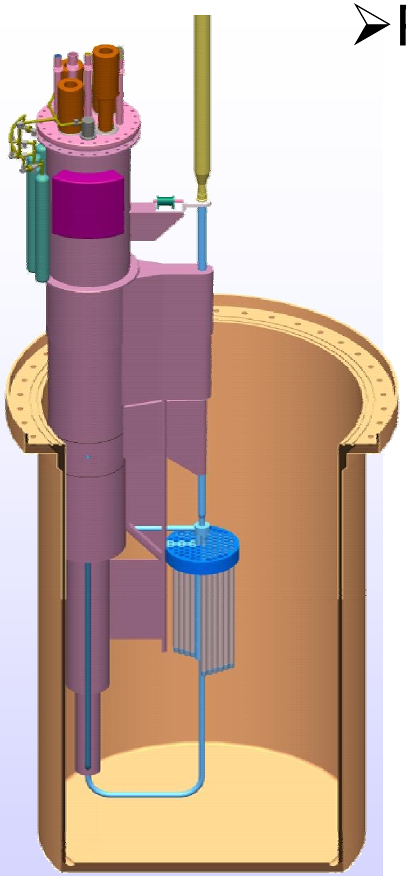
1. inner vessel
2. guard vessel
3. cooling tubes
4. cover
5. diaphragm
6. spallation loop
7. sub-critical core
8. primary pumps
9. primary heat exchangers
10. emergency heat exchangers
11. in-vessel fuel transfer machine
12. in-vessel fuel storage
13. coolant conditioning system

Design of MYRRHA
General characteristics



GENERAL CHARACTERISTICS	
Core external diameter	1,000 mm
Core height	1,800 mm
Fuel length	600 mm
Vessel inner diameter	4,400 mm
Vessel total height (cover not included)	7,000 mm
Vessel cover thickness	abt. 2 m
Gas plenum height above the coolant	< 500 mm
Nominal power	50 MW_{th}
Primary coolant	LBE
Coolant pressure	hydrostatic / +5 bar
Core inlet temperature	200 °C
Core outlet temperature	337 °C
Coolant velocity in the core	2.0 m/s
Primary coolant core flow rate (nominal)	2,500 Kg/s
Secondary coolant	water or steam

Design of MYRRHA
Spallation loop



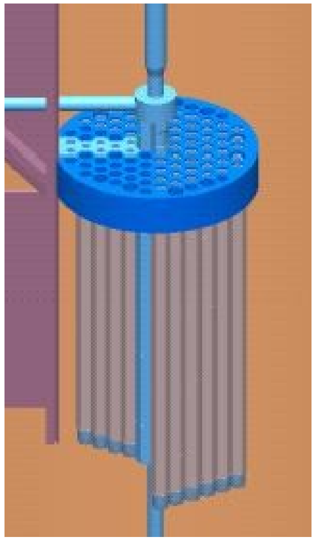
➢Reasons for the off-centre arrangement:

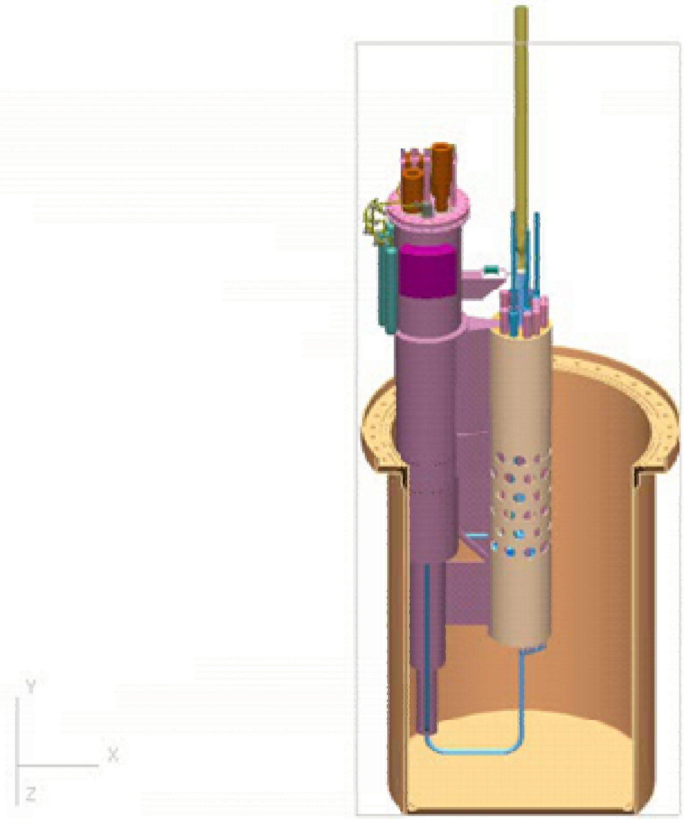
- The *small central hole* in the very compact core, which is mandatory to achieve the required neutron flux, offers only space for the LBE to follow in one direction (top-down path);
- The *circulation pumps* of the SL are located *under* the level of the target free surface (windowless target!) and there is clearly no possibility to do that in the small central channel;
- Locating the large SL confinement vessel centrally above the core would close the door for *easy access* to the core for the experimental rigs, jeopardising the flexibility of MYRRHA as a research irradiation facility.
- Off-centre arrangement *limits* the radiation *damage* of all sensitive components of the SL.

Design of MYRRHA Spallation loop

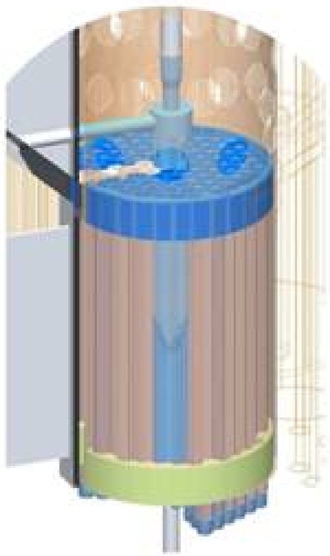
- For *periodic maintenance*, the SL can be *extracted* from the reactor. A *slot* in the core barrel is there-fore foreseen.

