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

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

Project Status

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MYRRHA

Project Status

JINR International Seminar on Interaction of Neutrons with Nuclei ISINN-21

May 20-25, 2013, Alushta (UA)

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On behalf of MYRRHA Team
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MYRRHA - Accelerator Driven System

Accelerator

(600 MeV - 4 mA proton)

Reactor

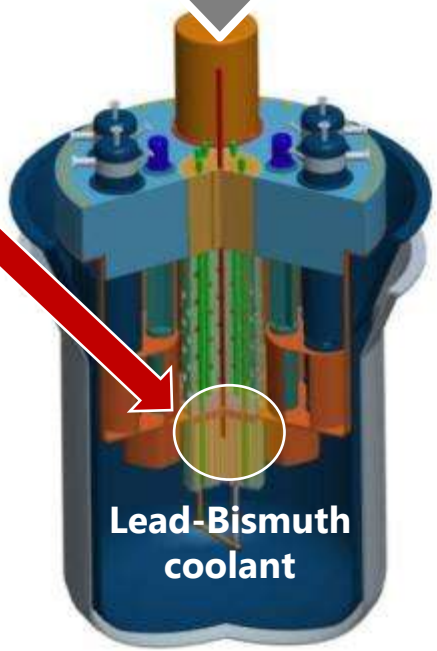
- Subcritical or Critical modes
- 65 to 100 MWth

Innovative & Unique

Spallation Source

Fast Neutron Source

Multipurpose Flexible Irradiation Facility



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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 (JRC/ITU),**
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.**

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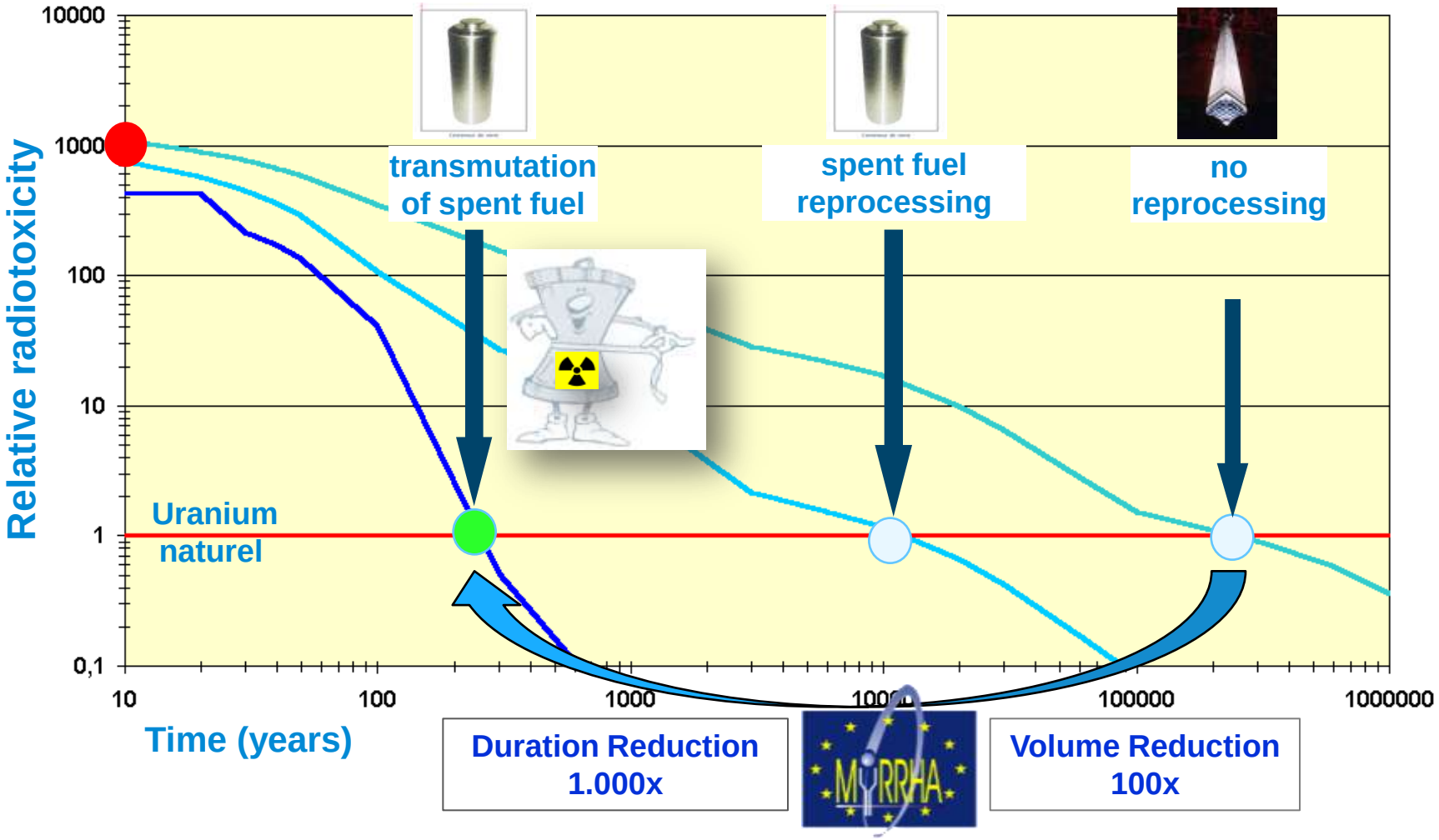
Motivation for Transmutation



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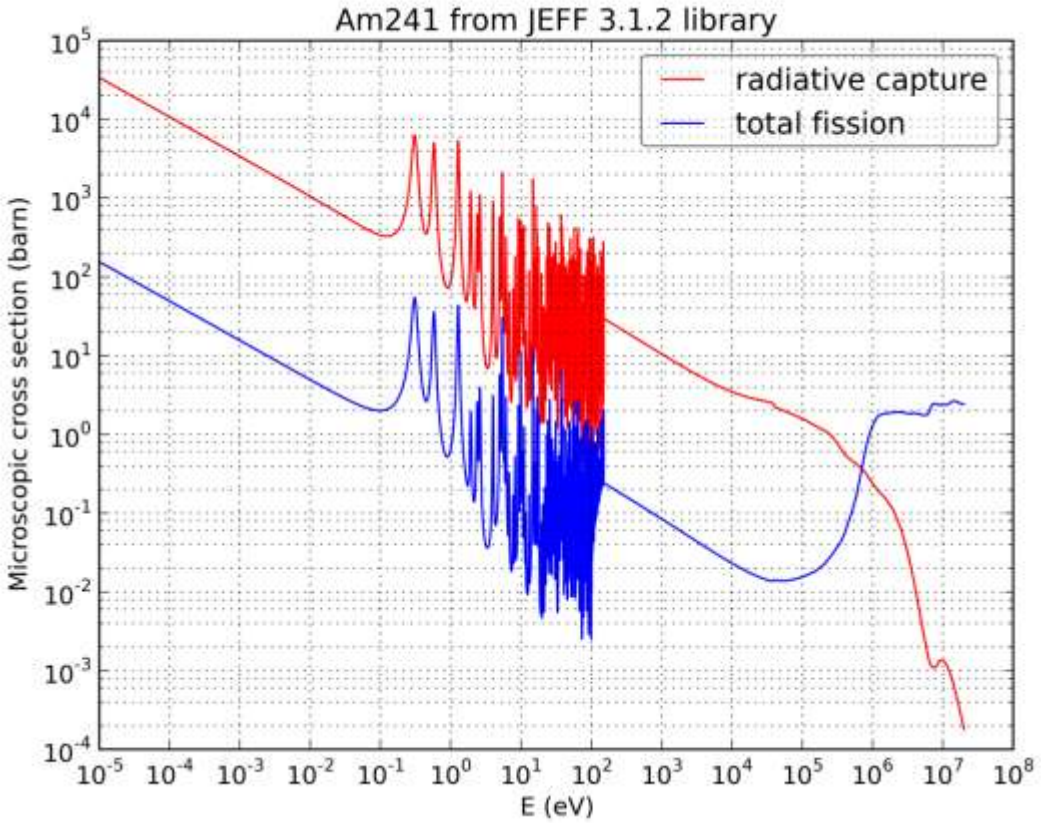
Fast Neutrons are unavoidable for transmutation

- To transmute MAs, we need to fission them
- The ratio Fission/Capture is more favourable with fast neutrons



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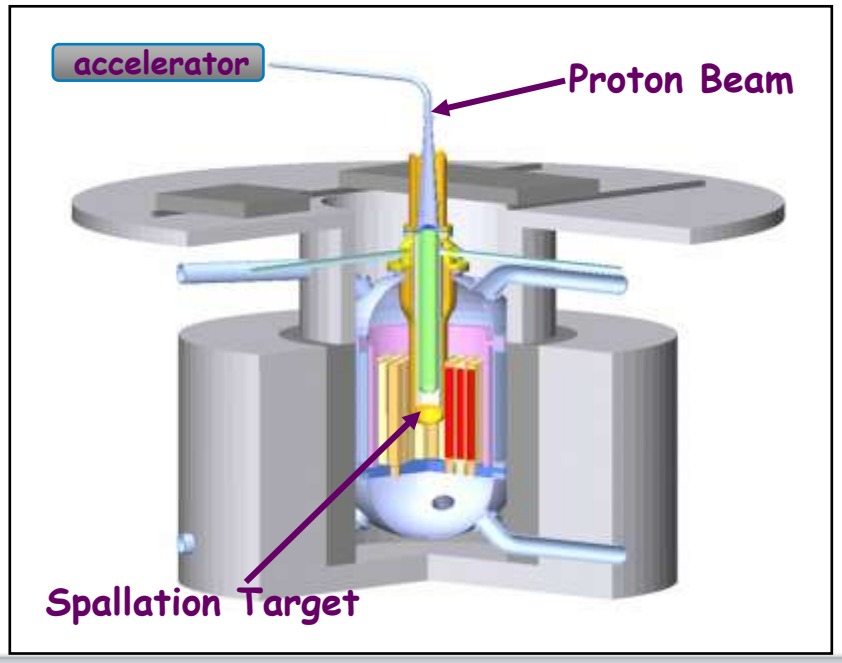
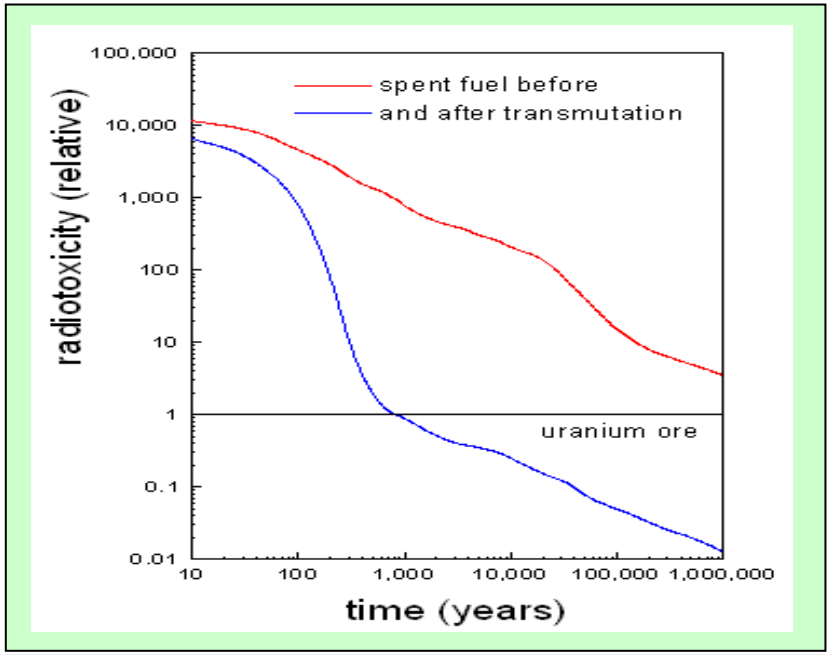
Is sub-criticality a luxury?

