Future Advanced Nuclear Systems

And Role of MYRRHA

Multipurpose h**Y**brid **R**esearch **R**eactor for **H**igh-tech **A**pplications

Contributing to the 3rd Pillar of the European Strategy for P&T

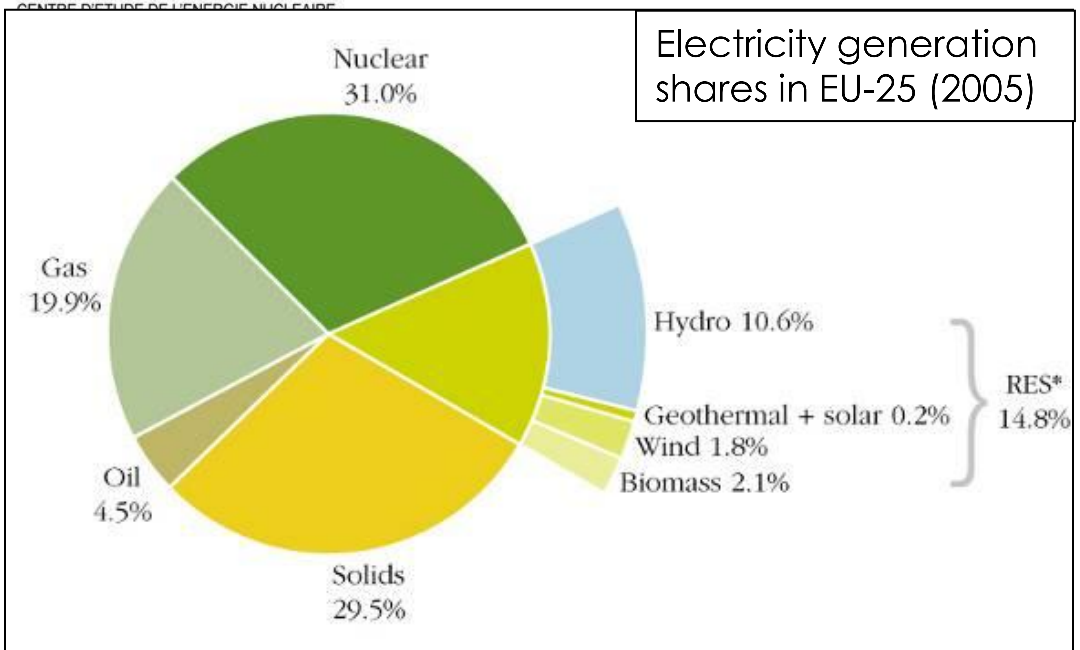
Prof. Dr. Hamid Aït Abderrahim, Dr. Dirk Vandeplassche

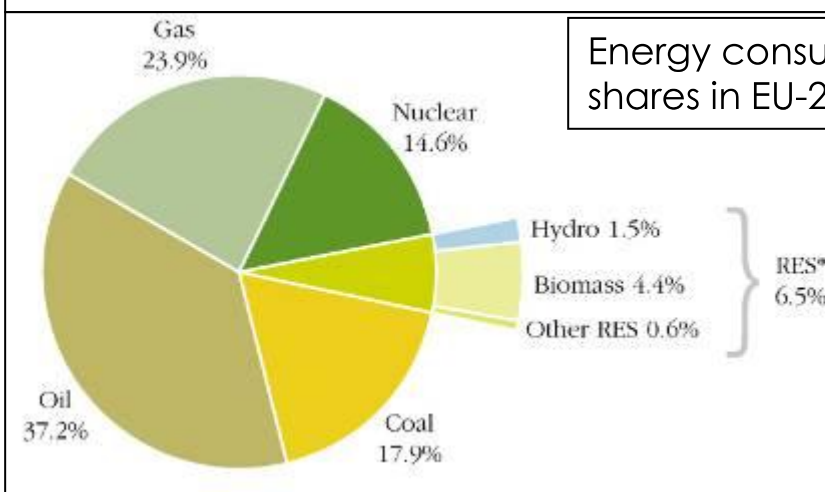
SCK•CEN, Boeretang 200, 2400 Mol, Belgium

haitabde@sckcen.be, dirk.vandeplassche@sckcen.be

or myrrha@sckcen.be

Nuclear energy in Europe





- 152 reactors in 15 countries in EU-27, producing 31% of EU's electricity
- The largest source of low carbon energy
- Excellent safety record
- Europe, a world leader – but competition is building up (Russia, Japan, USA, China, India)

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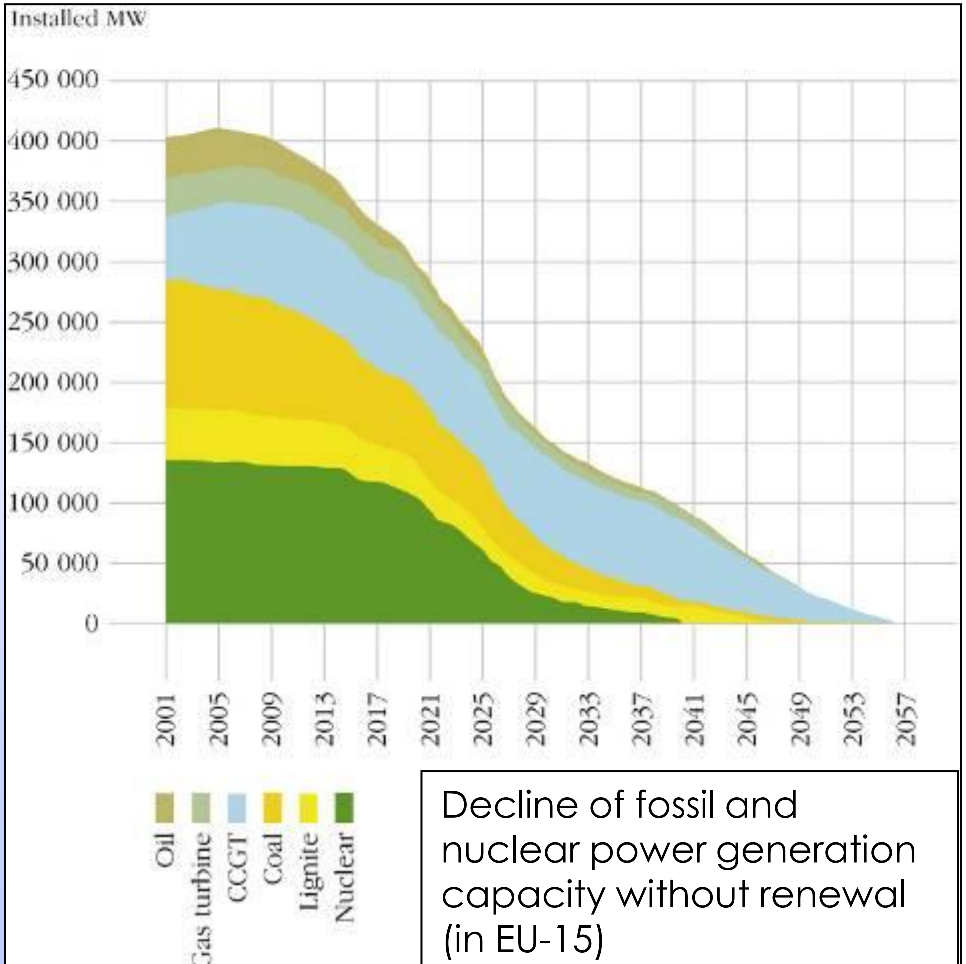
Power generation infrastructures



Decline of fossil and nuclear power generation capacity without renewal (in EU-15)

- Fossil and nuclear power generation plants are ageing
- Need to invest in plant lifetime management and
- Large investments are necessary to build new plants to satisfy demand
  - For nuclear, Gen III reactors (Finland, France)
- Action is needed **now** for paving the road for Gen IV!

Nuclear fission in Europe's low carbon energy policy

- **Nuclear fission contributes today 31% of EU electricity – the largest low carbon energy source**
  - ➔ **2020 : Maintain competitiveness in fission technology and provide long term waste management solutions**
- **For the longer term as indicated in the SET Plan, we need to act now to:**
  - ➔ **Complete the demonstration of Gen IV with closed fuel cycle for increasing sustainability,**
  - ➔ **Enlarge the nuclear fission applications beyond electricity production, namely towards H_2, Heat, H_20 desalination.**

Ambitious R&D and Demo programme need to start <u>now</u> to meet the required breakthroughs

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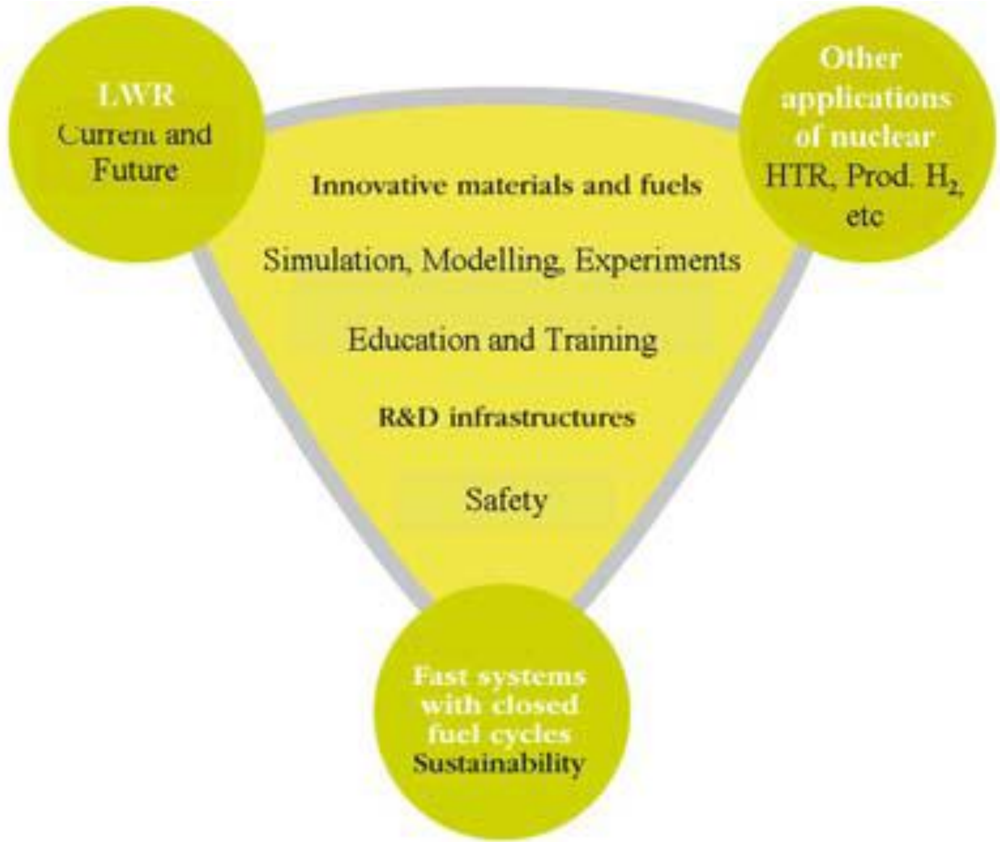
A collective vision: endorsers and contributors