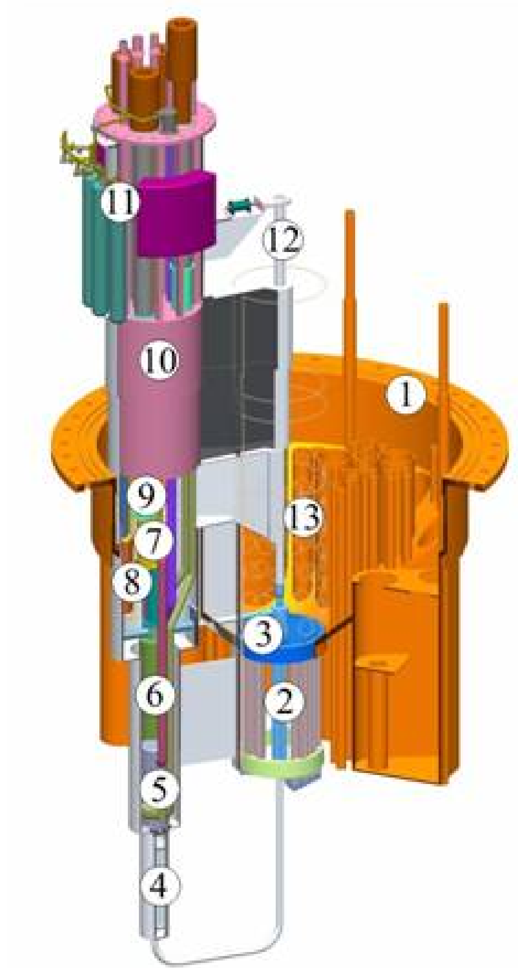
- Necessary "*patch*" to fill the special slot in the core support plate.





Design of MYRRHA Spallation loop

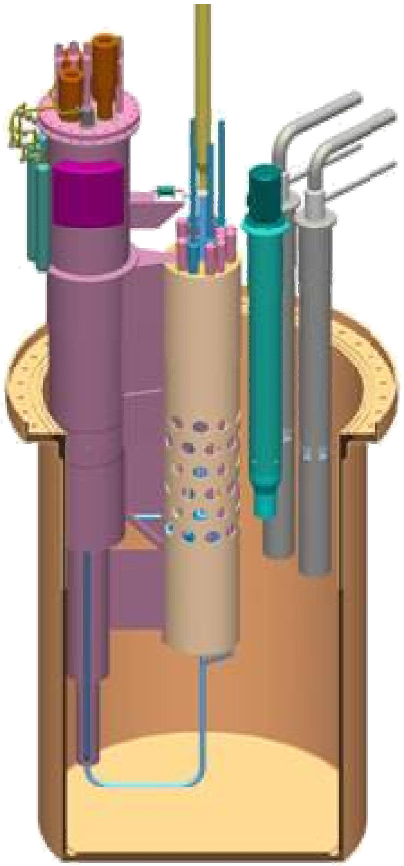




1. diaphragm
2. spallation target
3. core support plate slot
4. heat exchanger
5. turbine & pump
6. electromagnetic pump
7. hydraulic drive
8. Pb-Bi conditioning system
9. vacuum system with cryopumps
10. shielding bloc
11. regeneration circuit with absorber pumps
12. proton beam line
13. core barrel

Design of MYRRHA
Primary cooling system

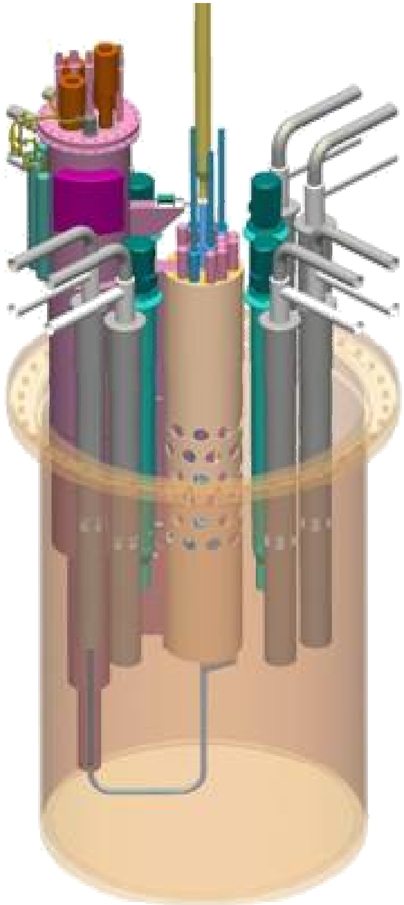
- The primary cooling system uses *water* as secondary coolant to evacuate the heat produced in the vessel.
- The eight *heat exchangers* (HX) have the straight tubes, are single pass and counter-current.



- The four primary pumps are vertical units with an *impeller* at the bottom end of a long shaft. A one-way *valve* is fitted on the discharge pipe of the pump to avoid a reverse flow when the pump is shut down.

Design of MYRRHA
Primary cooling system

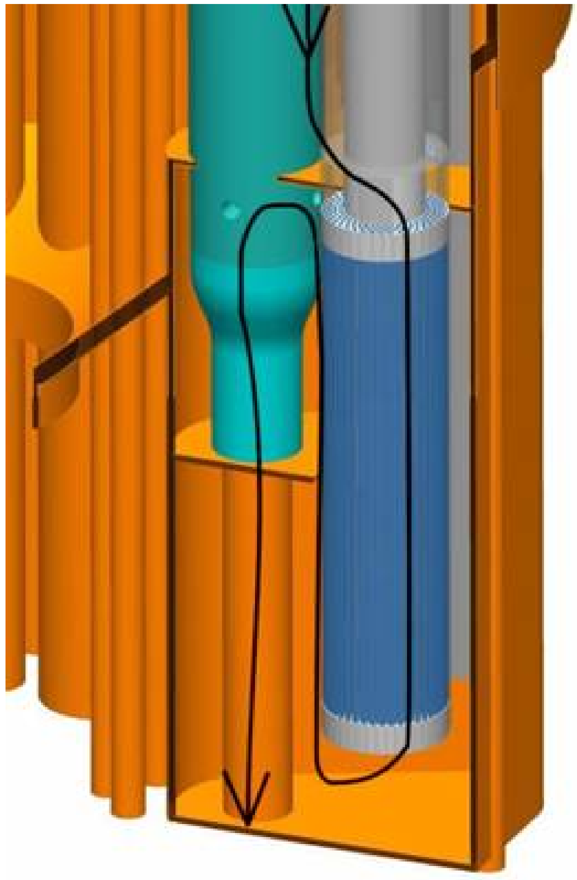
- The cooling system is *designed* for *60 MW_{th}*
- The total heat production in the vessel is the sum of the nominal *core* heat production (50 MW_{th}) and *other* heat sources (1.8 MW)



- *Four groups* with each one pump and two (secondary) 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*

Design of MYRRHA
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.