Both Critical reactors as well as ADS can be used as MAs transmuters

Nevertheless, critical reactors, heavily loaded with MAs, can experience severe safety issue due to reactivity effect induced by a smaller fraction of delayed neutrons.

ADS can operate in a more flexible and safer manner even if heavily loaded with MAs hence leading to efficient transmutation therefore we say that **sub-criticality is not a luxury but a necessity.**





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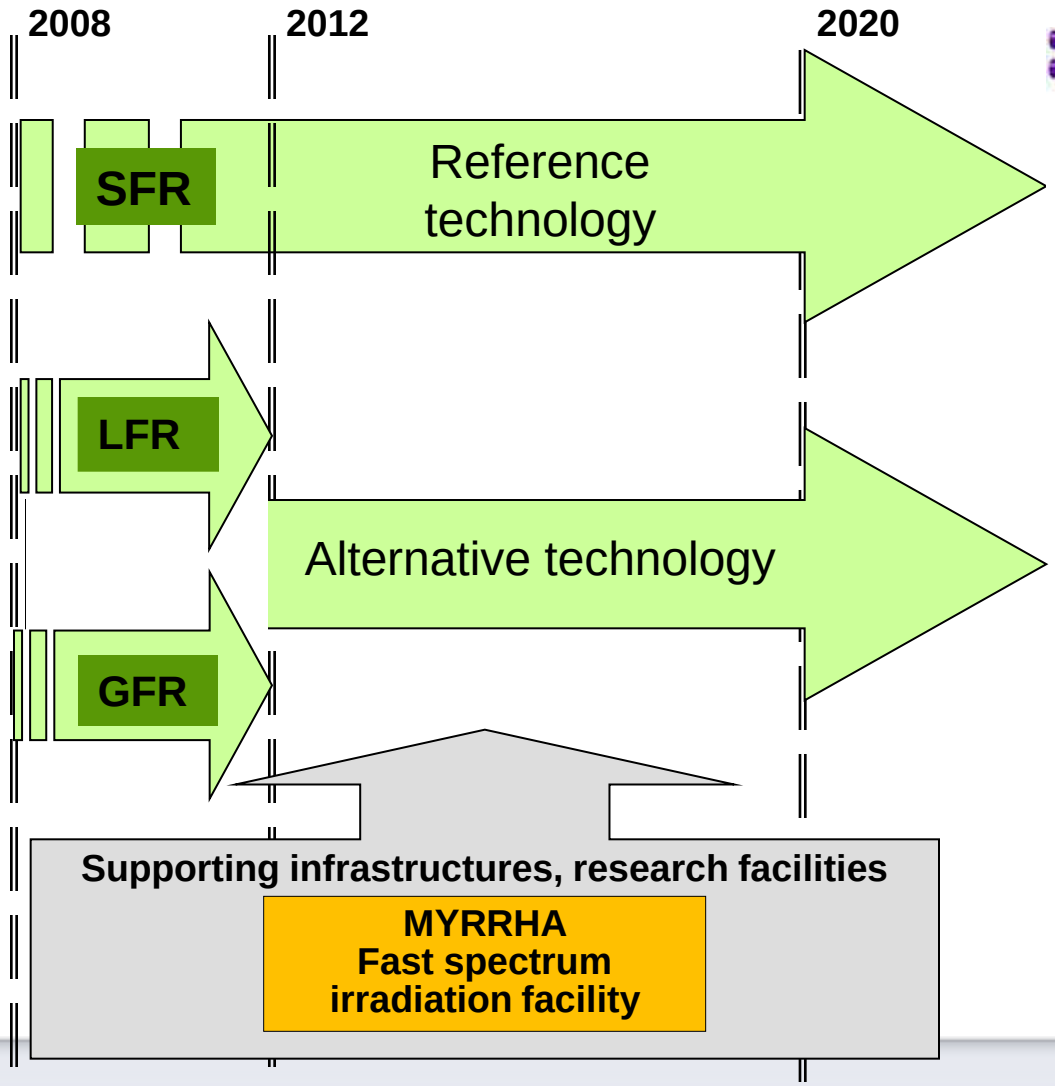
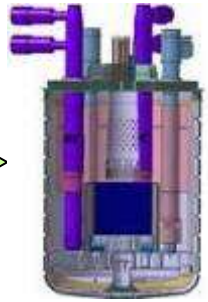
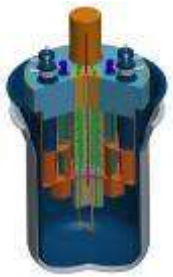
MYRRHA part of ESNII (European Sustainable Nuclear Industrial Initiative)





ASTRID
Prototype
(SFR)



MYRRHA
ETPP European
demonstration reactor
(LFR)

ALLEGRO
Experimental reactor
(GFR)

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SCK•CEN Continuity: tradition of «first of a kind»

1st pressurized water reactor (PWR) outside of US (BR3)

Inventor of innovative nuclear fuel (MOX fuel)

Highest performing material testing reactor in Europe (BR2)

World first underground laboratory for R&D on HL waste disposal (HADES)

World first lead based ADS (GUINEVERE & FREYA)

MYRRHA

World premiere project for transmutation of nuclear waste

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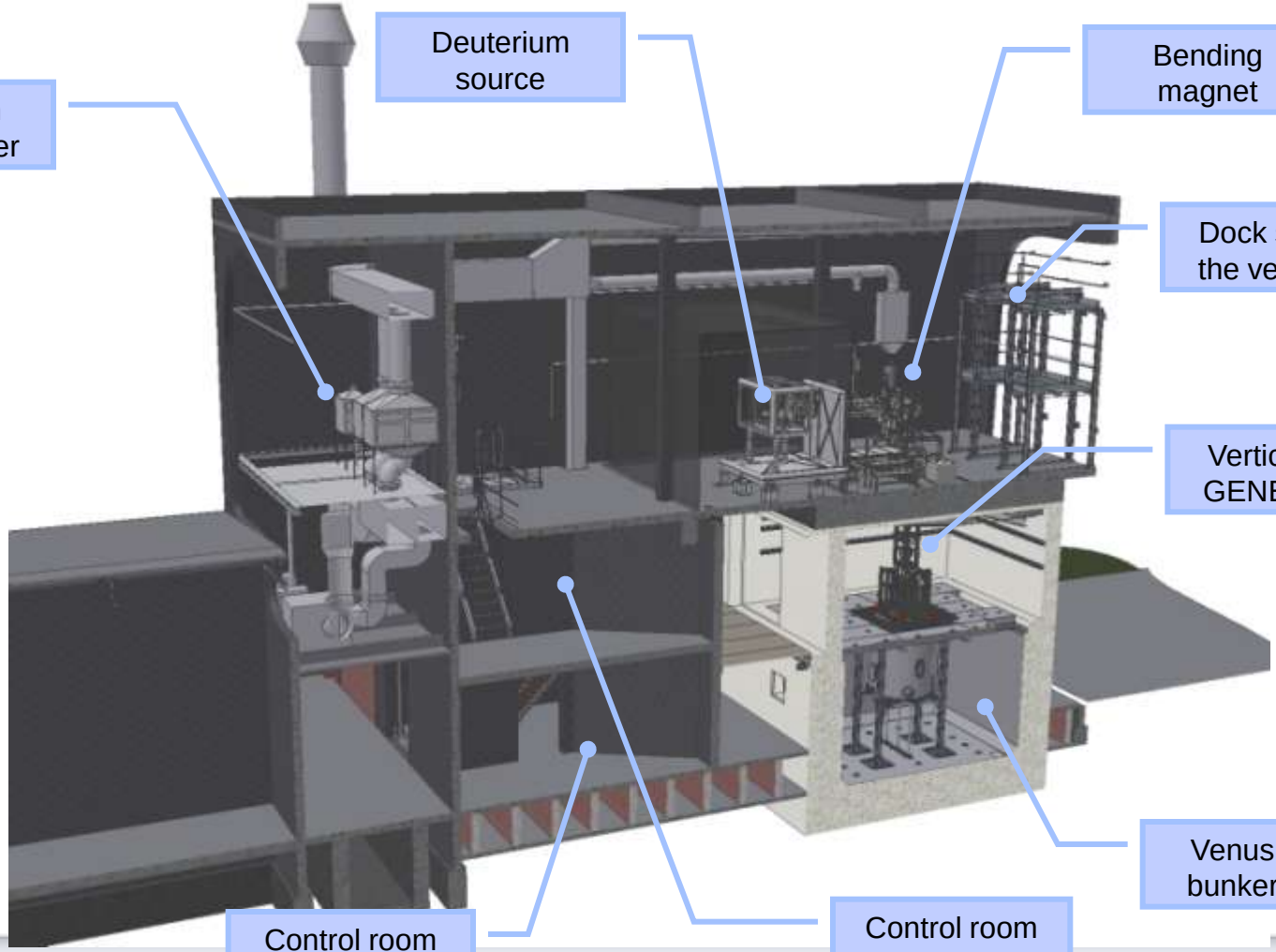
The VENUS-F installation for GUINEVERE and FREYA projects