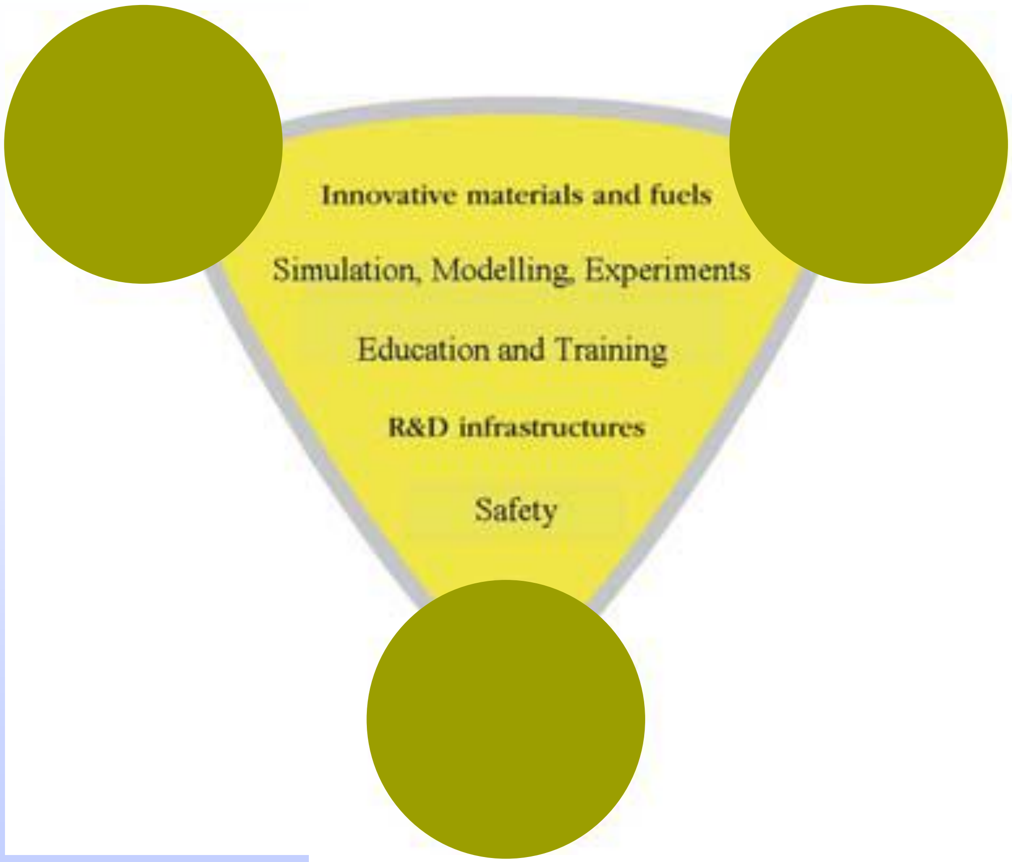
SNETP strategy structures the SRA (Strategic Research Agenda)



SNETP vision:

- Maintain safety and competitiveness of today's technologies,
- Develop Gen IV FR with closed cycle to enhance sustainability,
- Enlarge the nuclear fission portfolio beyond electricity production:
  H_2, Heat, H_20 desalination

SNETP strategy structures the SRA (Strategic Research Agenda)



SNETP vision:

Beyond the 3 pillars, a common trunk of activities:

- Material & Fuel research,
- Simulation, modeling and validation experiments,
- Dedicated / multipurpose research facilities,
- Last but not least:

  well trained and educated specialists in the various fields related to nuclear fission

Conclusions
Future of Nuclear Energy towards sustainability

- **Europe is a world leader in nuclear energy and SNETP helps holding this position**
- **Nuclear energy is competitive and is the largest low carbon source in the energy mix of Europe. It is contributing to Europe's security of supply.**
- **Nuclear energy path towards sustainability:**
  - **Today Gen II = PLIM (→ 2040)**
  - **Tomorrow Gen III = Deployment of new fleet (2010 → 2030) → 2100**
  - **After-tomorrow = Gen IV + Advanced fuel cycle + beyond electricity application, SMRs (R&D → 2020, prototypes → 2030, deployment beyond)**
- **Industry & utilities ready to invest in Gen II & III but need a climate of political trust**
- **Private & public funding & EC contribution needed for the Gen IV EII through new financial vehicle**

Fukushima effect

- Some countries decided to consider abandonning or not restarting nuclear energy (DE, CH, IT, …)
- Some are still in a position of wait and see (BE, SP,)
- Some are not changing their policy even increasing their engagement in nuclear energy (FR, FI, CZ, SK, BG, UK, RO, ROK, CN, RU, IN …)
- **SRA of SNETP is in updating phase => Safety chapter resulting from lessons of the stress tests**

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MYRRHA

Multipurpose h**Y**brid **R**esearch **R**eactor for **H**igh-tech **A**pplications
Contributing to the 3rd Pillar of the European Strategy for P&T

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MYRRHA - Accelerator Driven System

Accelerator

(600 MeV - 4 mA proton)

Reactor

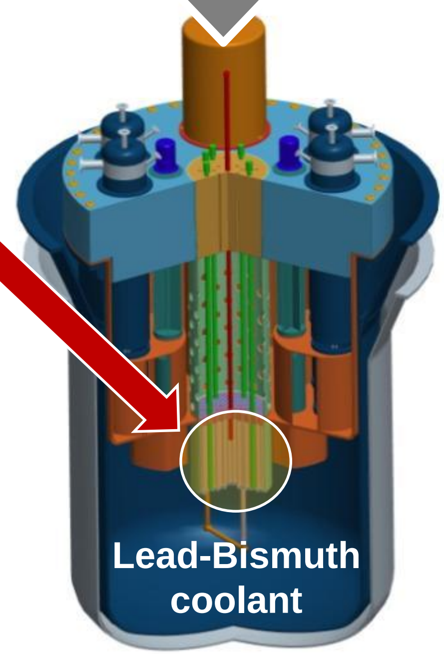
- Subcritical or Critical modes
- 65 to 100 MWth

Innovative & Unique

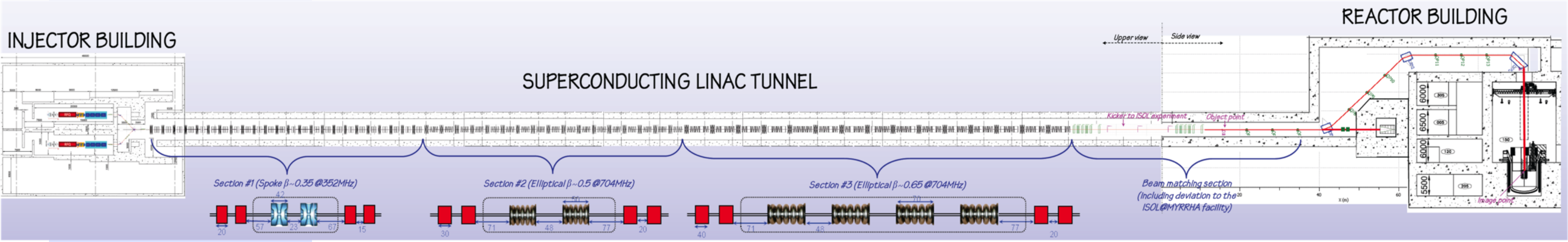
Spallation Source

Fast Neutron Source

Multipurpose Flexible Irradiation Facility



The MYRRHA linear accelerator



Dirk Vandeplassche, Luis Medeiros Romão

MYRRHA Accelerator Challenge

fundamental parameters (ADS)	
particle	p
beam energy	600 MeV
beam current	4 mA
mode	CW
MTBF	> 250 h

challenge !

failure = beam trip > 3 s

implementation	
superconducting linac	
frequency	176.1 / 352.2 / 704.4 MHz
reliability = redundancy	double injector
	“fault tolerant” scheme

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Scenario and philosophy

- Structure of collaborations
  - Euratom Framework Programmes 5 – 6 – 7
  - core partners
    - CNRS/IN2P3 – IPN (Orsay)
    - CEA – IRFU (Saclay)
    - U. Frankfurt – IAP
    - INFN – LASA (Milano)
  - bilateral agreements with research institutes (MoU's)
    - University of Louvain
    - CNRS (several labs)
    - IAP
    - CERN
    - GANIL/Spiral2
    - ESS
    - ...
  - privileged industrial partnerships
    - for components (ECR source, RF amplifiers, ...)
    - for global systems (cryogenics, controls, ...)
    - for integration

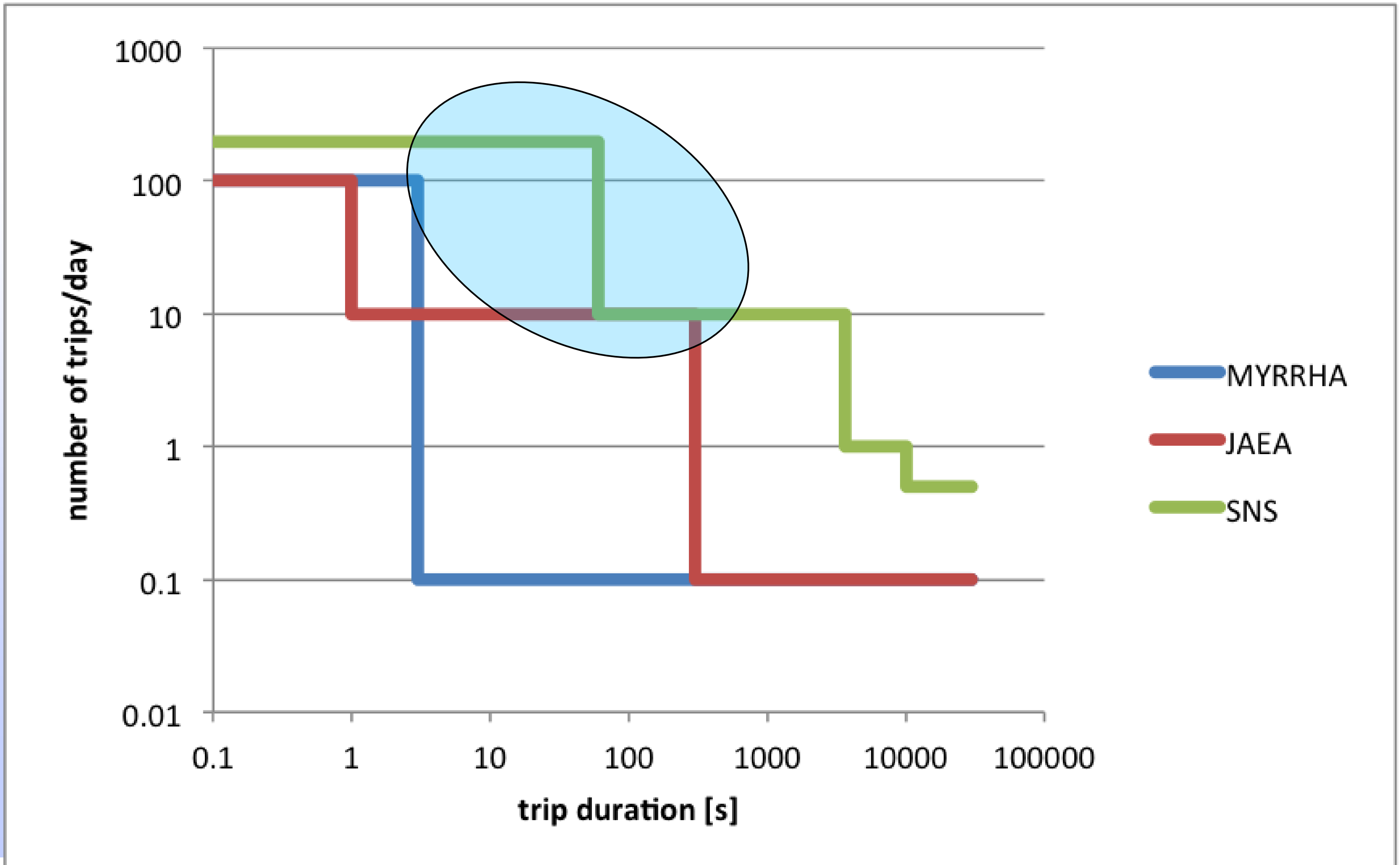
About beam trips

- requirements from reactor design
- structural tolerance:

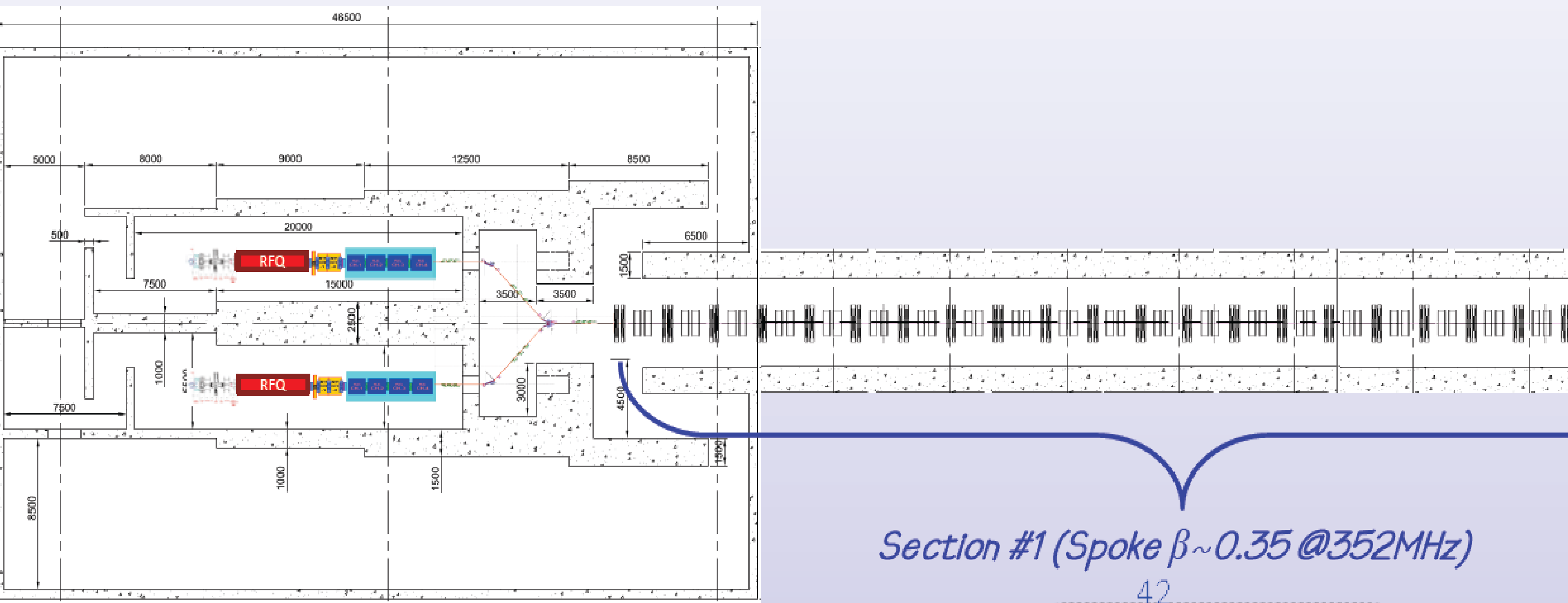
Table 1: Range of Parameters for Accelerator Driven Systems for four missions described in this whitepaper

	Transmutation Demonstration	Industrial Scale Transmutation	Industrial Scale Power Generation with Energy Storage	Industrial Scale Power Generation without Energy Storage
Beam Power	1-2 MW	10-75 MW	10-75 MW	10-75 MW
Beam Energy	0.5-3 GeV	1-2 GeV	1-2 GeV	1-2 GeV
Beam Time Structure	CW/pulsed (?)	CW	CW	CW
Beam trips (t < 1 sec)	N/A	< 25000/year	<25000/year	<25000/year
Beam trips (1 < t < 10 sec)	< 2500/year	< 2500/year	<2500/year	<2500/year
Beam trips (10 s < t < 5 min)	< 2500/year	< 2500/year	< 2500/year	< 250/year
Beam trips (t > 5 min)	< 50/year	< 50/year	< 50/year	< 3/year
Availability	> 50%	> 70%	> 80%	> 85%

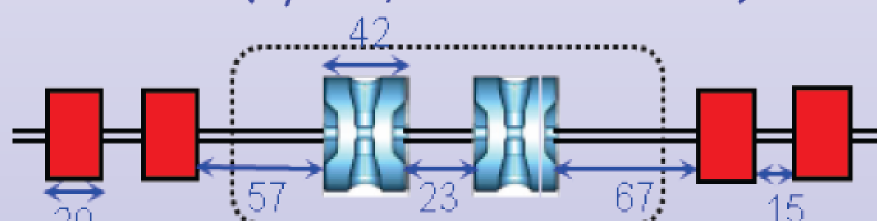
About beam trips



INJECTOR BUILDING



Section #1 (Spoke β~0.35 @352MHz)



Courtesy of Jean-Luc Biarrotte, IPN

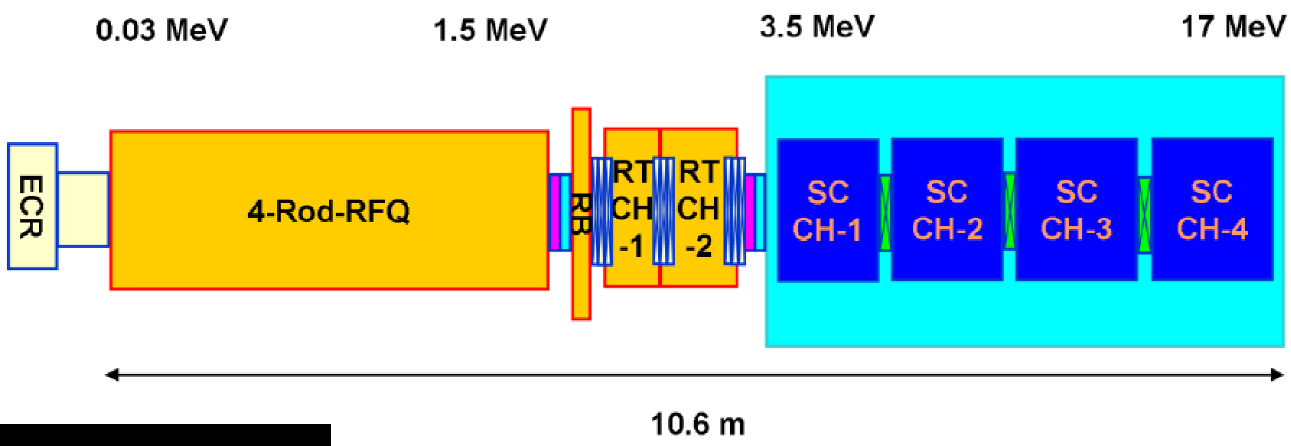
MYRRHA linac

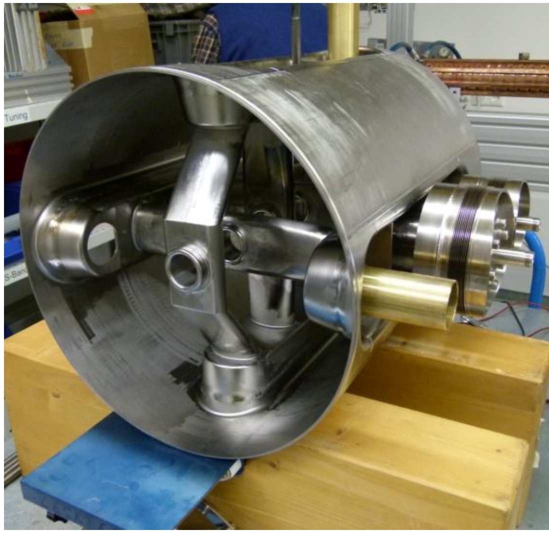
- key concepts
  - moderate requirements
  - "conservative" technological solutions
  - modularity for **fault tolerance**
- keys to reliability (availability) and fault tolerance
  1. ***redundancy***
     - common sense, experience
     - modeling confirms
  2. powerful diagnostics: predictive and self-diagnostics
  3. strict component MTBF control
  4. repairability

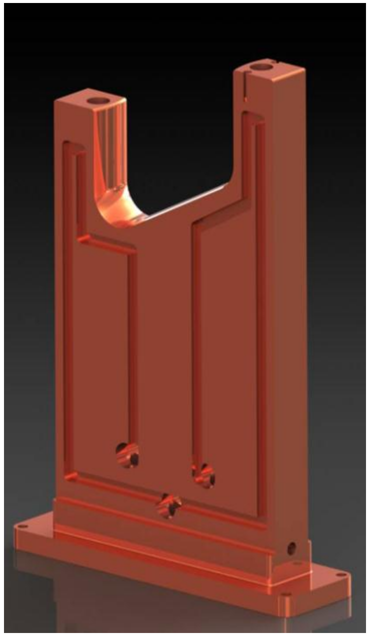
MYRRHA Accelerator eXperiment
research & development programme

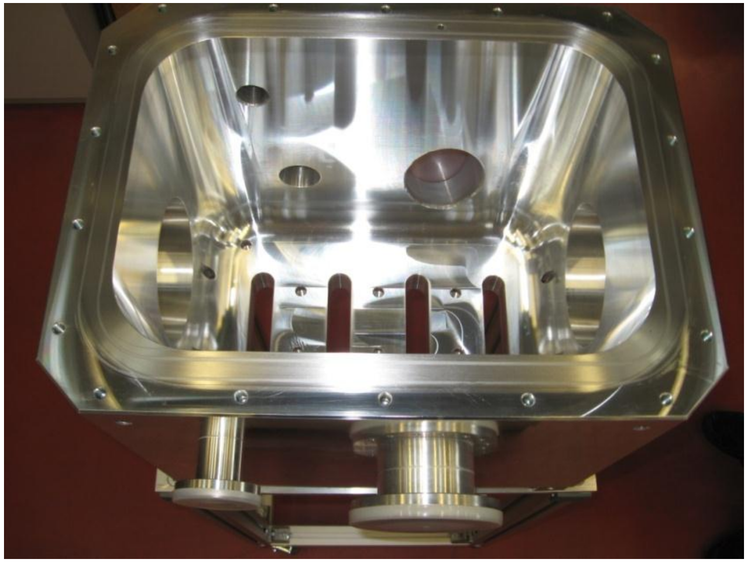
Linac components: injector

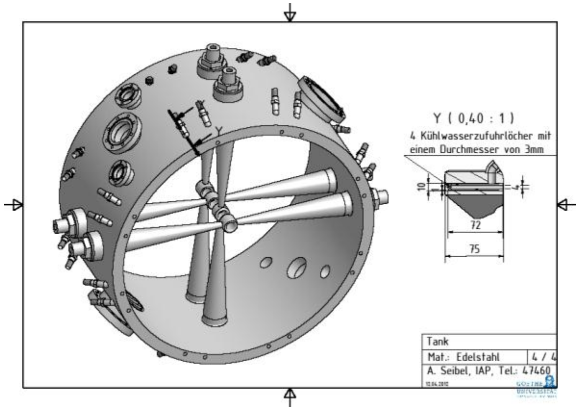
176 MHz, 5mA (MAX)