Design of MYRRHA
Primary cooling system

	Boiling HX	Not-boiling HX
Liquid inside the tubes	**water**	**PbBi**
Number of tubes	216	164
O.D. of tubes	5/8"	5/8"
Pitch of the tubes	1.4 x 5/8"	1.4 x 5/8"
O.D. of HX	**400 mm**	**432 mm**
Effective length	1355 mm	1383 mm
Pressure	**7 bar**	**25 bar**
Water mass flow rate	**20 kg/s**	**85 kg/s**
Inlet/outlet water temp.	140 / 165°C	140 / 160°C
Flow steam quality out	12,9%	-
Vapor void fraction	86%	-
PbBi flow rate out	375 kg/s	375 kg/s
Inlet/outlet PbBi temp.	337 / 200°C	337 / 200°C
Water velocity inlet/outlet	0.68 / 4.4 m/s	3.66 m/s
Steam velocity tubes outlet	26 m/s	-
Von Mises stress	**91 MPa**	**69 MPa**

Design of MYRRHA Primary cooling system

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NOTE

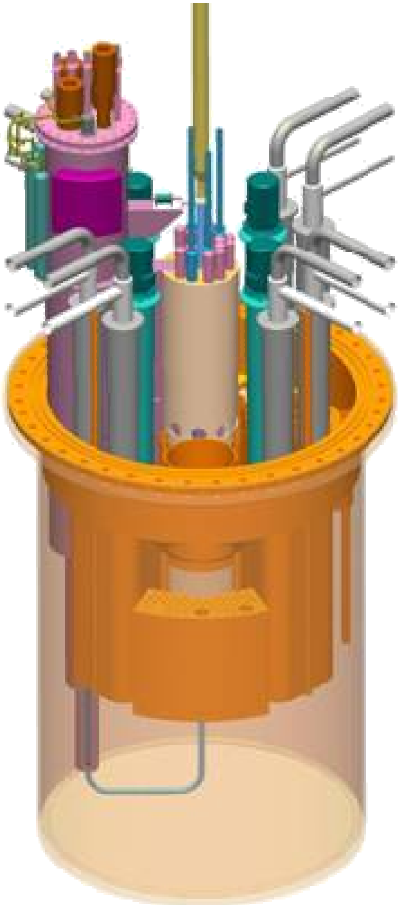
Corrosion/erosion considerations:

Preliminary calculations for XT-ADS (Eurotrans) boiling water HX show that max. 40 μm Fe_2O_3-equivalent on both tube sides is allowed:

in such case, water pressure has to be reduced from 25 bar to 9 bar to preserve the cooling capacity.

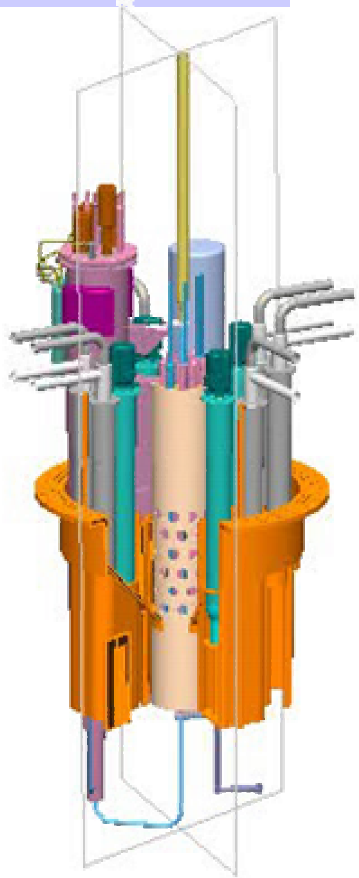
Design of MYRRHA Diaphragm

- 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 exchangers, handling machines) and for the smaller irradiation devices.

Design of MYRRHA Diaphragm



Design of MYRRHA
Diaphragm

Stresses in diaphragm

- Assessed with Pro/Mechanica
- the mechanical stress caused by the (Pb-Bi and pump) pressure is acceptable;
- the thermal (=secondary) stresses (in case of a wall temperature difference of 137°C) is rather high (~320 MPa);
- It is necessarily to re-assess the stresses with more realistic boundary conditions by taking into account the convective heat transfer from the liquid metal to the diaphragm rather than the prescribed temperature difference of 137°C over the diaphragm wall, which is a very conservative constraint.