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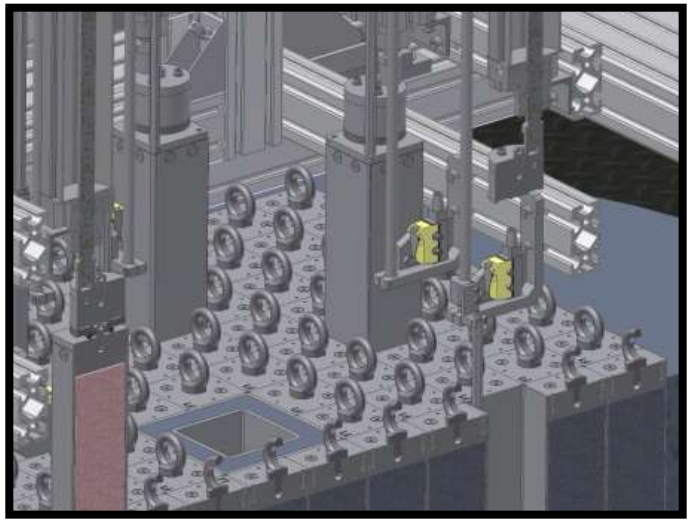
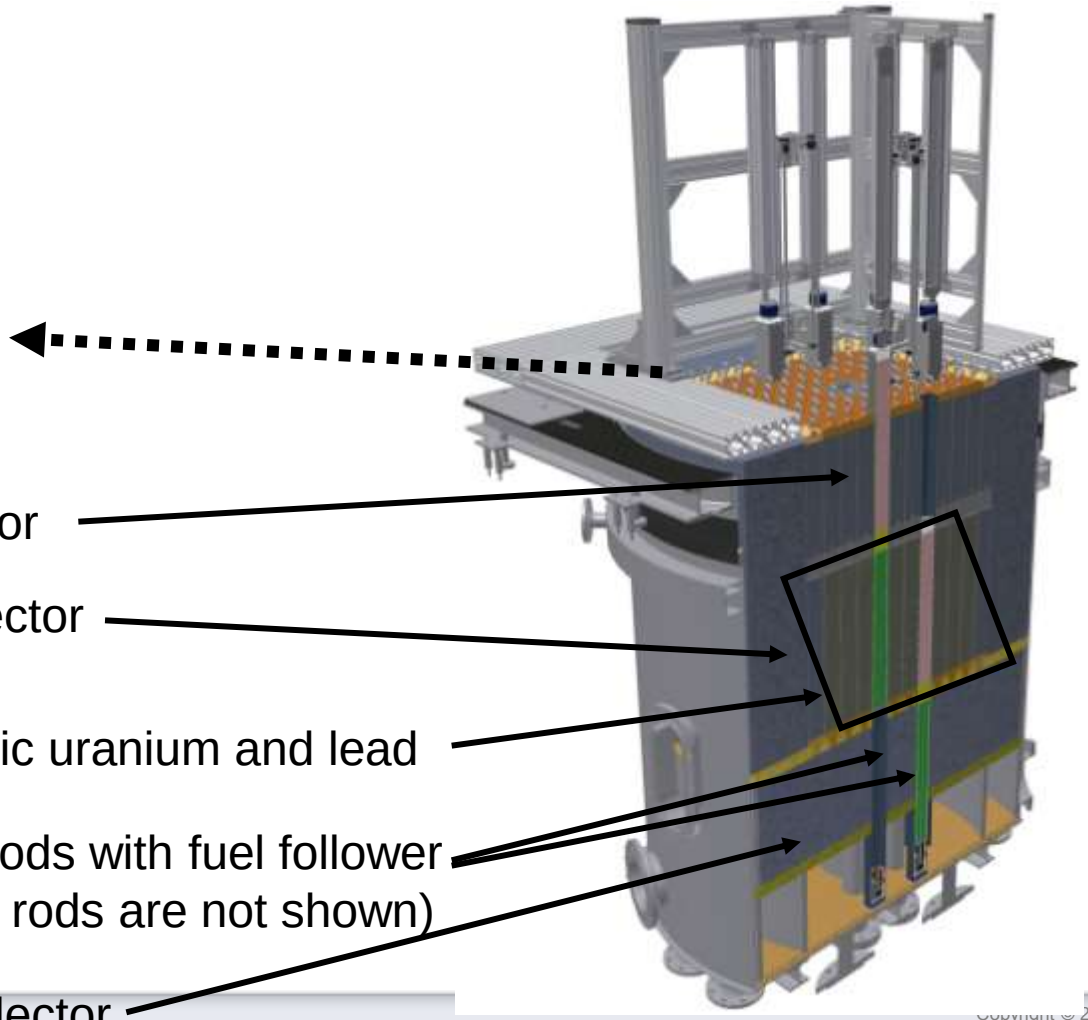
The VENUS-F configuration for GUINEVERE & FREYA





Pb top reflector

Pb radial reflector

Core in metallic uranium and lead

6 B_4C safety rods with fuel follower
(2 B_4C control rods are not shown)

Pb bottom reflector

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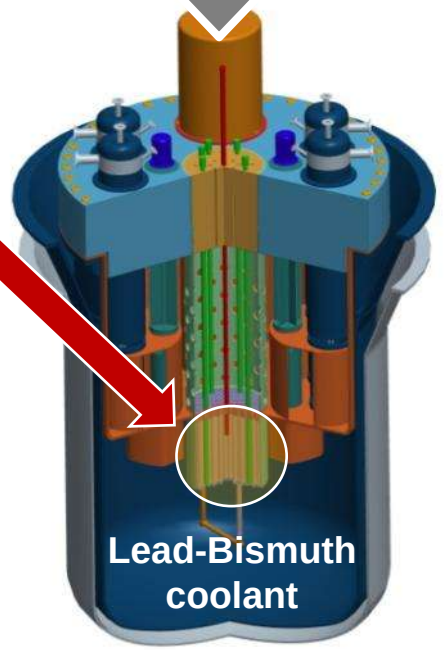

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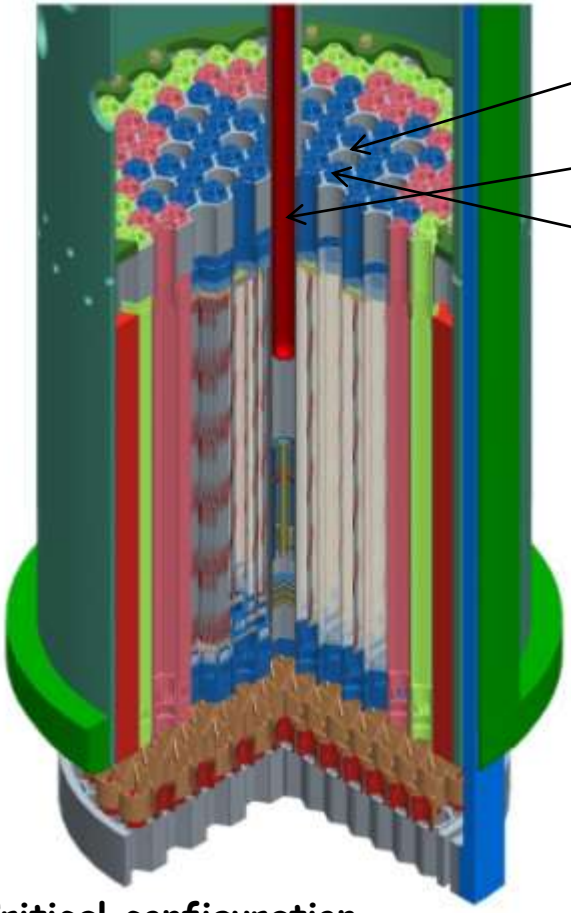
Critical and sub-critical

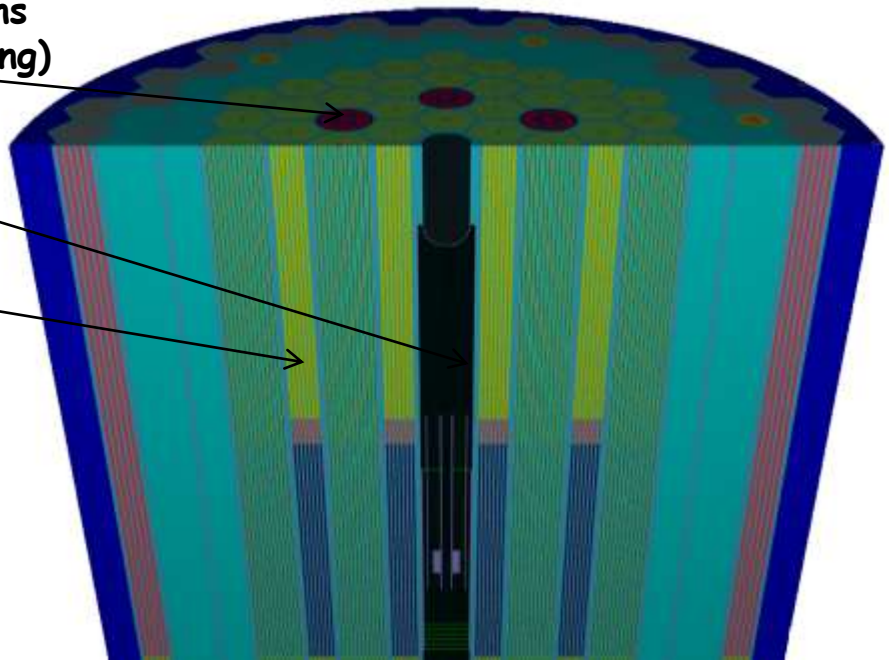


Critical configuration
~100 MWth

In-Pile Sections
(material testing)

Spallation
target

FA
(MOX)



Sub-critical configuration:

- 600 MeV, < 4mA proton beam
- 65 - 75 MWth
- K_{eff} ~0.95-0.96
- LBE spallation target (with beam window)
- LBE pool