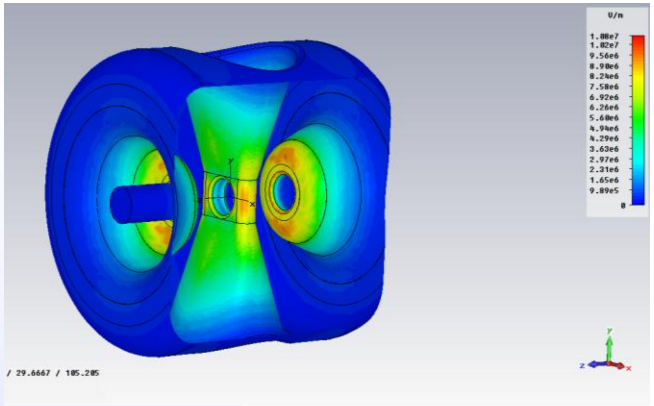


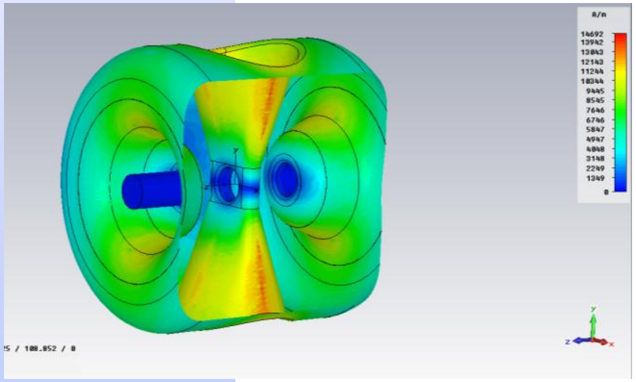


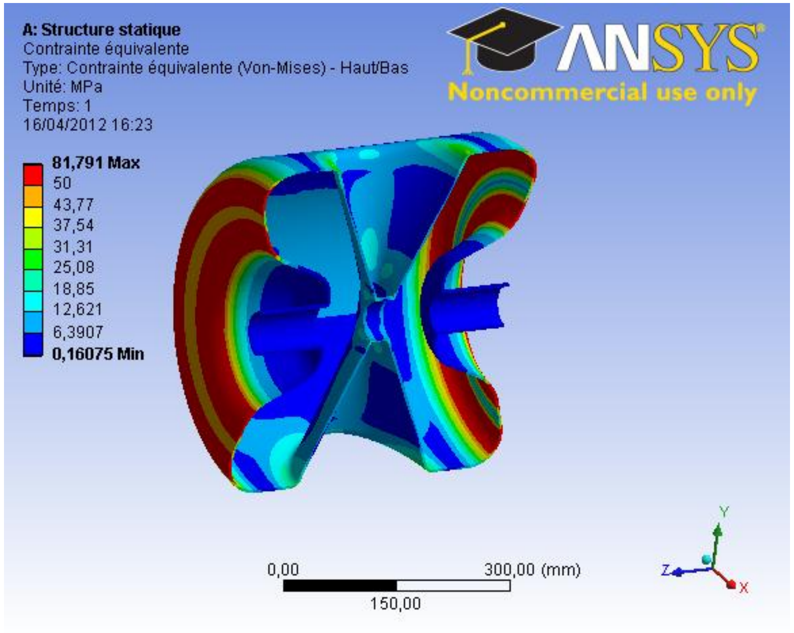




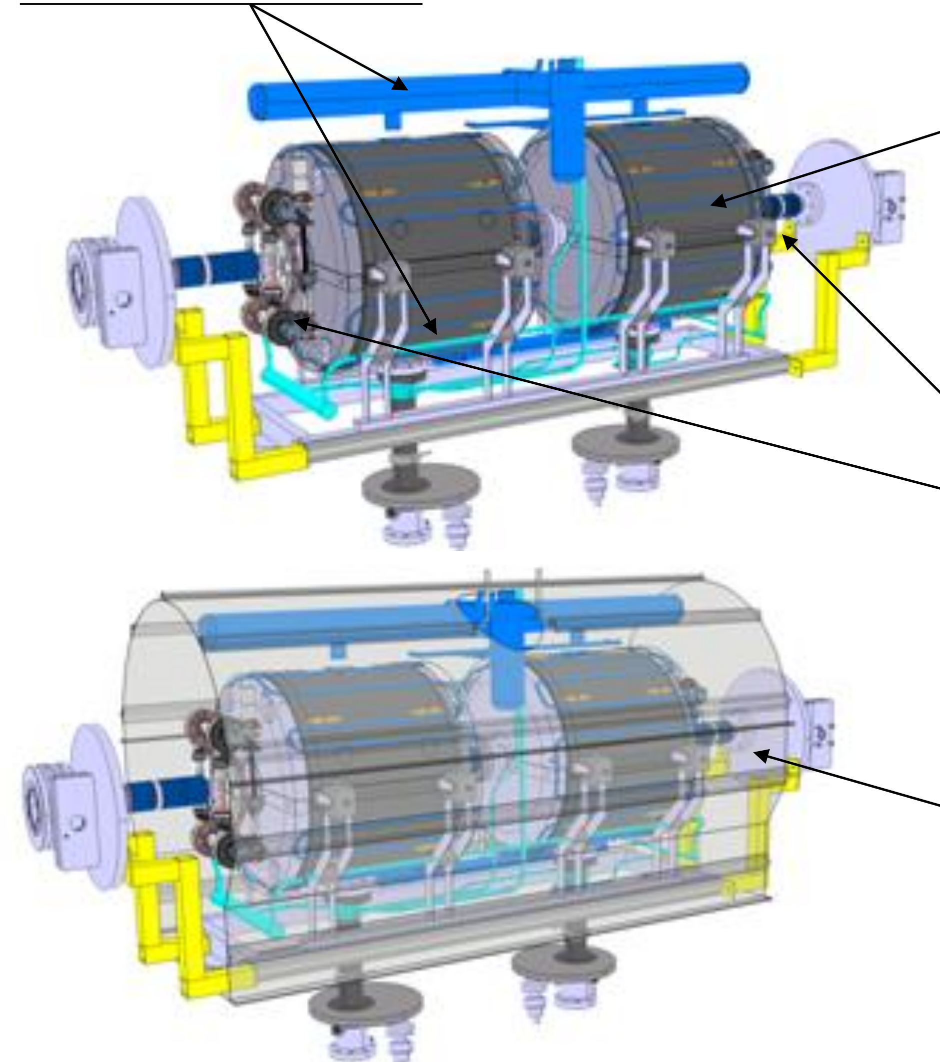
Linac components: spokes







Linac components: spokes



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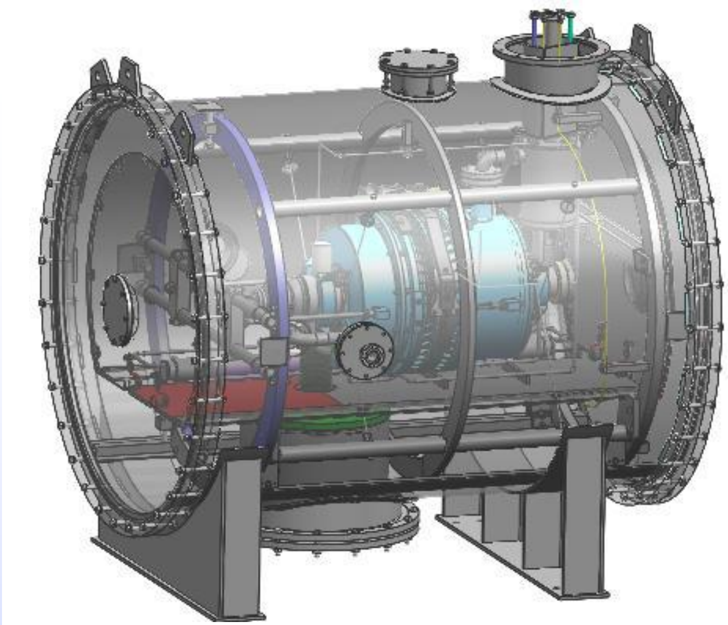
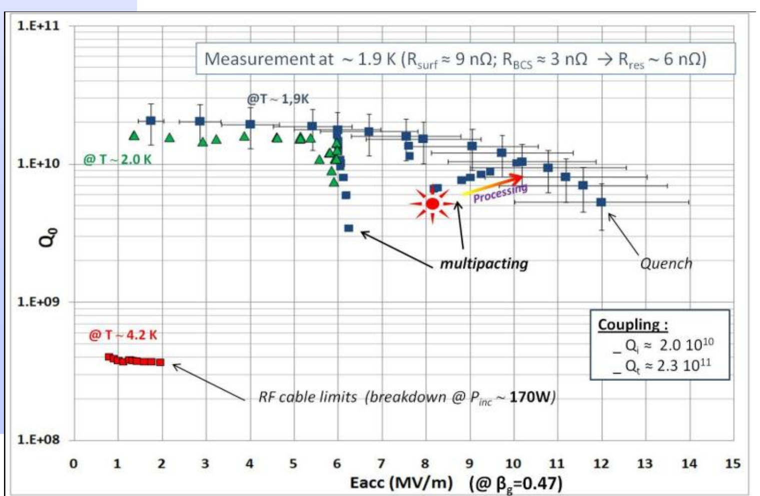
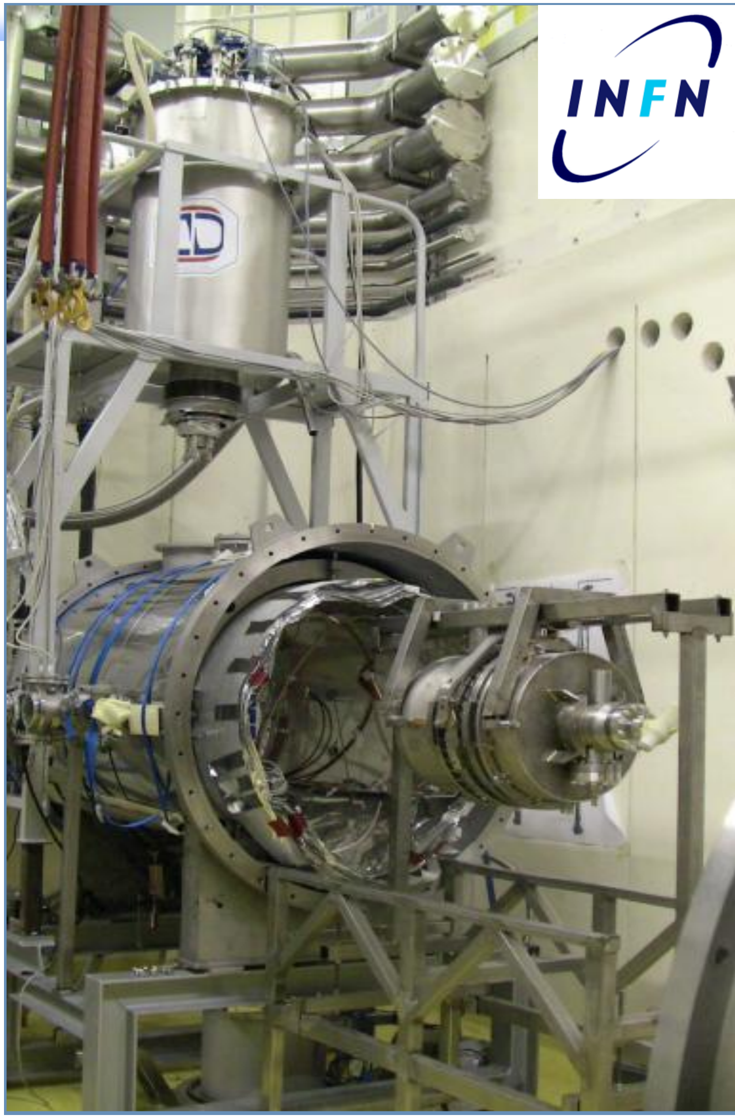
Linac components: elliptical







Linac components

- power RF : Solid State envisaged
- LLRF for fault recovery < 3 s : 2 digital loops
  - RF loop
  - tuning loop: adaptive and predictive system evaluated
- power converters : modularity
- cryogenics : 2K
- controls : EPICS

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MLA R&D program

1. reliability focused
2. yield vision on MTBF > 250 h
   - reliability modeling for choice of components
   - fault modeling with error analysis
   - on line linac simulation and matching
   - self-diagnostics
   - predictive diagnostics

   → avoid false interlocks
3. address critical issues through prototyping
   - RFQ
   - cryomodules
   - non-interceptive beam diagnostics
   - robust controls