Design of MYRRHA Diaphragm

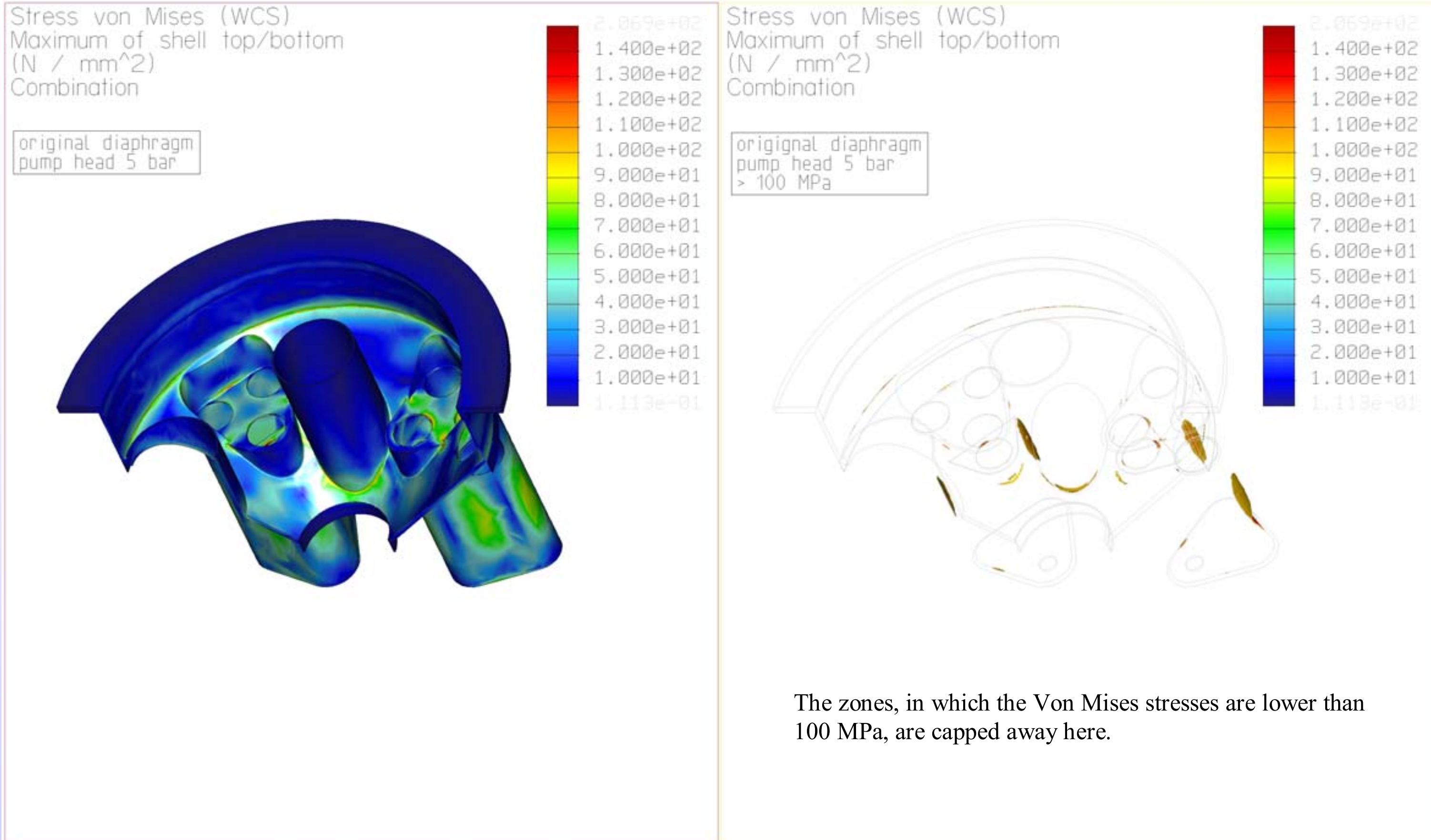


Figure 4. Von Mises stress for pump head 5 bars

Design of MYRRHA Diaphragm

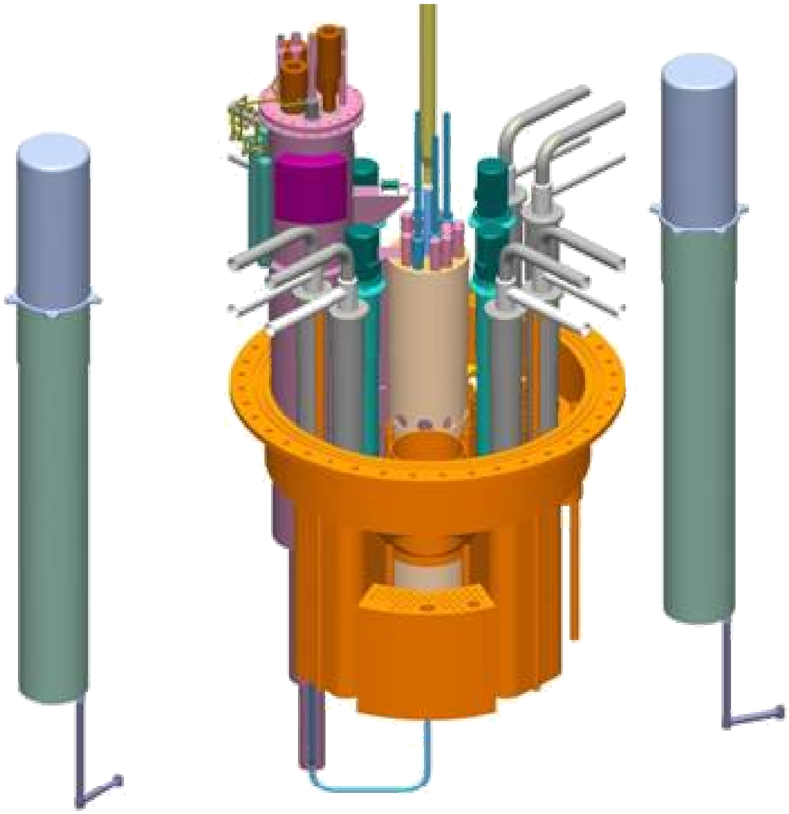
Figure 10. Von Mises stress for thermal load.

Design of MYRRHA
In-vessel fuel manipulators

- The fuel handling is performed *underneath* the core:
  - the room situated directly above the compact core will be *occupied* by instrumentation of the IPS, 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.