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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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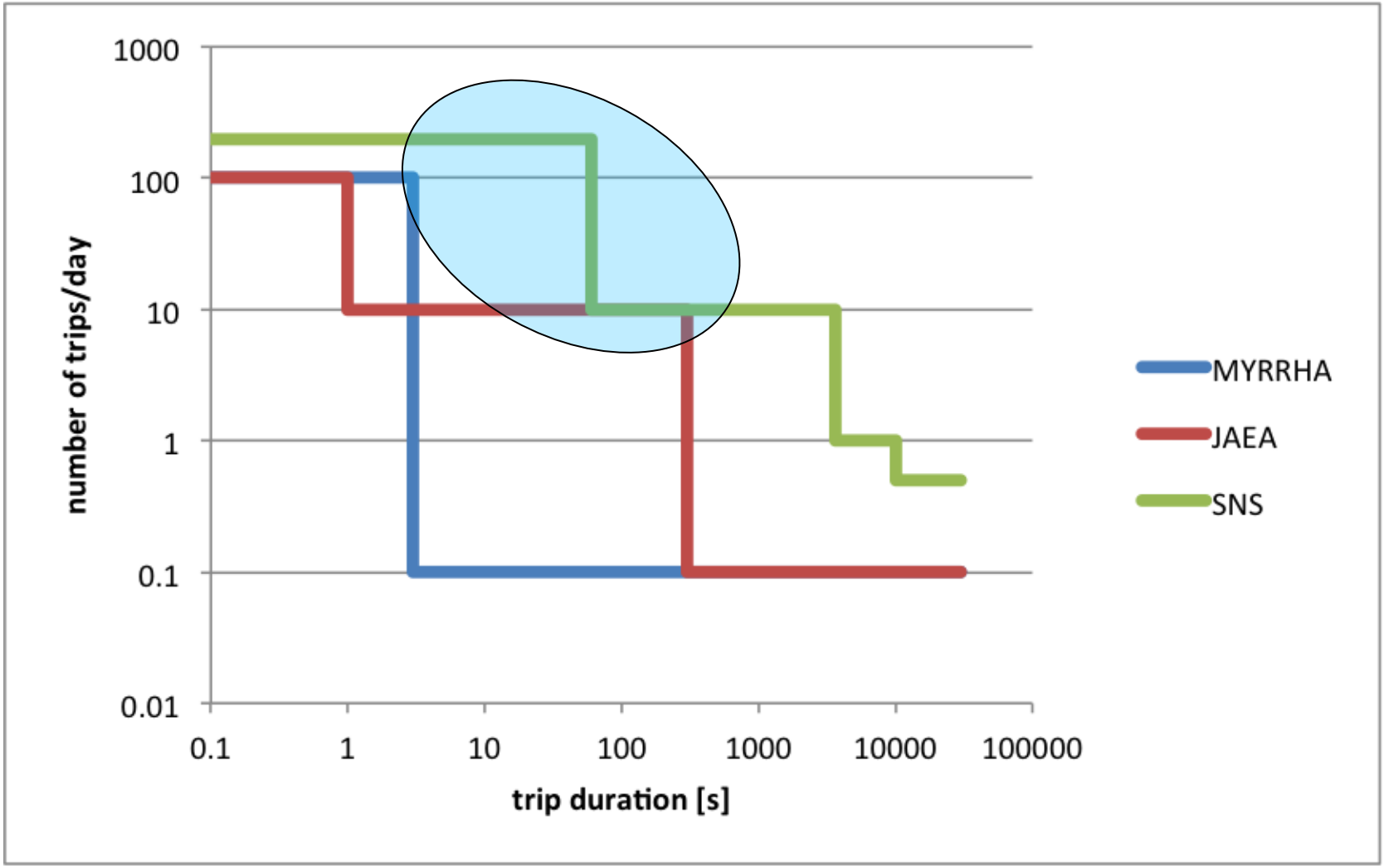
About beam trips



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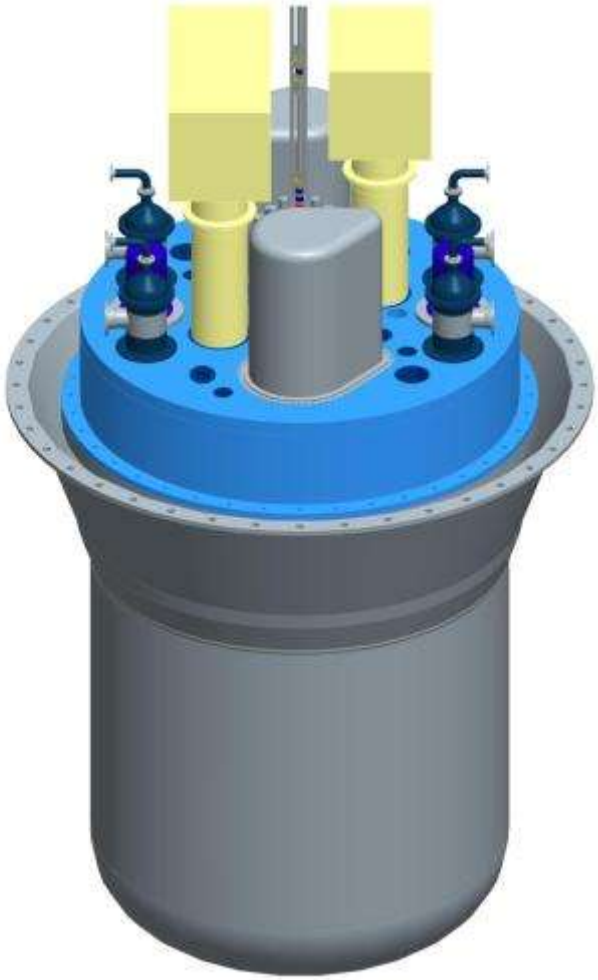
Reactor layout

- 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



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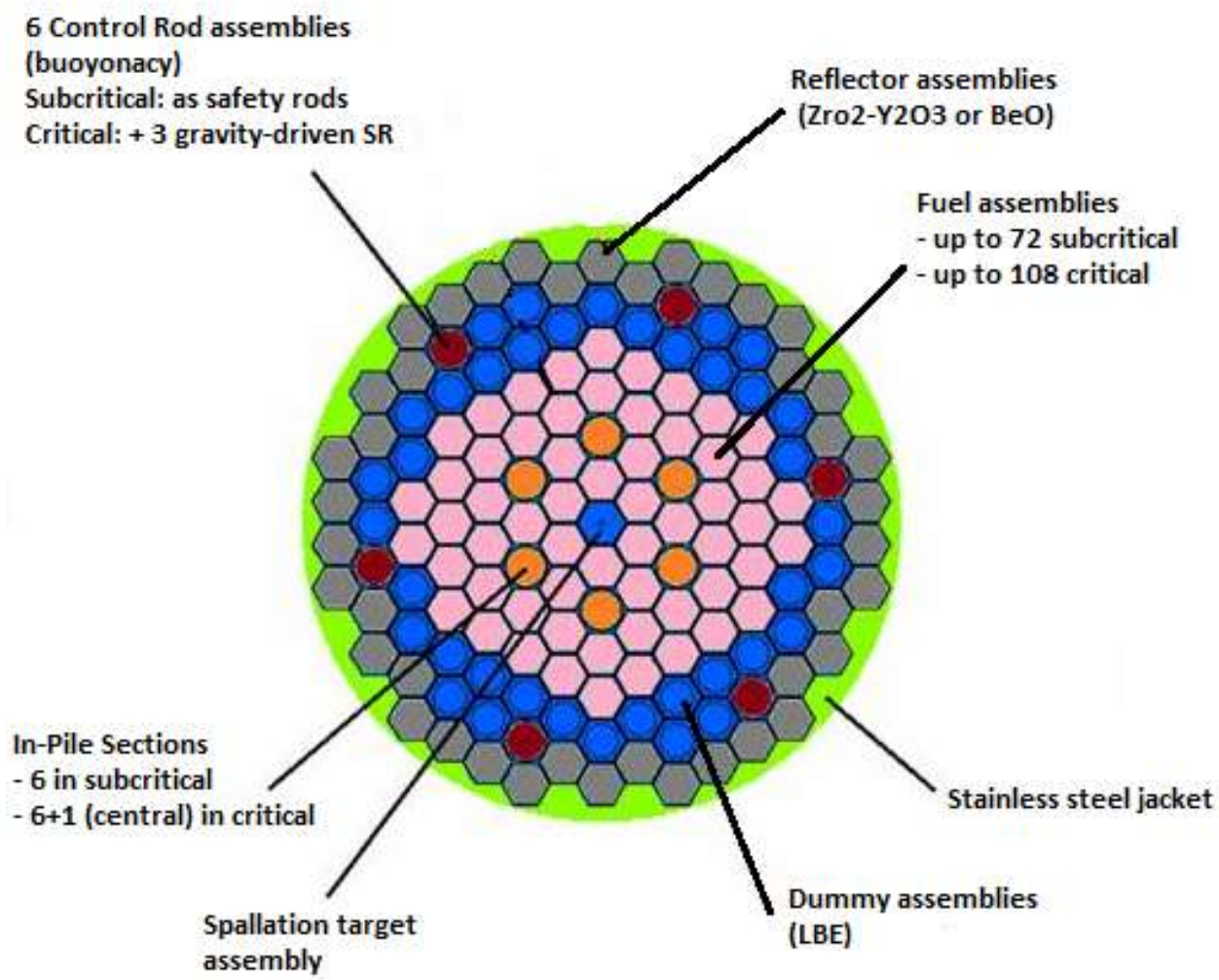
Core and Fuel Assemblies