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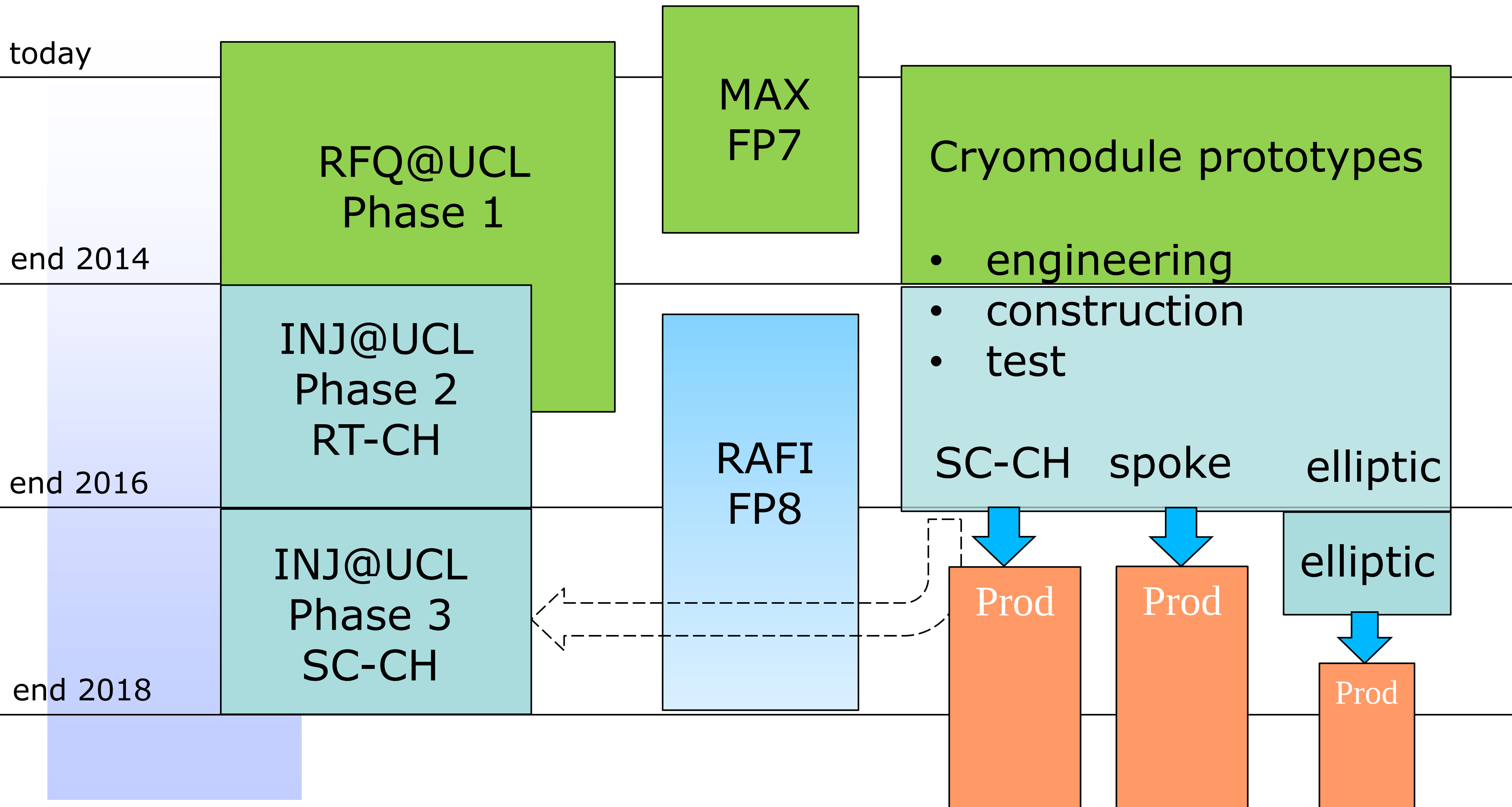
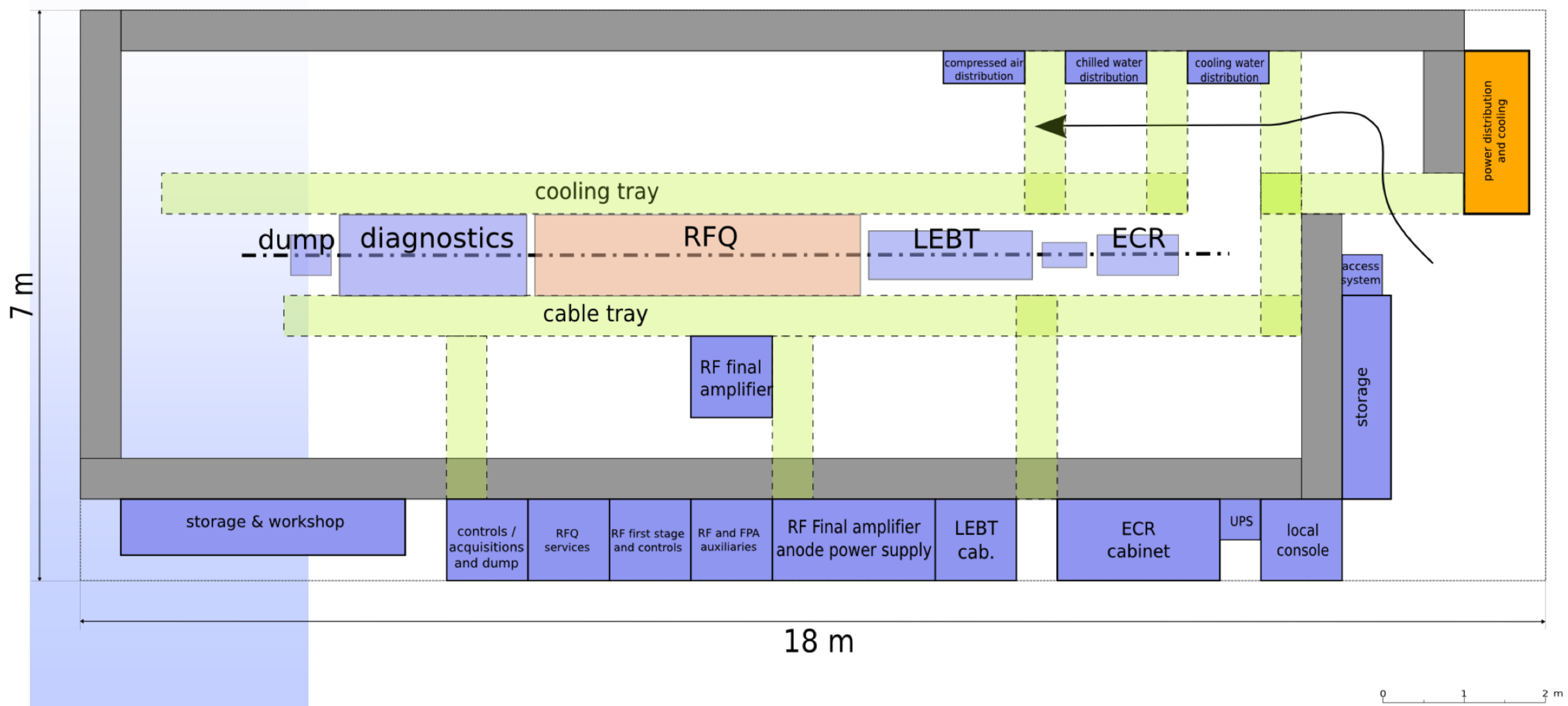
MLA R&D program

4. investigate future oriented solutions
   - SS RF
   - modular power converters
   - μTCA for Physics
   - White Rabbit
5. initiate collaborations with industry
   - ECR ion source
   - control system
   - cryomodule

MLA R&D diagram



MLA R&D program: RFQ@UCL

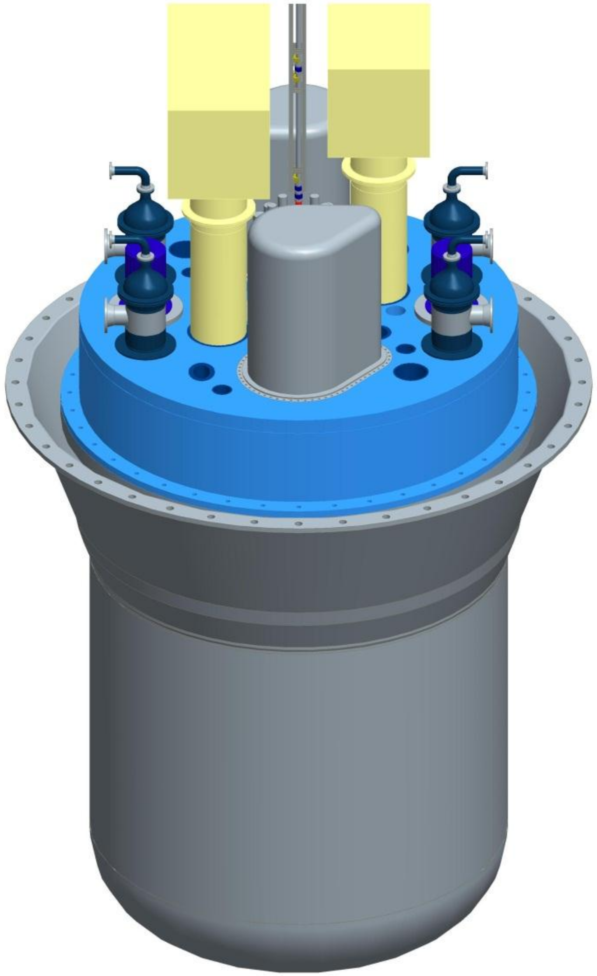


Concluding remarks

- Linac for MYRRHA has a credible design
- reliability goal is fundamentally realistic
- conditions are favourable:
  - wide effort on SC RF, synergies between many HPPA applications, reliability is common concern
  - more reliable and fault tolerant auxiliaries (e.g. SS RF amplifiers, modular power converters) contribute to our reliability goal being more practically realistic than ever.