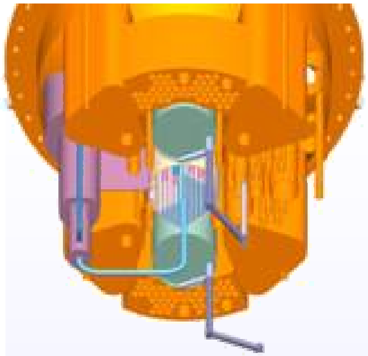
Design of MYRRHA
In-vessel fuel manipulators

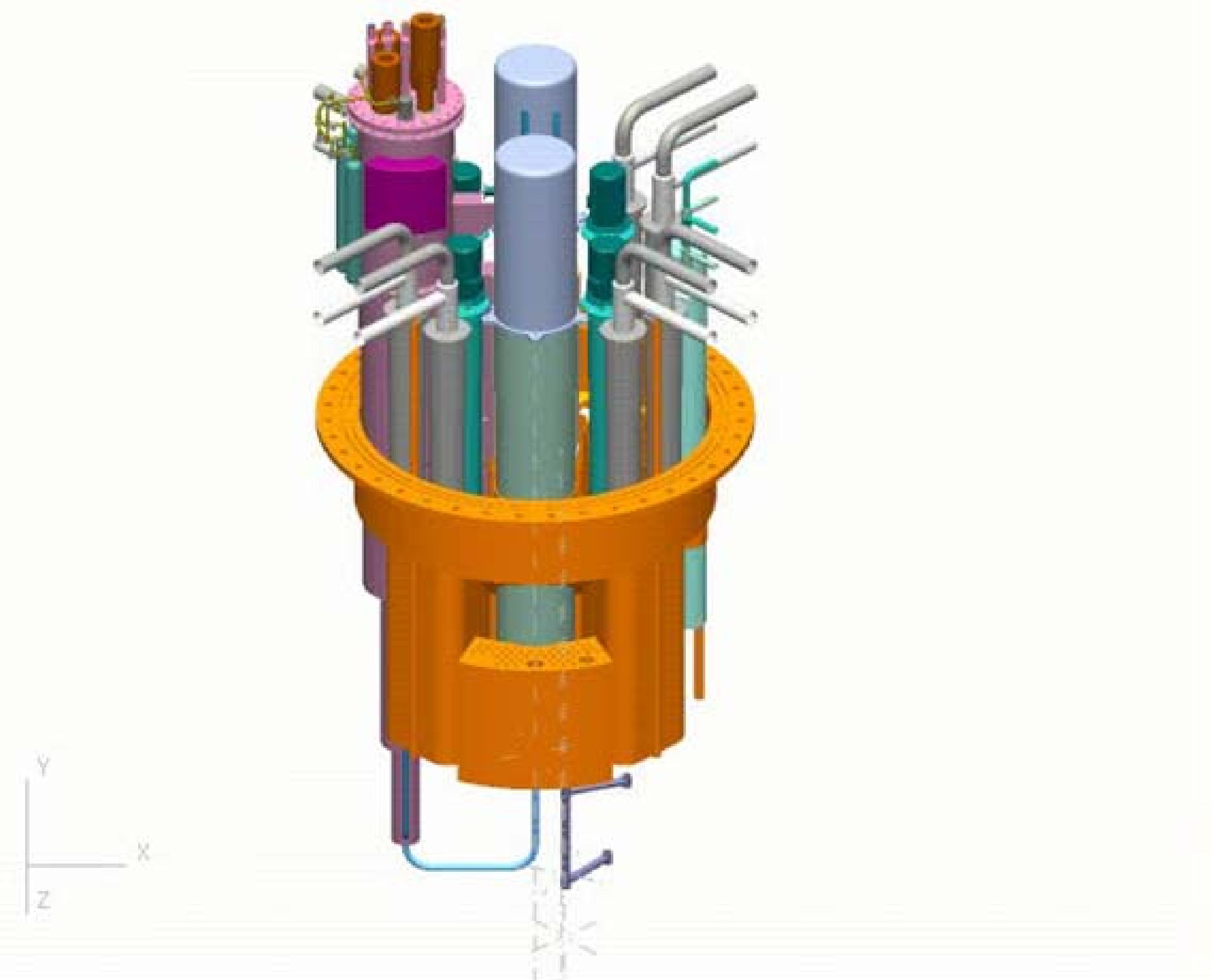
- *Two* handling systems are inserted in a penetration of the reactor cover on opposite sides of the core.
- Each system has a *rotating plug*, with an *offset arm*.



- 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.

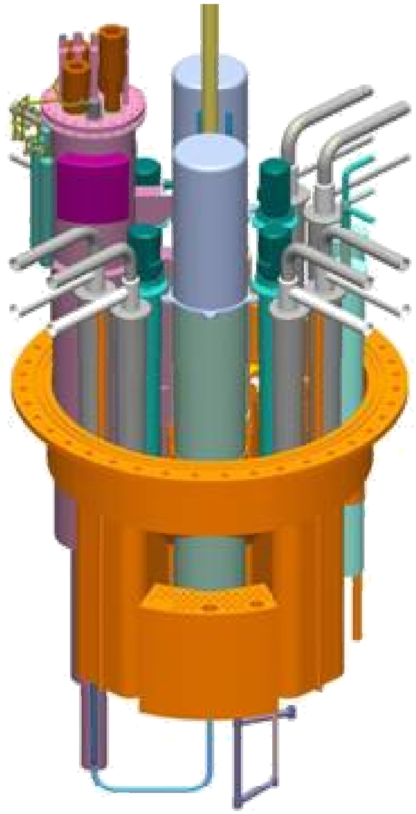
Design of MYRRHA
In-vessel fuel manipulators





Design of MYRRHA
Emergency cooling system

- The *4 MW$_{th}$* heat production after loss of flow and beam shut-off consists of :
  - the *core decay* heat: max. 7% of nominal power after 3 months of operation;
  - the decay heat in the in-vessel *fuel storage*: max. 0.5% after 1 month of maintenance;
  - ^{210}Po decay heat : 0.1% after 3 years of operation.
- There is no other way than the primary coolant for evacuating this heat. Most favourable way = natural convection.