- 151 positions
- 37 multifunctional plugs

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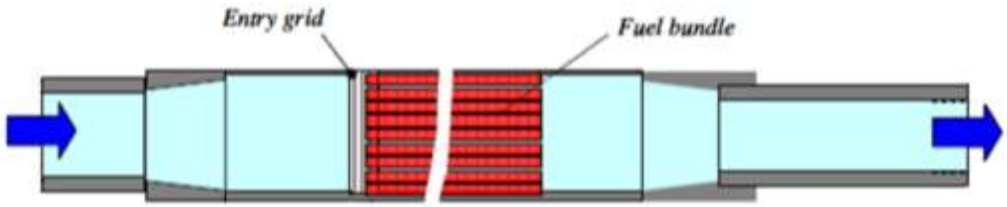
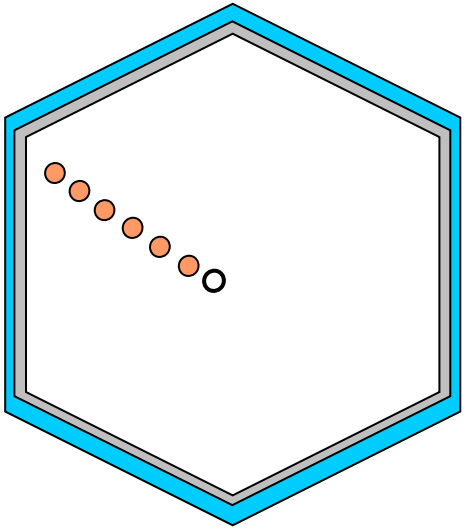
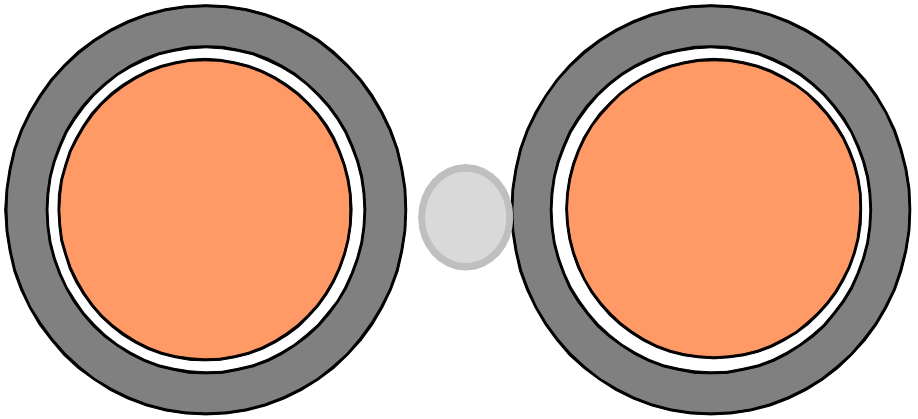
Core and Fuel Assemblies



- Fuel (MOX)
  - Cladding in 15-15 Ti
  - Wire wrap
  - Wrapper in T91





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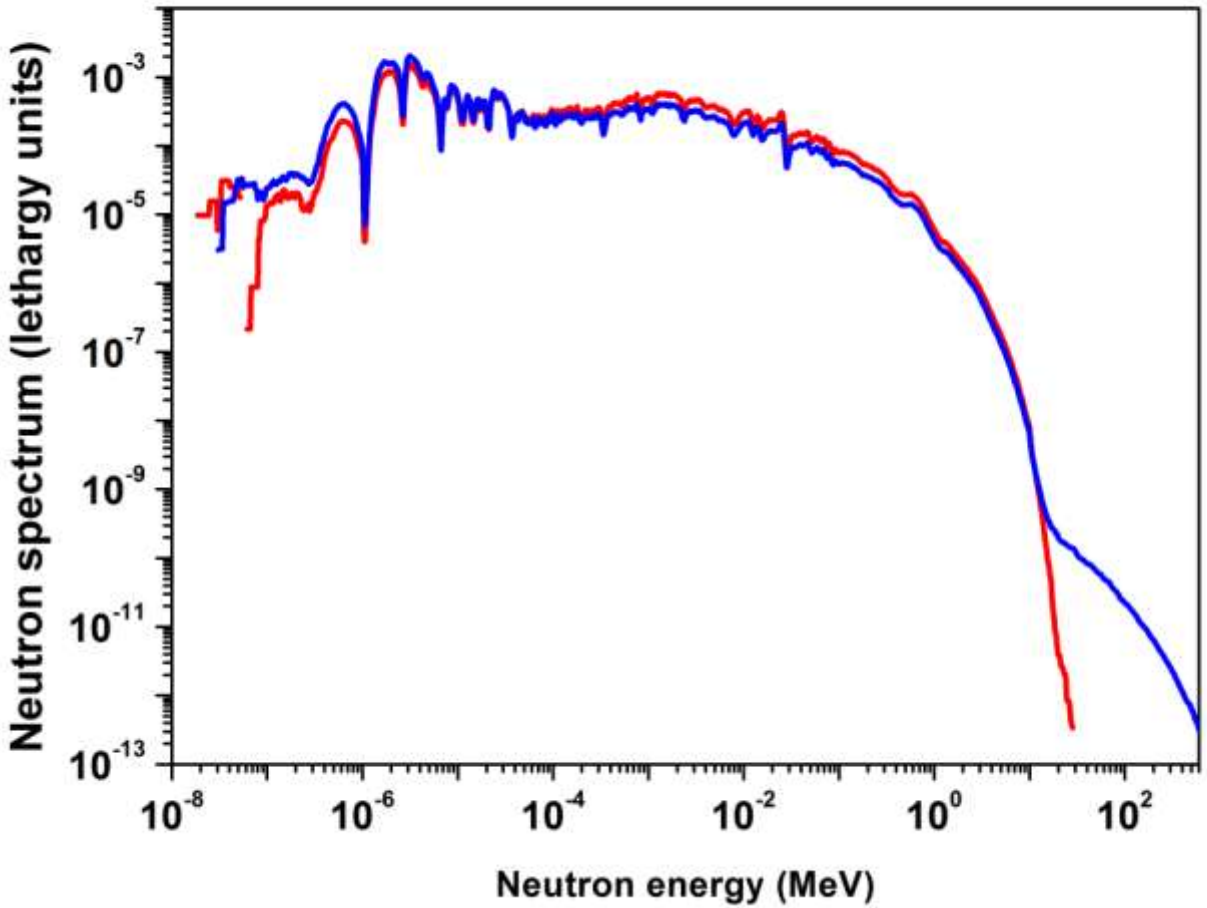
Neutron spectra: critical vs. sub-critical



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Core neutronics challenges: nuclear data uncertainties

Requirements of licensing authorities:

- **To 2014, the codes and data libraries must be selected and validated. This validated set of codes & data must be used for further neutronics calculations of MYRRHA**

- **This means that nuclear data library, once chosen (JEFF-3.2 most probable in 2014), must be used in all calculations of reactor safety parameters (k_{eff}, reactivity coefficients,…) for next 20-30 years.**

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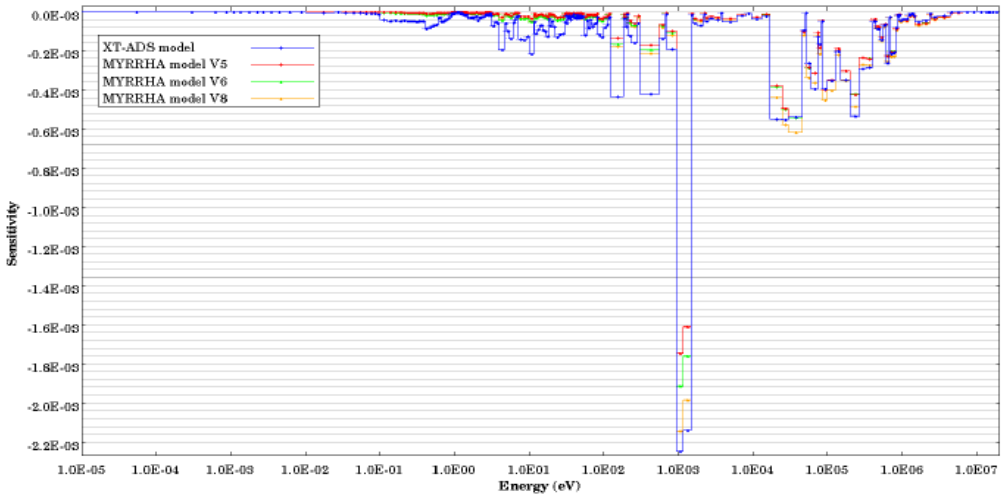
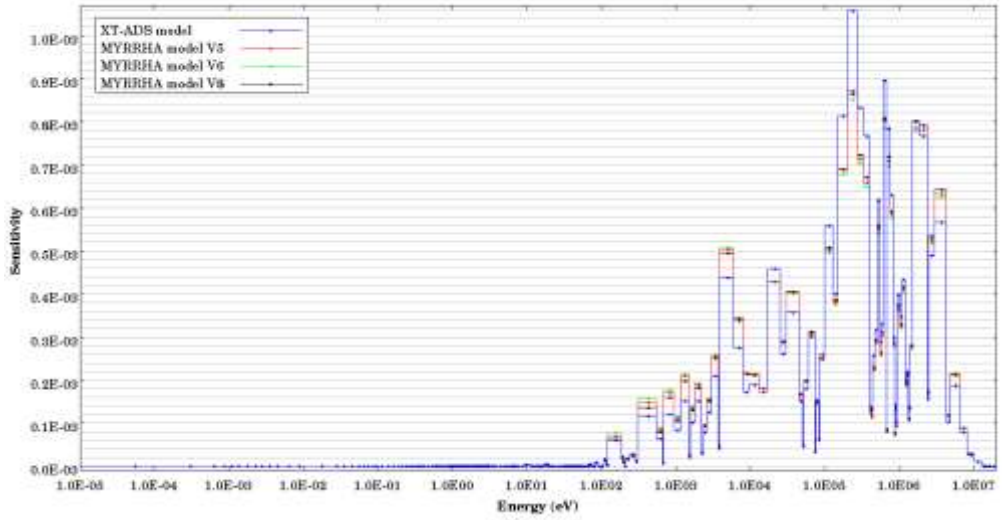
Sensitivity & Uncertainty analysis: k_{eff} sensitivity profiles