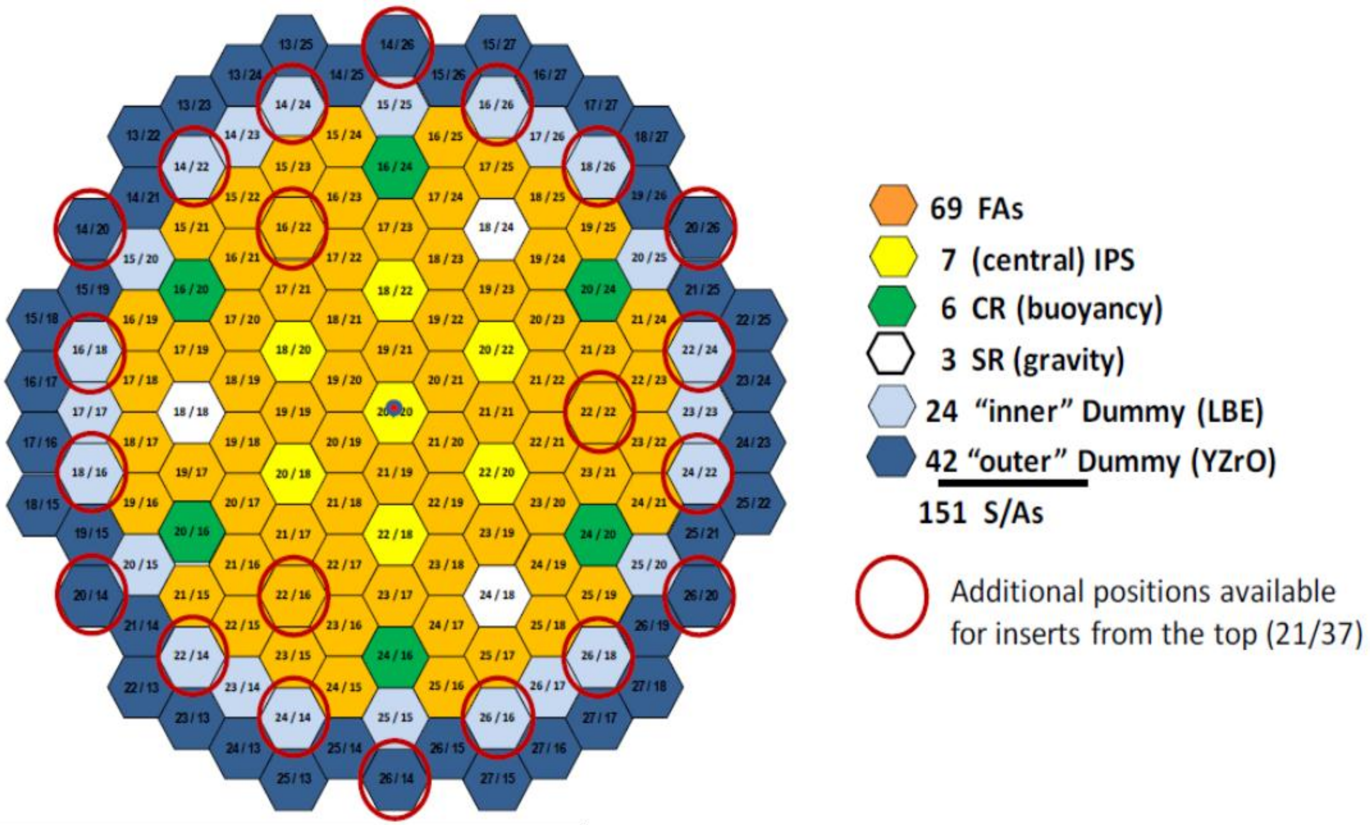
Reactor layout

- Reactor Vessel
- Reactor Cover
- Core Support Structure
  - Core Barrel
  - Core Support Plate
  - Jacket
- Core
  - Reflector Assemblies
  - Dummy Assemblies
  - Fuel Assemblies
- Spallation Target Assembly and Beam Line
- Above Core Structure
  - Core Plug
  - Multifunctional Channels
  - Core Restraint System
- Control Rods, Safety Rods, Mo-99 production units
- Primary Heat Exchangers
- Primary Pumps
- Si-doping Facility
- Diaphragm
  - IVFS
- IVFHS
  - IVFHM

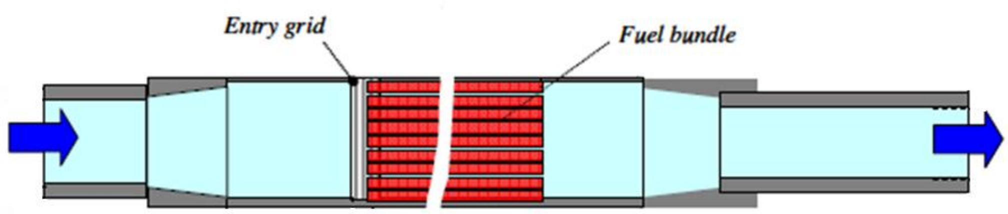


Core and Fuel Assemblies

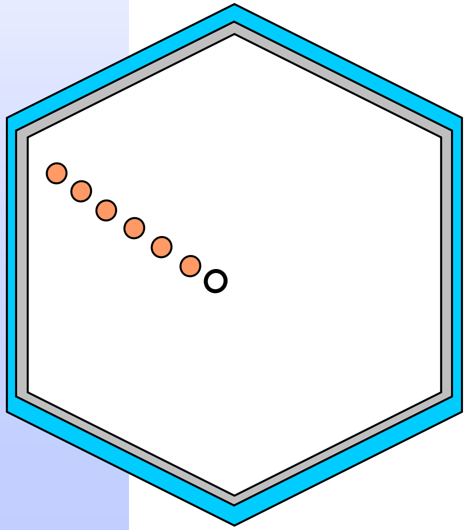
- 151 positions
- 37 multifunctional plugs

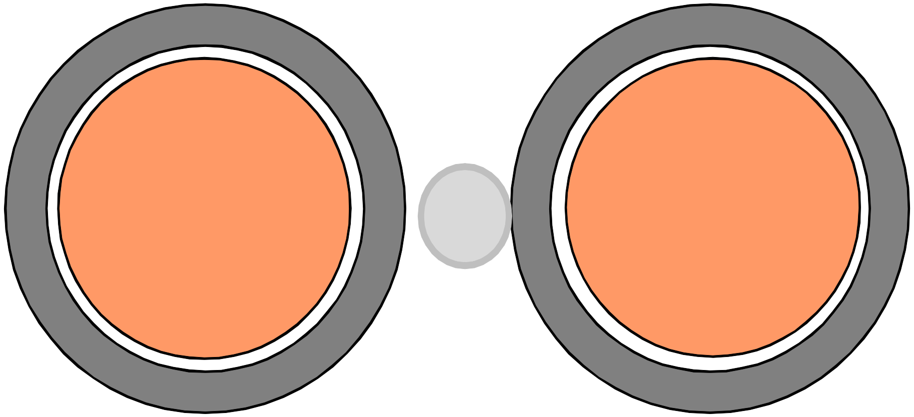


Core and Fuel Assemblies



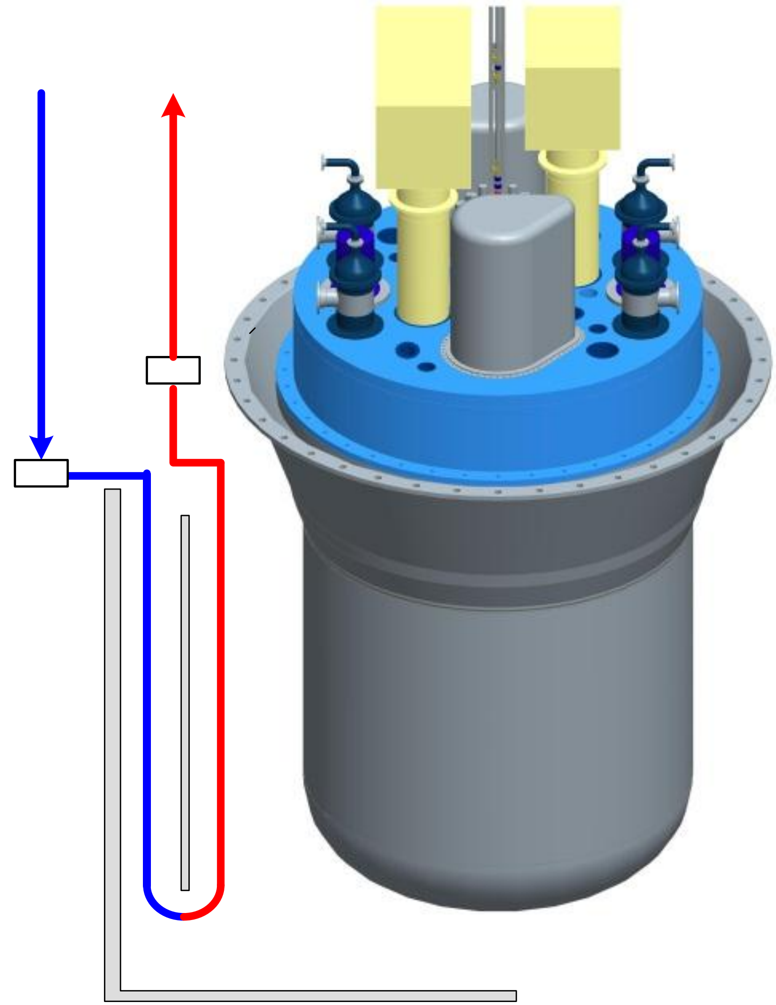
- Fuel
  - Cladding in 15-15 Ti
  - Wire wrap
  - Wrapper in T91



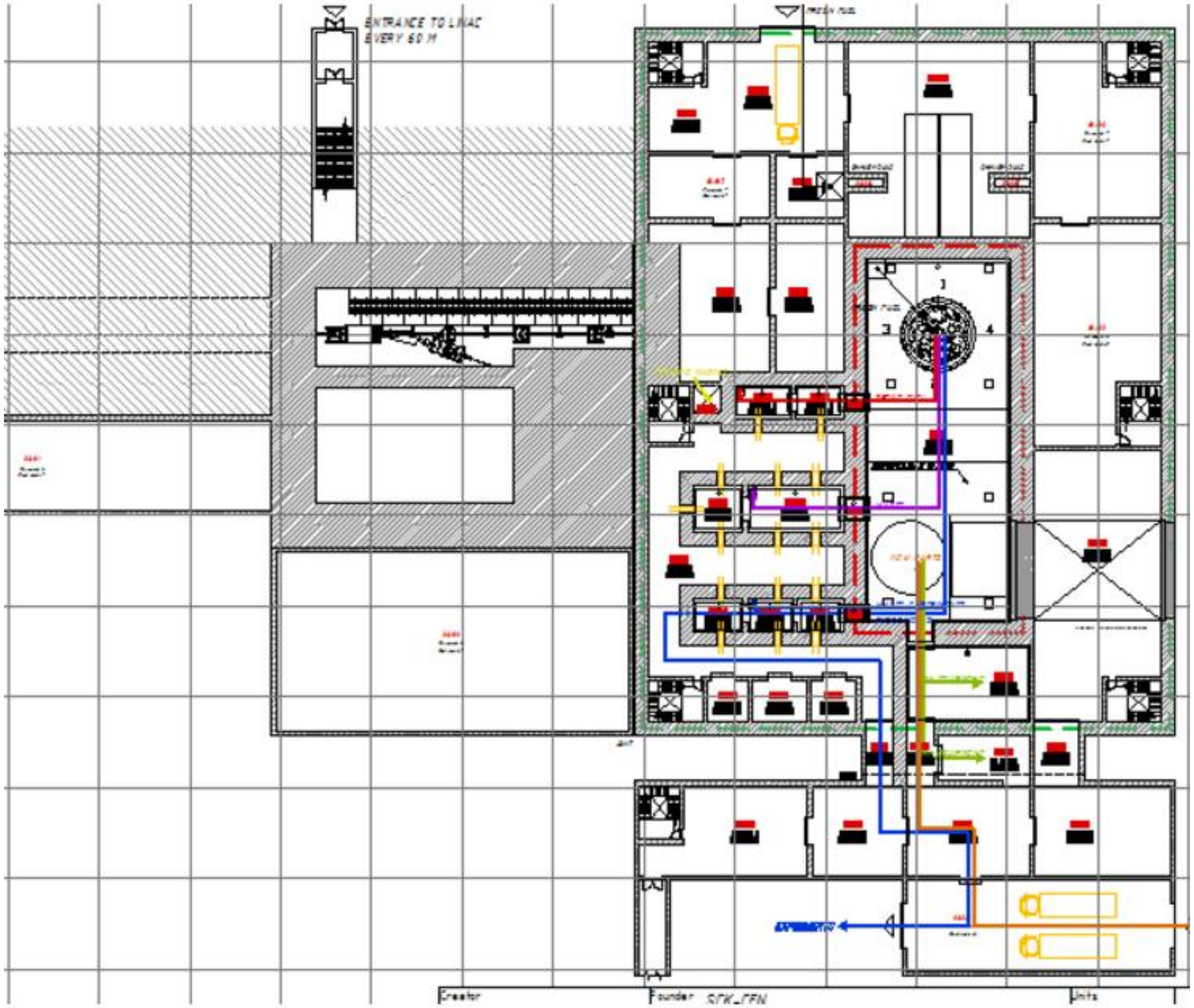


Cooling systems

- Decay heat removal (DHR) through secondary loops
  - 4 independent loops
  - redundancy (each loop has 100% capability)
  - passive operation (natural convection in primary, secondary and tertiary loop)
- Ultimate DHR through RVCS (natural convection)