Design of MYRRHA
Emergency cooling system

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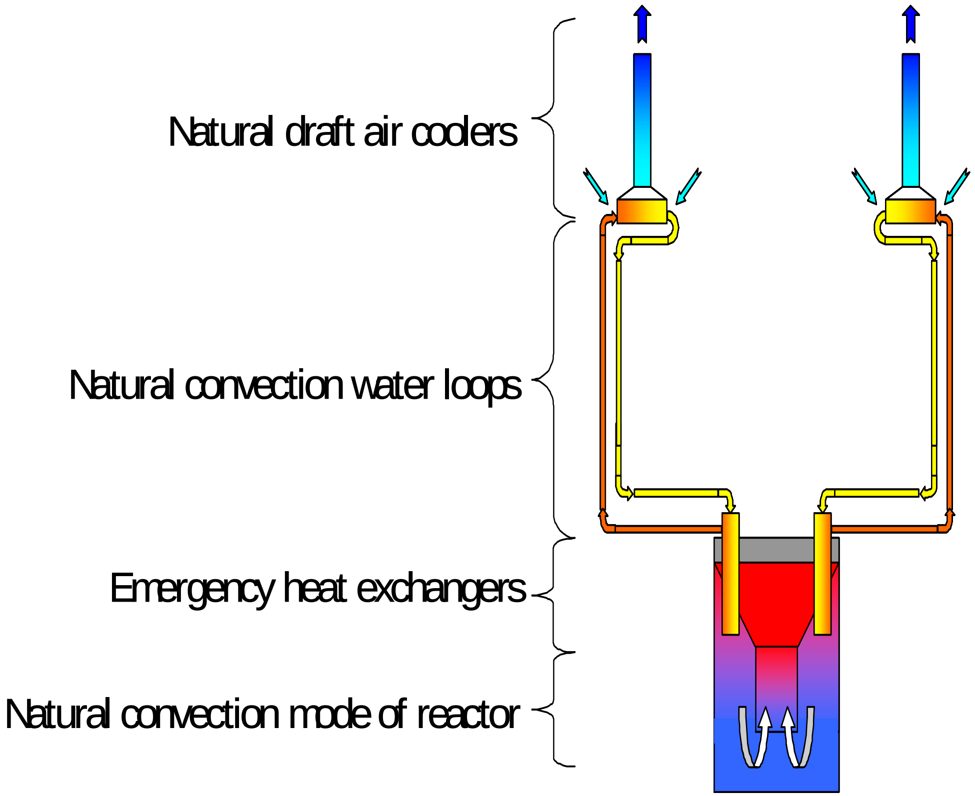
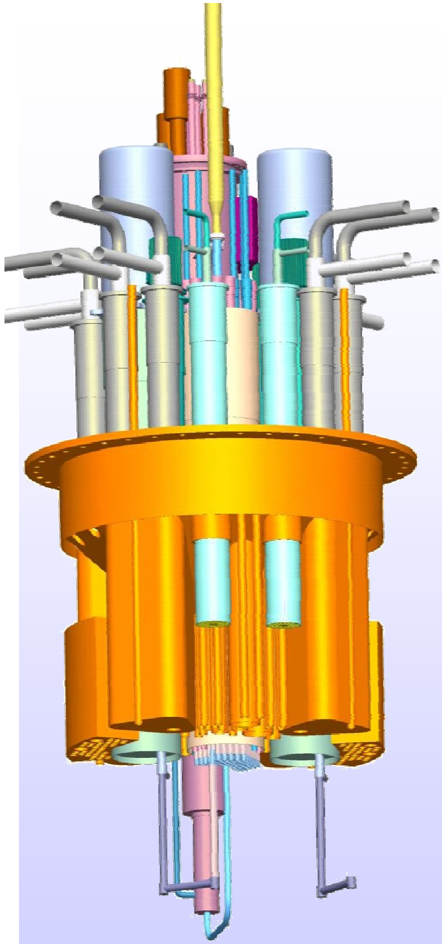
- *redundant*: two completely independent loops, each one consisting of 3 circuits operating in natural convection mode
- a *passive* system: there are no pumps, no human intervention is required and there are no power operated valves,
- maintain the reactor temperature within safe limits at all times, after *loss of heat sink*.
- Sizing :
  - water/air HX : TE
  - Chimneys : TE
  - LBE/water HX : SCK•CEN