^{56}Fe neutron capture



^{238}Pu nu-bar



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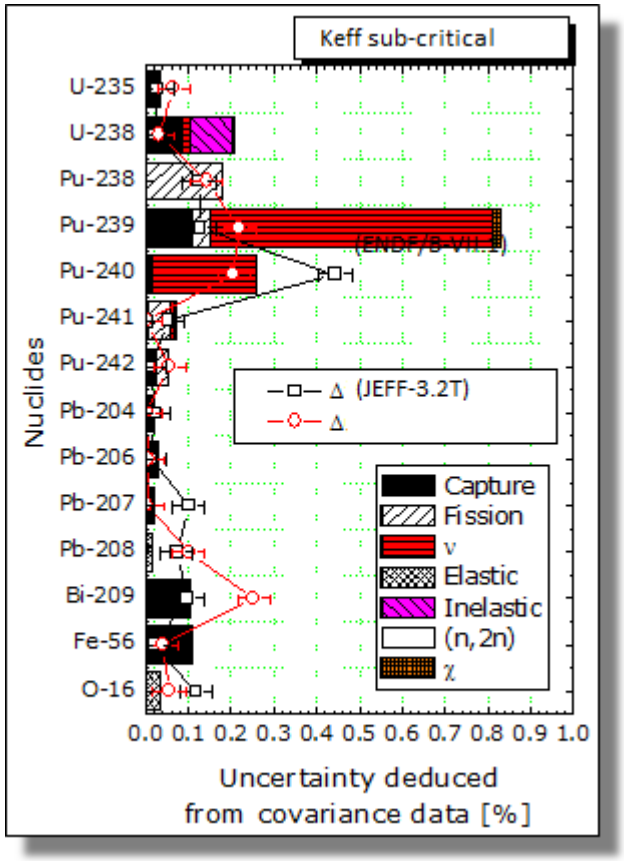
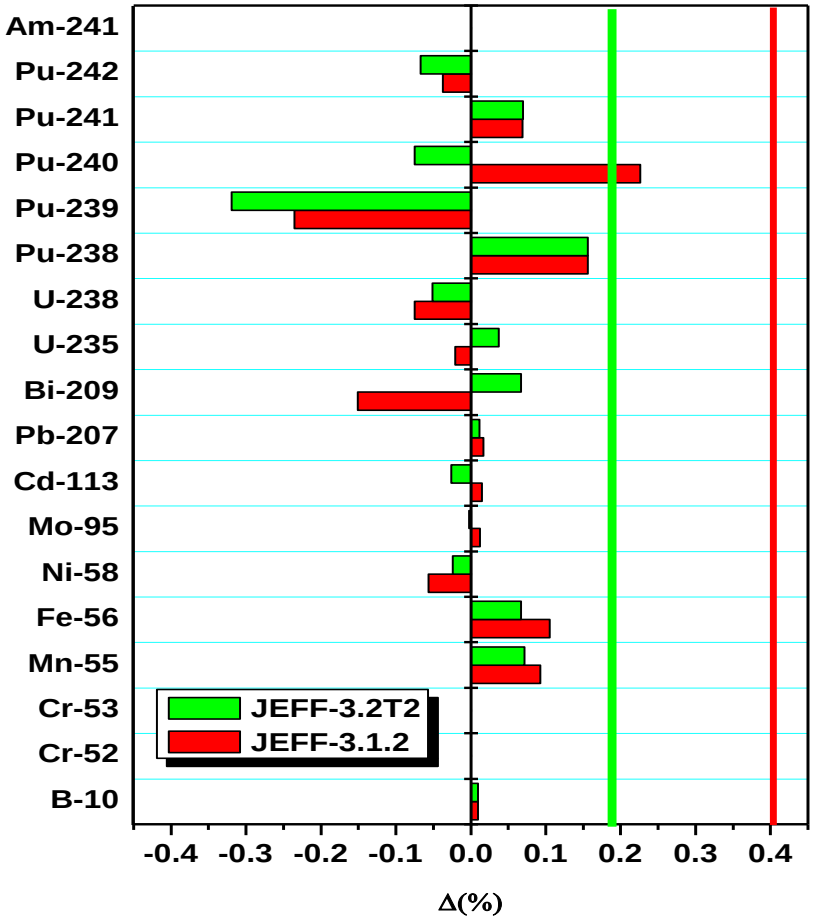
Uncertainties

$$\left(\frac{\delta k}{k}\right)^2 = GMG^T$$

G – vector of sensitivity coefficients
M – covariance matrix



Sensitivity to cross section library change from ENDF/B-VII.1 to JEFF



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Priority list to improve uncertainty data

- ✓ ^{238}Pu fission, capture and (n,2n) cross-sections,
- ✓ ^{240}Pu fission neutron yield,
- ✓ ^{241}Pu fission and elastic scattering cross-sections,
- ✓ ^{239}Pu neutron capture and fission neutron yields,
- ✓ ^{56}Fe neutron capture, elastic and inelastic scattering cross-sections;
- ✓ ^{55}Mn neutron capture cross section,
- ✓ ^{209}Bi neutron capture and (n,2n) cross-sections

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Comparison to VENUS-F

Besides the isotopes of U (fuel) and ^{56}Fe (structural), another major contributor into the total uncertainty is the elastic scattering cross section of ^{208}Pb.

^{208}Pb is present in large quantities in LBE, but was not observed to contribute significantly into k_{eff} uncertainty for MYRRHA

Spectrum	Average energy (MeV)
MYRRHA critical	0.38
MYRRHA sub-critical	0.61
VENUS-F	0.47

Sensitivity profiles to be refined…

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CHANDA FP7 project (kick-off soon): CHAllenge of Nuclear Data

Two Work Packages of this 4-year project are directly related to MYRRHA project:

WP10 "Development of nuclear data for Myrrha reactor safety analyses"

Nuclear data required for the development, safety assessment and licensing of MYRHHA will be studied and recommendations for improvements will be given. This work package will provide support to evaluation projects, such as JEFF, by identifying issues in current nuclear data files for MYRRHA-relevant elements and isotopes

WP11 "Development of a methodology for uncertainty assessment and minimization in ADS target and accelerator safety analyses "

Development of new methodology to assess uncertainties of high-energy (above 20 MeV) data…. These methods will be used to estimate the uncertainties on parameters identified as critical for the safety analysis of MYRRHA operating in sub-critical mode.

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But MYRRHA is more than research on ADS & Transmutation

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Multipurpose facility
ADS demonstration & P&T Research

Fuel research
Φ_{tot} = 0.5 to 1.10^{15} n/cm^2.s

Material research
Φ_{Fast} = 1 to 5.10
(En>1 MeV) in lar

Φ = 1 to 5.10^{14} n/cm^2.s
(ppm He/dpa ~ 10)
large volumes

50 to 100 MWt
Φ_{Fast} = ~10^{15} n/cm
(En>0.75 MeV

h energy LINAC
0 MeV – 1 GeV
irradiation time

Fission GEN IV

V

Φ_{th} =
(En<0.4 eV)

Radio-isotopes

Silicon doping

.1 to 1.10^{14} n/cm^2.s
(En<0.4 eV)

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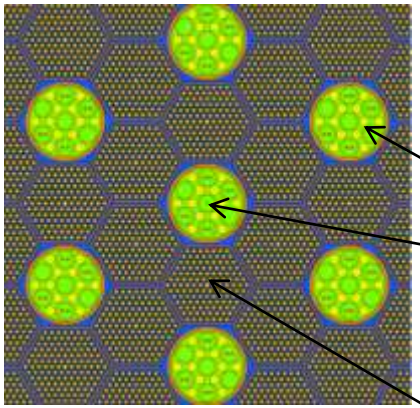
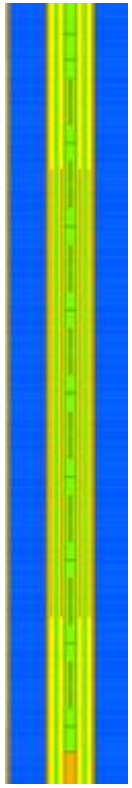
Material Irradiation Performances for Fast Reactors



In-Pile Sections

Fuel Assemblies



Operation mode	Central IPS		Peripheral IPS	
	dpa/EFPY*	Φ_{tot}	dpa/EFPY	Φ_{tot}
Critical @ 100 MW**	24.5	3.05E+15	22.1	2.73E+15
Sub-critical @73 MW	28.5**	3.32E+15	23.1	2.75E+15

* 365 days of irradiation at full power
** Rescaled to 90% of max. power to fit temperature limits
*** Beneath spallation target → conditions for IMIFF

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Multipurpose facility
ADS demonstration & P&T Research

Material research
Φ_{Fast} = 1 to 5.10^{14} n/cm².s
(En>1 MeV) in large volumes

Fuel research
Φ_{tot} = 0.5 to 1.10^{15} n/cm².s

Φ = 1 to 5.10^{14} n/cm².s
(ppm He/dpa ~ 10)
in medium-large volumes

gh energy LINAC
00 MeV – 1 GeV
g irradiation time

Fusion

Φ_{th} = 0.5 to 2.10^{15} n/cm².s
(En<0.4 eV)

Radio-isotopes

Silicon doping

Φ_{th} = 0.1 to 1.10^{14} n/cm².s
(En<0.4 eV)