Integration into building



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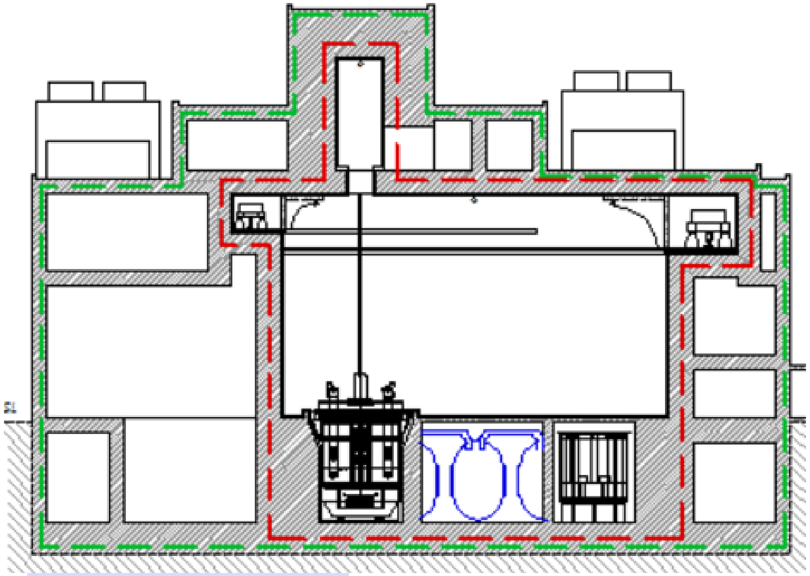
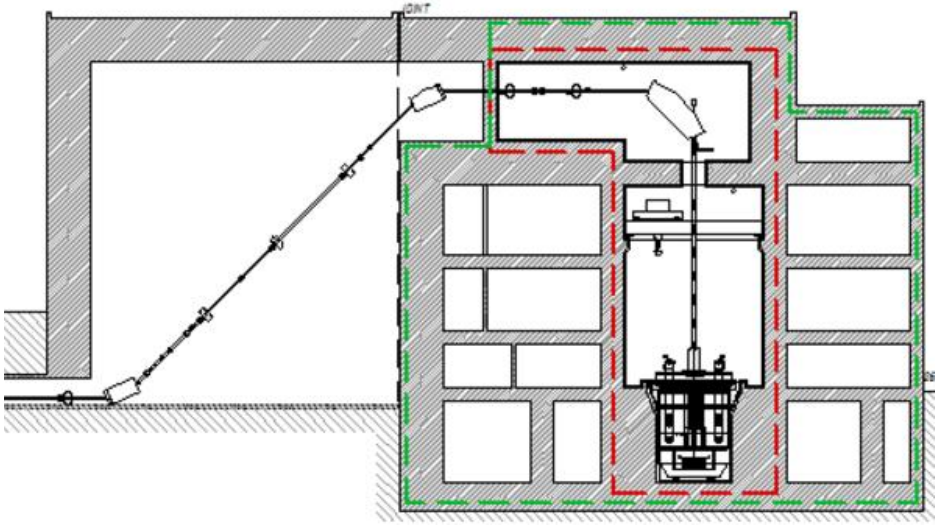




Multipurpose facility

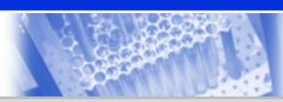
Fuel research

Φ_{tot} = 0.5 to 1.10^{15} n/cm^2.s

Material research

Φ_{Fast} = 1 to 5.10^{14} n/cm^2.s

(En>1 MeV) in large volumes



Fission GEN IV

Fusion

Φ = 1 to 5.10^{14} n/cm^2.s

(ppm He/dpa ~ 10)

in medium-large volumes

50 to 100 MWth

Φ_{Fast} = ~10^{15} n/cm^2.s

(En>0.75 MeV)

Waste

Multipurpose
h**Y**brid
Research
Reactor for
High-tech
Applications

High energy LINAC

600 MeV – 1 GeV

Long irradiation time

Fundamental research

Φ_{th} = 0.5 to 2.10^{15} n/cm^2.s

(En<0.4 eV)

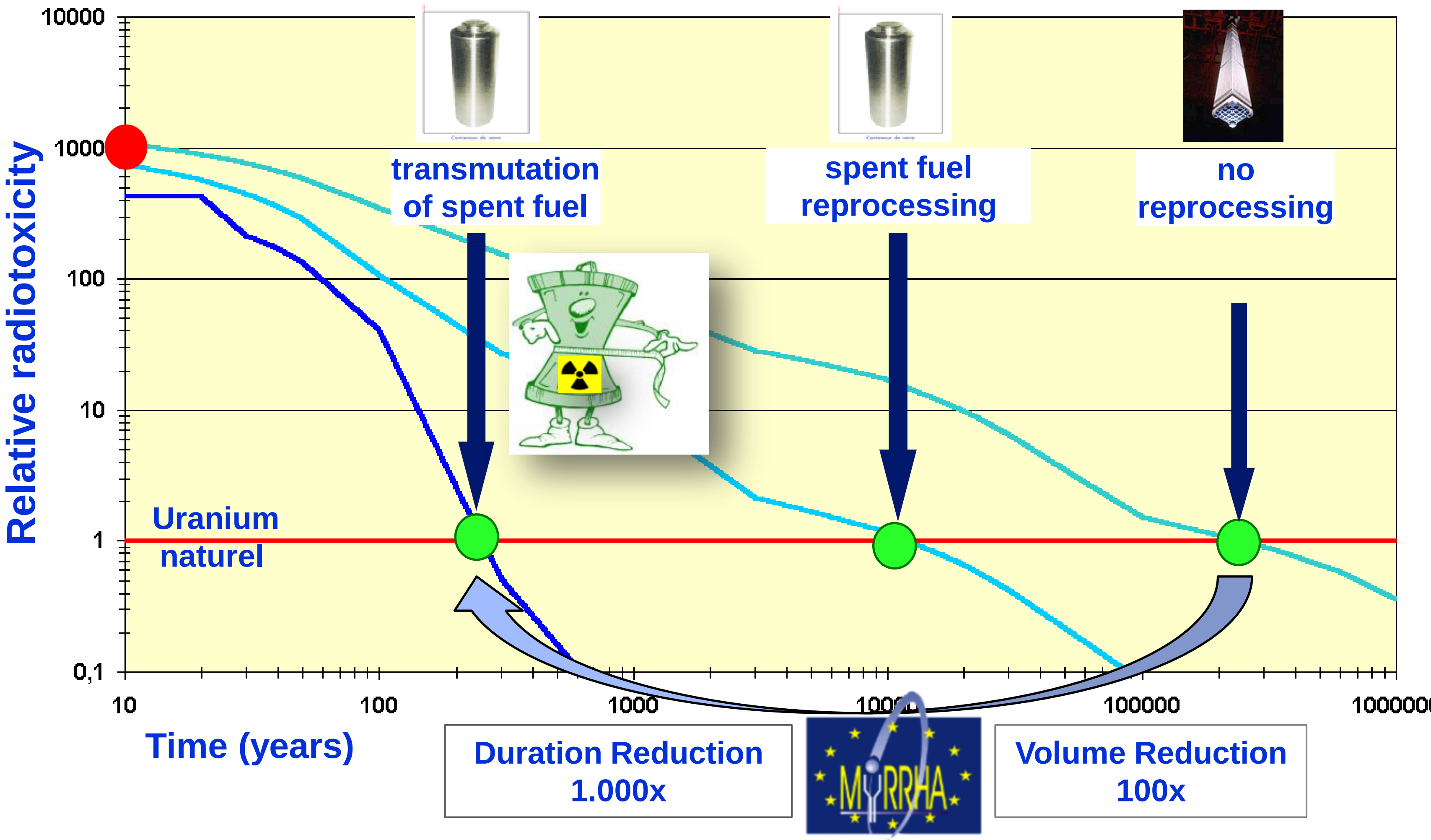
Radio-isotopes

Φ_{th} = 0.1 to 1.10^{14} n/cm^2.s

(En<0.4 eV)

Silicon doping

Motivation for transmutation



European Strategy for P&T

- **The implementation of P&T of a large part of the high-level nuclear wastes in Europe needs the demonstration of its feasibility at an "engineering" level. The respective R&D activities could be arranged in four "building blocks":**

1. **Demonstration of the capability to process a sizable amount of spent fuel from commercial LWRs in order to separate plutonium (Pu), uranium (U) and minor actinides (MA),**
2. **Demonstration of the capability to fabricate at a semi-industrial level the dedicated fuel needed to load in a dedicated transmuter,**
3. **Design and construction of one or more dedicated transmuters,**
4. **Provision of a specific installation for processing of the dedicated fuel unloaded from the transmuter, which can be of a different type than the one used to process the original spent fuel unloaded from the commercial power plants, together with the fabrication of new dedicated fuel.**

Why ADS Transmutation

- In the frame of the Waste Management research programme of the EC since FP5 till FP7, various project (IP-ADOPT, PATEROS, EUROTRANS, ARCAS) various options of the fuel cycle have been studied and showed the need to consider the progress of ADS R&D and demonstration to allow future decisions when considering:
  - Efficient burning of the LWR MA stockpile legacy
  - Considering the double-strata closed fuel cycle
  - Minimise the MA quantities in the electricity production park (even in the future FR park)
  - Allow regional approach for accommodating various national policies related to nuclear energy

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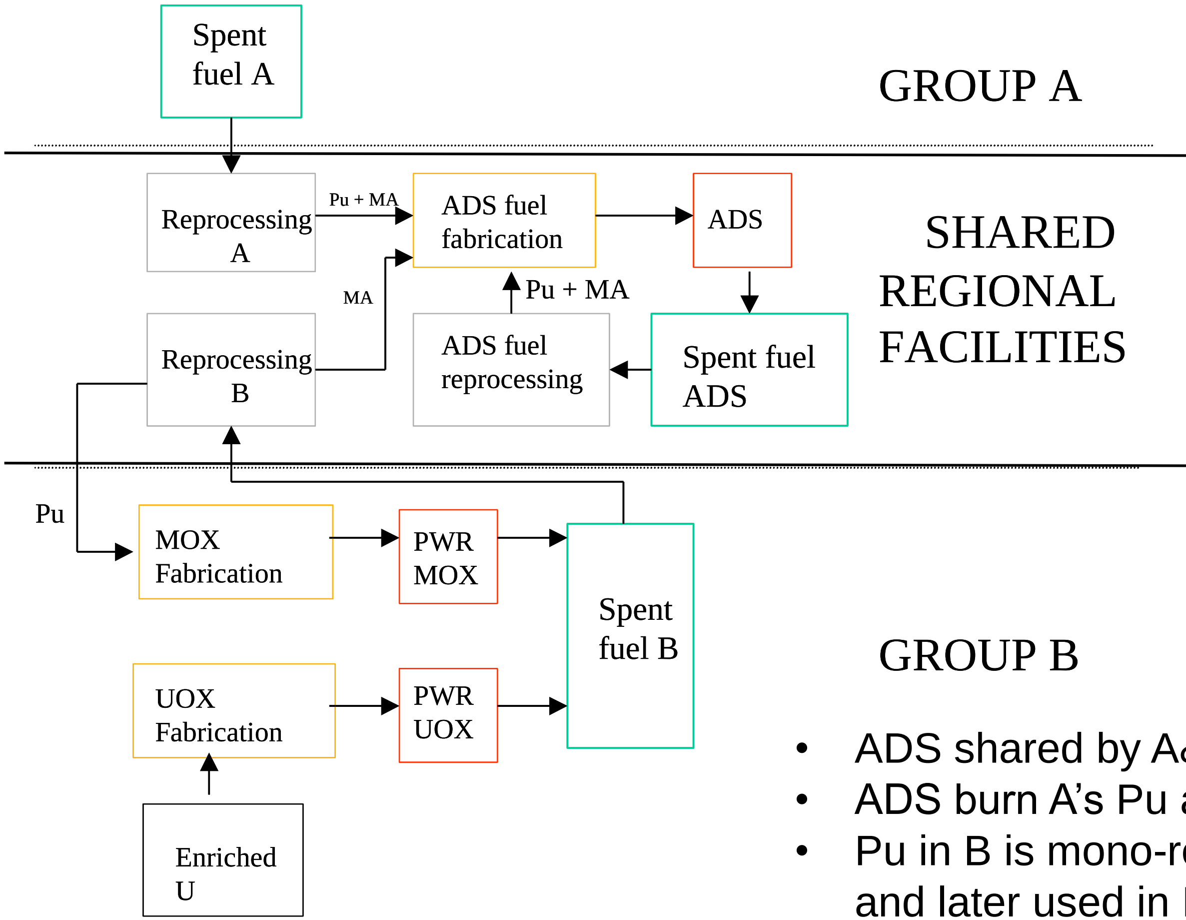
FP6-PATEROS
A European approach to P&T