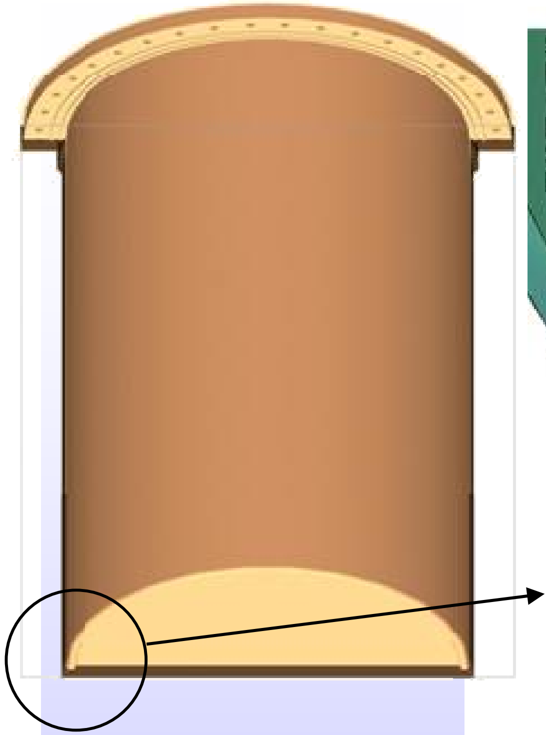


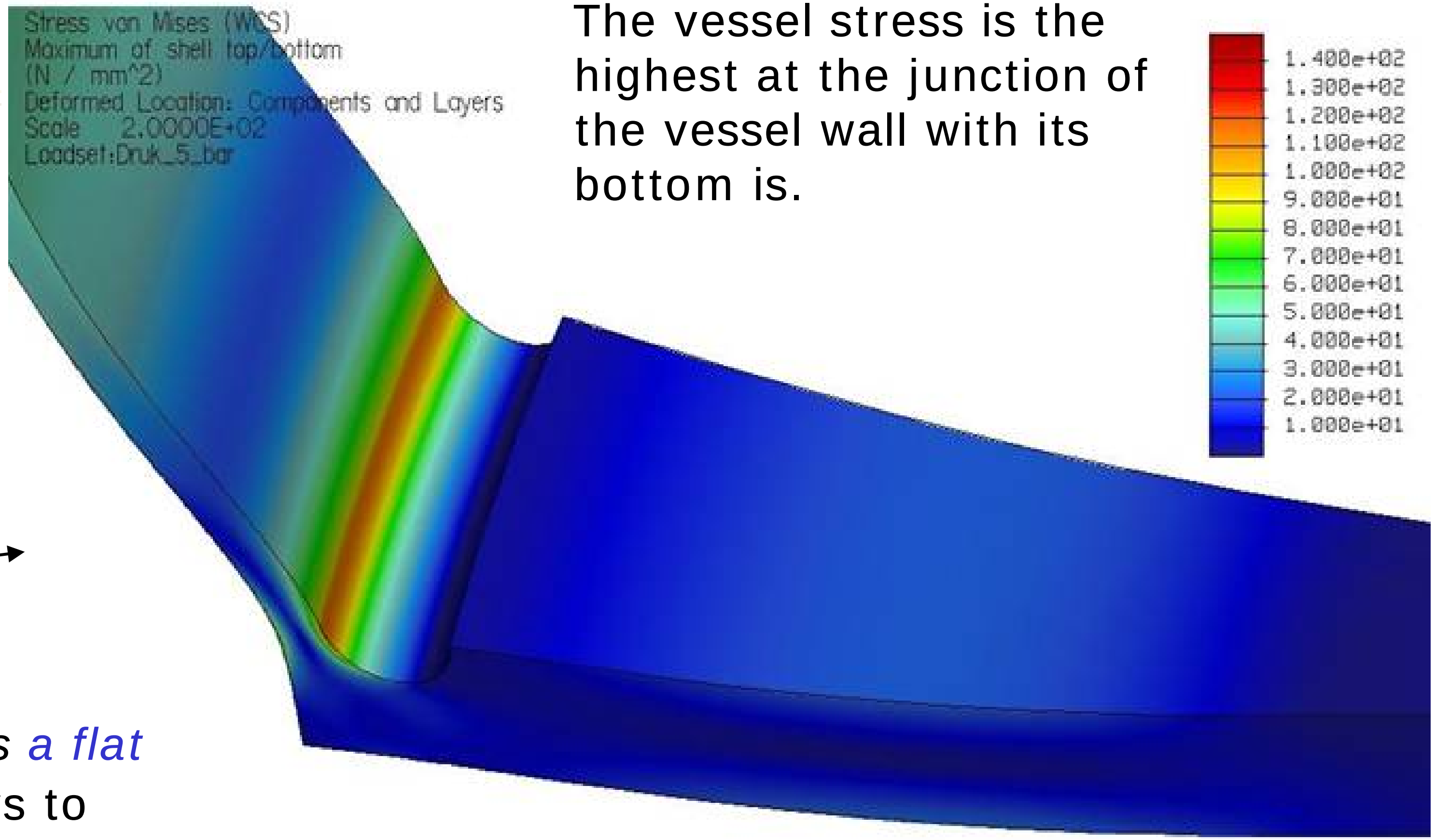
Design of MYRRHA Emergency cooling system



- The transients of emergency situations were calculated by RELAP code; some important conclusions are:
  - Protected loss of heat sink and loss of flow (PLOHLOF):
    - No peak in T of fuel and cladding
    - The EHXs are sufficient to cool the fuel with natural convection
  - Unprotected loss of heat sink (UPLOH):
    - Sufficient delay (~1300s) to stop the beam and take appropriate actions;
    - T_{clad} rises to 597°C (allowed 650°C)
    - T_{fuel} rises to 2107°C (allowed 2650°C)

Design of MYRRHA
Inner vessel

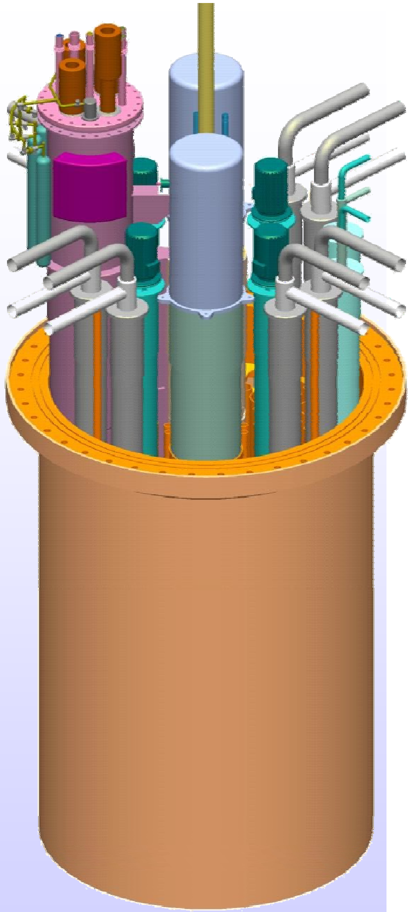




The vessel stress is the highest at the junction of the vessel wall with its bottom is.

The inner vessel has a flat bottom, which allows to minimize the volume of Pb-Bi in the vessel.

Design of MYRRHA
Inner vessel

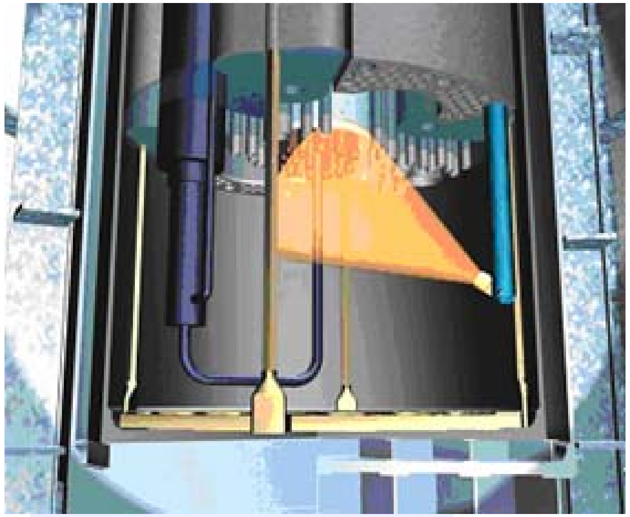


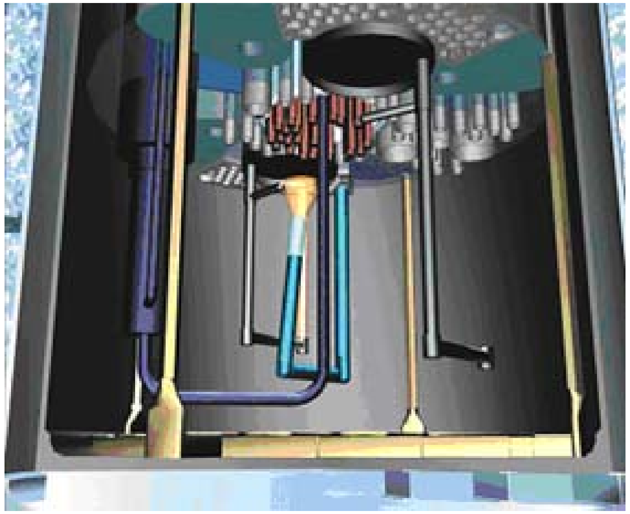
INNER VESSEL		
material		A316 L
inner diameter		4400 mm
outer diameter		4490 mm
thickness bottom plate		150 mm
radius joint wall with bottom		55 mm
flange	outer diameter	5375 mm
	thickness	150 mm
overall height		7000 mm