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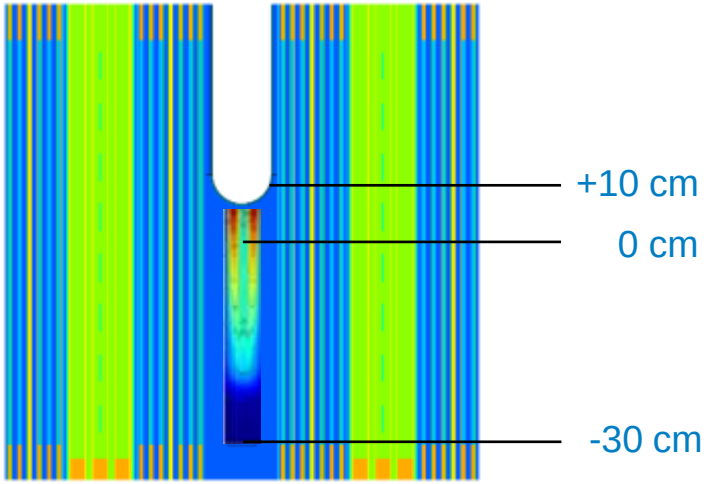
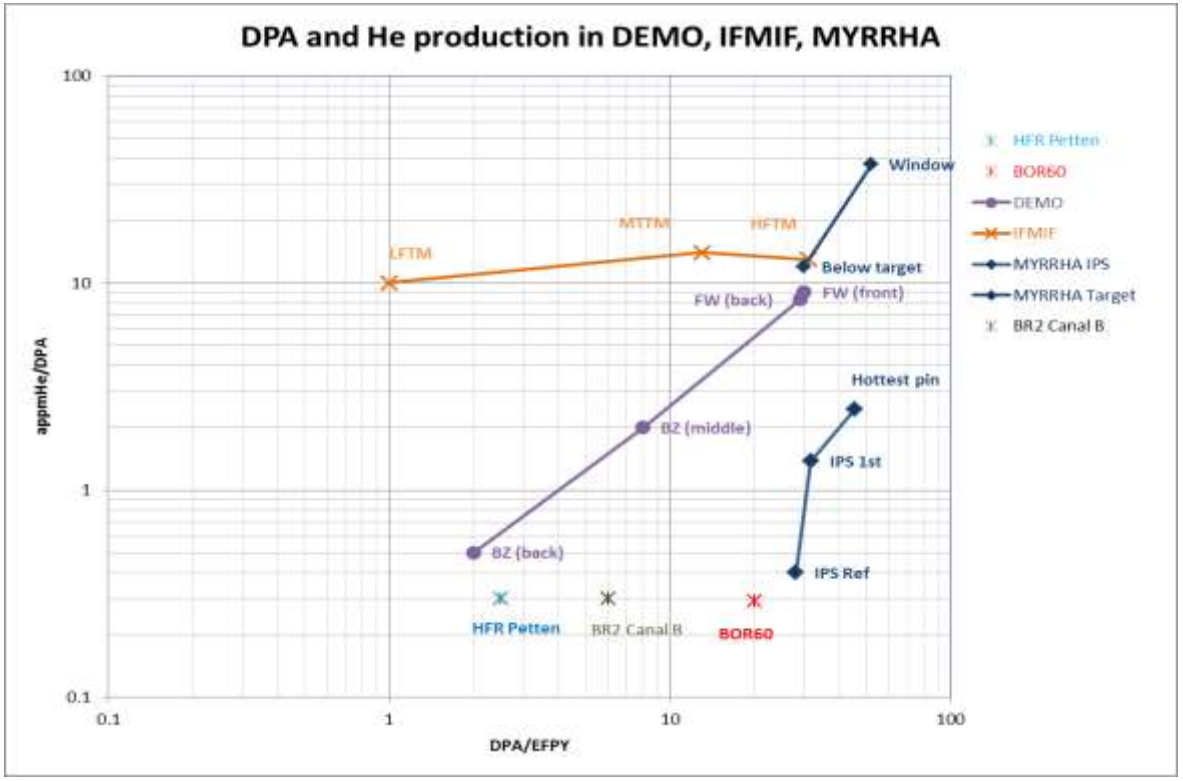
Prepare the path for Fusion DEMO
Irradiation capabilities under the spallation target





Estimated damage induced in DEMO and proposed irradiation conditions in IFMIF and MYRRHA-IMIFF

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Multipurpose facility
ADS demonstration & P&T Research

Fuel research

Mater

Φ_{Fast} = 1 t

(En>1 MeV)

Φ = 0.5 to 1.10^{15} n/cm^2.s

Φ = 1 to 5.10^{14} n/cm^2.s

dpa ~ 10)

arge volumes

energy LINAC

MeV – 1 GeV

radiation time

Silicon doping

to 1.10^{14} n/cm^2.s

En<0.4 eV)

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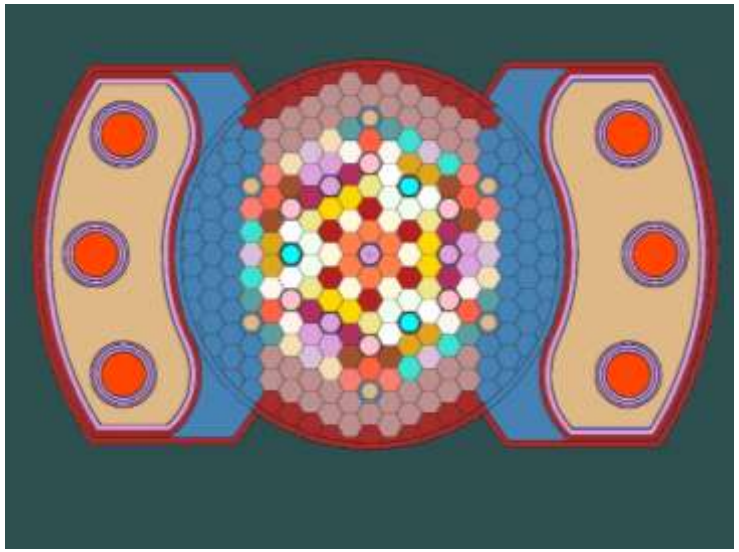
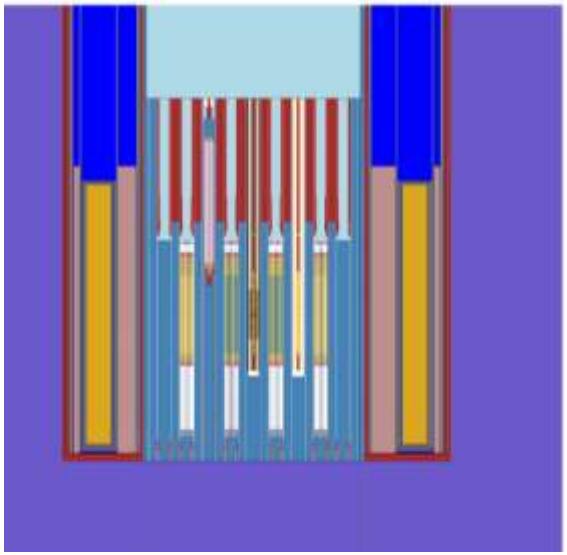
Si doping

Horizontal cut



Vertical cut



Beryllium moderated and water cooled rig

Operation mode	nv0-flux*	Cd-ratio*
Critical @ 100 MW	5.23E+12	73.0
Sub-critical @73 MW	5.48E+12	69.5

* Averaged over left and right kidney (different moderator layer thickness)

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Φ_{tot} = 0.5 to 1.10^{15} n/cm^2.s

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(En>1 MeV)

Φ = 1 to 5.10^{14} n/cm^2.s
(ppm He/dpa ~ 10)
volumes

gy LINAC
– 1 GeV
ation time

Radio-isotopes

Φ_{th} = 0.5 to 2.10^{15} n/cm^2.s
(En<0.4 eV)

Φ_{th} 0.1 to 1.10^{14} n/cm^2.s
(En<0.4 eV)

Silicon doping

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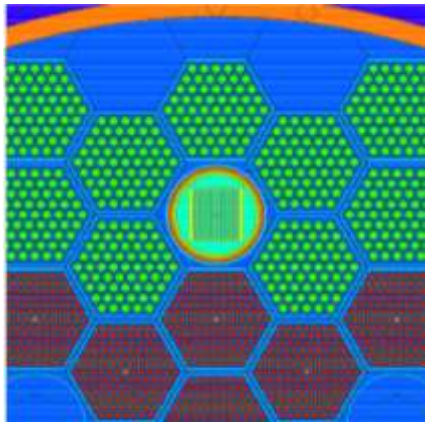
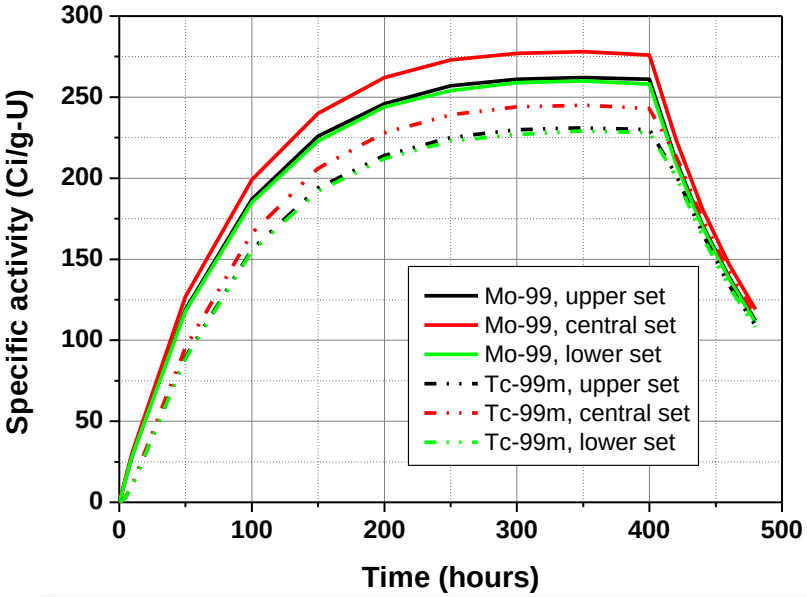
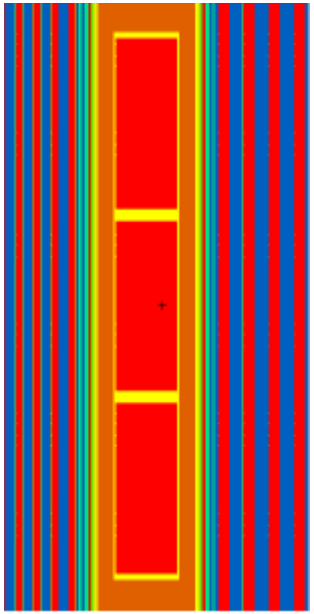
Radioisotope production capability

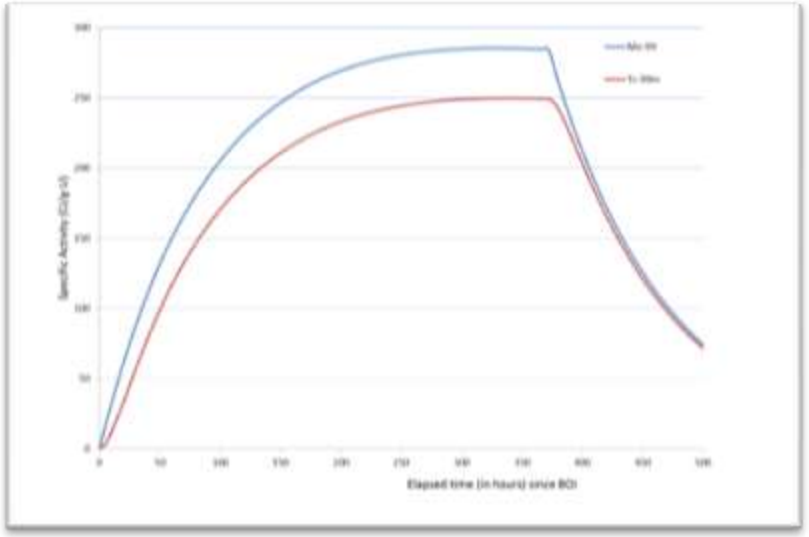


Sub-critical @73 MW:
Max. 275 Ci/g-U





Critical @100 MW:
Max. 275 Ci/g-U



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Multipurpose facility
ADS demonstration & P&T Research