- P&T useful for countries
  - in phase out
  - with active nuclear programme
- Reduction of volume & heat load of waste
- P&T should be seen at a regional/European level
- Scenario studies: 4 country groups
  - A: stagnant or phase-out
  - B: continuation and Pu optimisation for FRs
  - C: subset of A in “nuclear renaissance”
  - D: non-nuclear to go nuclear

FP6-PATEROS
A European approach to P&T



- ADS shared by A&B
- ADS burn A's Pu and A&B's MA
- Pu in B is mono-recycled PWR and later used in FR

Scenario 1 objective: elimination of A's spent fuel by 2100

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MYRRHA international reviewing

2001: International Strategic Guidance Committee

2002: International Technical Guidance Committee

2003: Review by Russian Lead Reactor Technology Experts (ISTC#2552p project)

2005: Conclusions of the European Commission FP5 Project PDS-XADS (2001-2004)

2006: European Commission FP6 Project EUROTRANS (2005-2009): Conclusions of Review and Justification of the main options of XT-ADS starting from MYRRHA

2007: International Assessment Meeting of the Advanced Nuclear Systems Institute

2008: European Commission FP7 Project Central Design Team (CDT) at Mol for MYRRHA detailed design

2009: MIRT of OECD/NEA on request of Belgian Government

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European context

ESFRI
European
Strategic
Forum for
Research
Infrastructure

SET Plan
European
Strategic
Energy
Plan

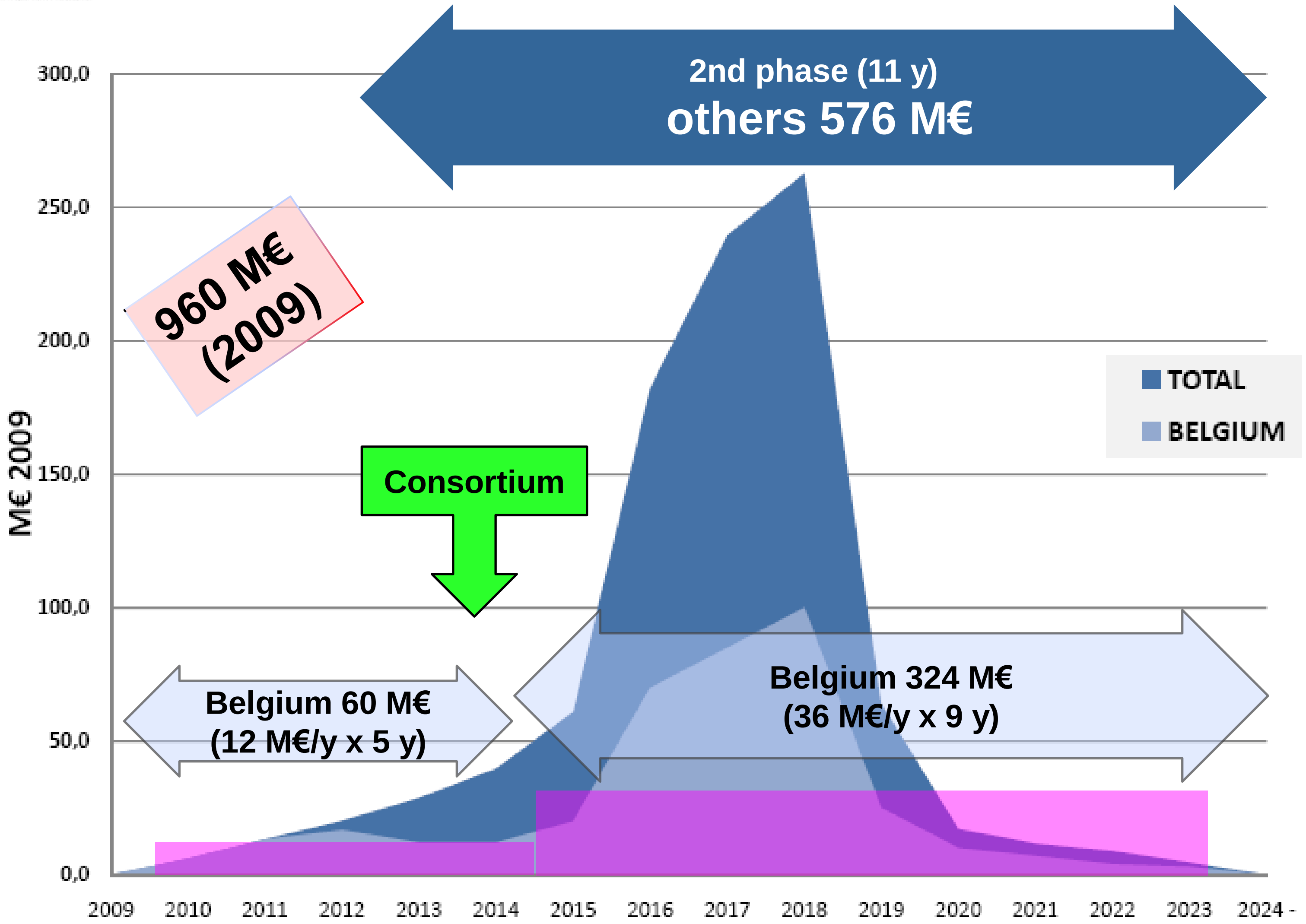
Knowledge Economy

Energy Independence

27.11.2010
Confirmed on ESFRI priority list projects

15.11.2010
in ESNII
(SNETP goals)

Belgian commitment: secured
International consortium: under construction



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The project schedule

2010-2014	**2015**	**2016-2018**	**2019**	**2020-2022**	**2023**	**2024-**
Front End Engineering Design	Tendering & Procurement	Construction of components & civil engineering	On site assembly	Commissioning	Progressive start-up	Full exploitation

Minimise technological risks

Accelerator x Spallation target x Sub-critical reactor

Secure the licensing

- **PDP** preliminary dismantling plan
- **PSAR** preliminary safety assesment
- **EIAR** environmental impact assesment

Secure a sound management and investment structure

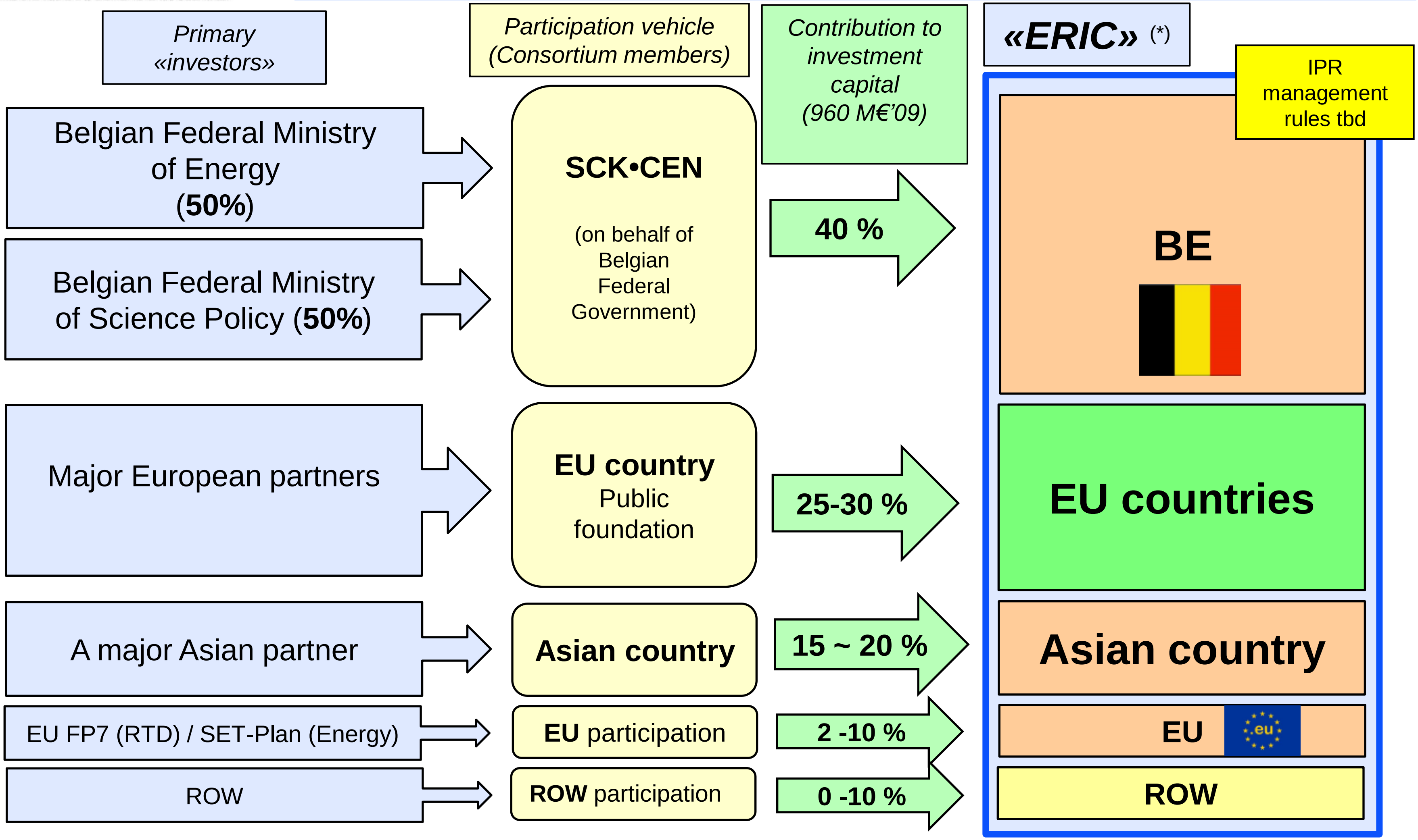
- Central Project Team
- Owner Consortium Group
- Owner Engineering Team

FEED (Front End Engineering Design)

2010-2014

MYRRHA: an international project

International Members Consortium – Phase 1
As of early 2012



(*) European Research Infrastructure Consortium

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

Joining the MYRRHA project

- Belgium is welcoming international participation in the MYRRHA consortium
- Membership eligibility for the international MYRRHA consortium is based on a balanced in-cash/in-kind contribution

- Until end 2014:
  - Partners are invited to express their interest in a participation in the MYRRHA programme by sending an **Expression of Interest** to SCK•CEN by end of **August 2012**.
  - After having received this Expression of Interest, the candidate Partner will confirm the contribution level of its commitment by sending a **Commitment Letter** by end of **December 2012**.
  - After having received the Commitment Letter, the candidate Partner and SCK•CEN will enter immediately into negotiation on their co-operation aiming at the signature of a **Bilateral Agreement** covering the Investment Phase and/or the Operation Phase. This Bilateral Agreement should be signed and enter into force before the **mid 2013**.

MYRRHA: EXPERIMENTAL ACCELERATOR DRIVEN SYSTEM

A pan-European, innovative and unique facility at Mol (BE)