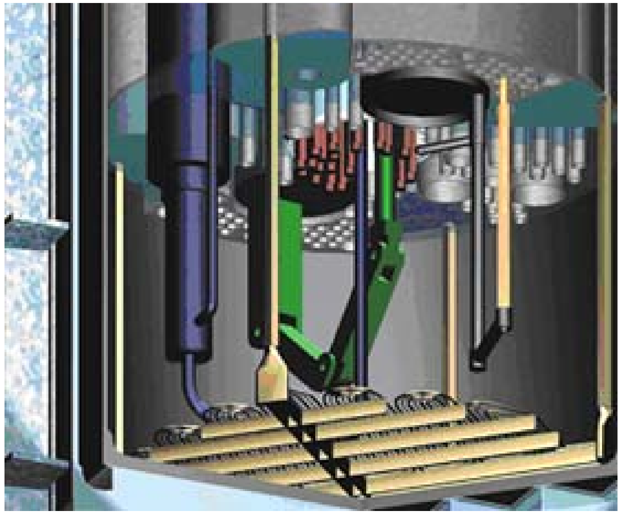
Design of MYRRHA
Remote handling

- Direct access for personnel is highly improbable:
  - *High activation* on top of the reactor due to neutrons streaming through the beam;
  - *^{210}Po (α) contamination* in open times when extracting components during maintenance;
  - The choice of an *oxygen-deficient atmosphere* in the MYRRHA hall limiting the LBE contamination during maintenance.
- Therefore, all in-service inspection & repair (ISIR) and maintenance operations are performed by remote handling, reducing the personnel exposure.
- The MYRRHA remote handling approach has been evaluated by *O.T.L.* on basis of existing and demonstrated technology in the fusion facility JET.

Design of MYRRHA
In-Service Inspection & Repair







Two *permanently* installed In-Vessel Inspection Manipulators (*IVIM*) with US camera to provide a *general overview*. (periscope type device with three degrees of freedom)

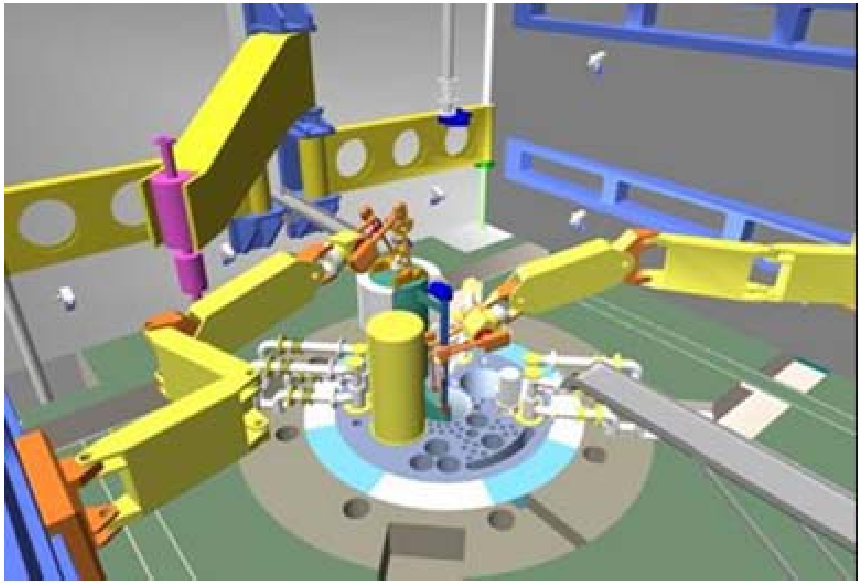
Another *IVIM* positions the camera close to critical components for *detailed* inspection. (anthropomorphic type device with five degrees of freedom)

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

O.T.L. concludes positive on the feasibility of the proposed RH approach.

Design of MYRRHA
Ex-vessel remote handling

- All ex-vessel maintenance operations are performed by a remote handling system, which is based on the *Man-In-The-Loop principle*:
  - force reflecting servo-manipulators
  - Master-Slave mode: the slave servo-manipulators are com-manded by remote operators using kinematically identical master manipulators
  - supported with closed-cycle TV (CCTV) feedback
- The arms are equipped with dedicated *tooling* for completing all classical maintenance and repair (cutting, welding, screwing, ...)



O.T.L. concludes positive on the feasibility of the proposed RH approach.

Design of MYRRHA Conclusions

- The MYRRHA design provides an extremely *flexible core management* for the fuel assemblies and for the experimental irradiation devices due to
  - the fuel handling from underneath the core;
  - the off-centre positioned spallation confinement vessel;
  - the pool-type reactor.
- The design of the primary & emergency cooling circuits assures a *safe and adequate cooling* of the sub-critical core.
- Sufficient *resistance against corrosion/erosion* is obtained by limiting the LBE velocity below 2.0 m/s.
- All in-vessel components can be removed and exchanged by *remote handling*, which reduces the personnel exposure.
- MYRRHA is now open to a larger European community in the frame of the integrated FP6 project *EUROTRANS* (XT-ADS).

Design of MYRRHA
Conclusions (cont'd)

- The studies so far definitely have shown no insuperable difficulties and it is demonstrated that the main components can be sized within allowable stress limits to fulfil their task within safety limits.
- A visualisation system based on ultrasonic technology is proposed for the in-vessel, under-LBE inspection. A support R&D programme has been launched.