Fuel research

Mate
Φ_{Fast} = 1
(En>1 Me

^{14} n/cm^2.s
ba ~ 10)
ge volumes

Fundamental research

nergy LINAC
eV – 1 GeV
adiation time

Φ_{th} = 0.5 to 2.10^{15} n/cm^2.s
(En<0.4 eV)

Radio-isotopes

Silicon doping

Φ_{th} = 0.1 to 1.10^{14} n/cm^2.s
(En<0.4 eV)

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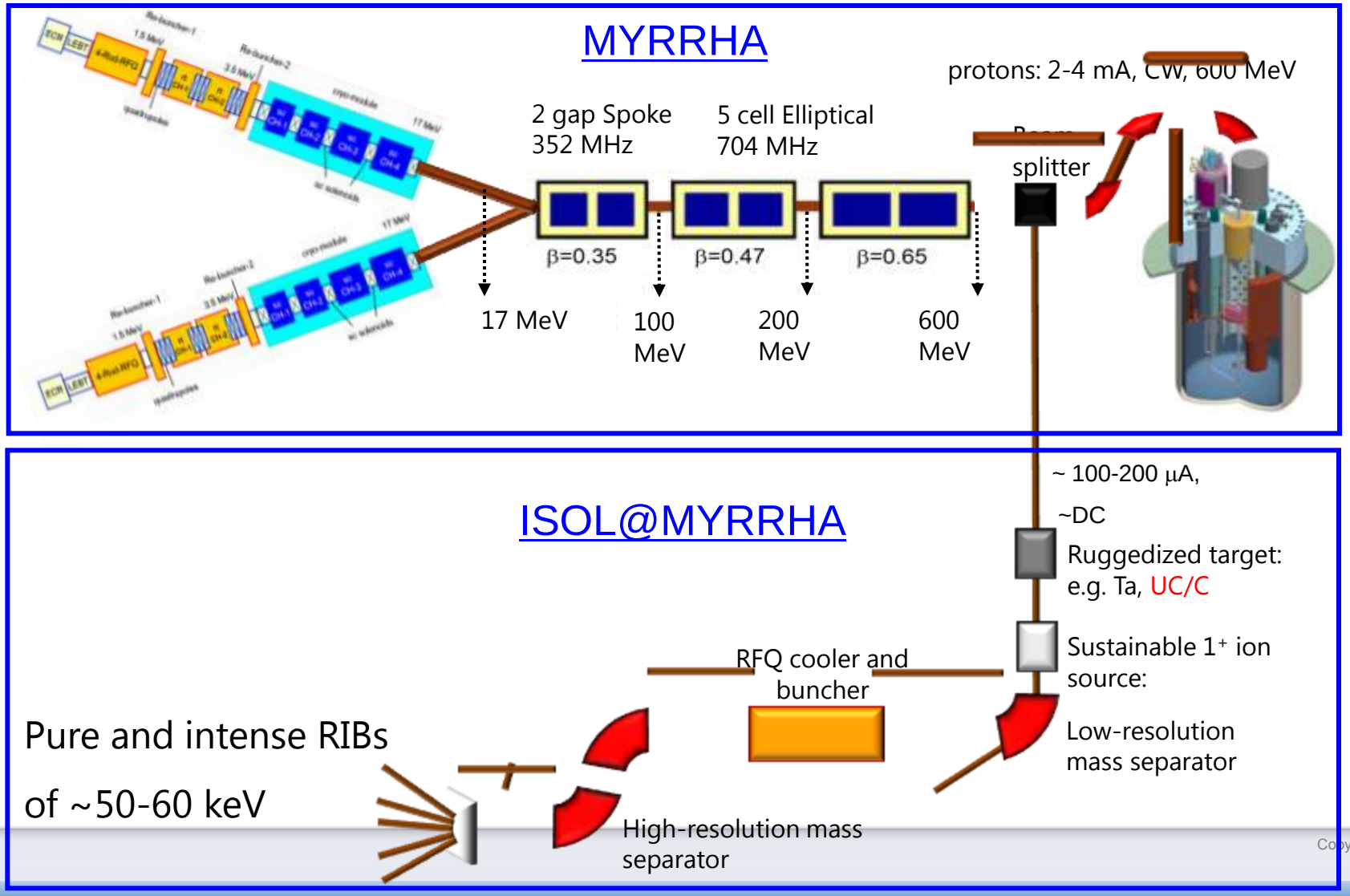
ISOL@MYRRHA
For fundamental physics applications



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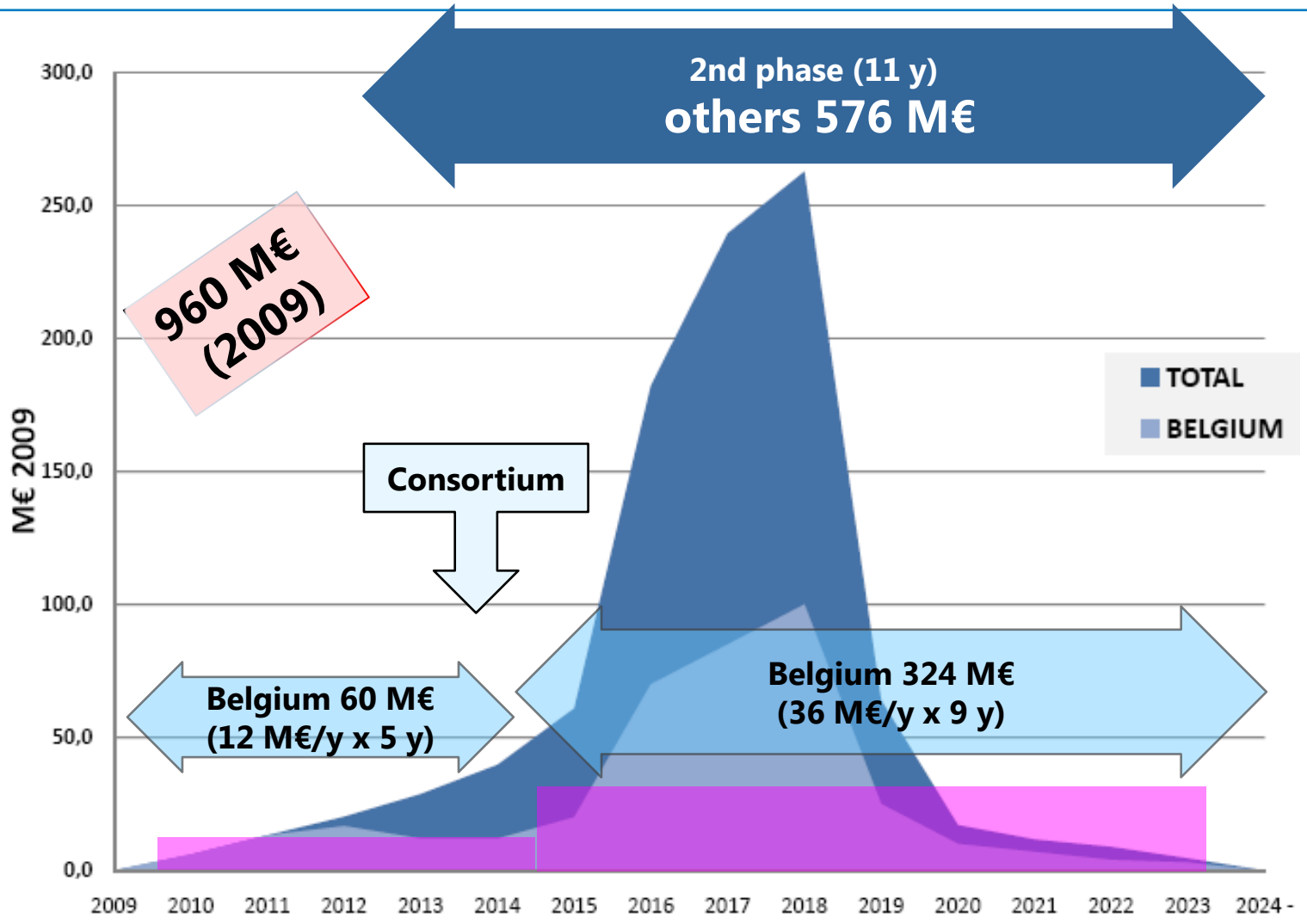
Belgian commitment: secured
International consortium: under construction



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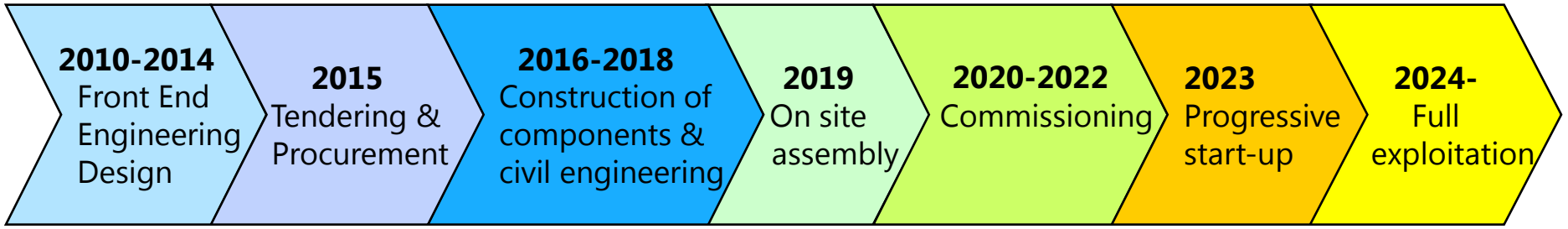
The project schedule
Executing presently the FEED Phase: 2010-2014



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

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MYRRHA: an international network

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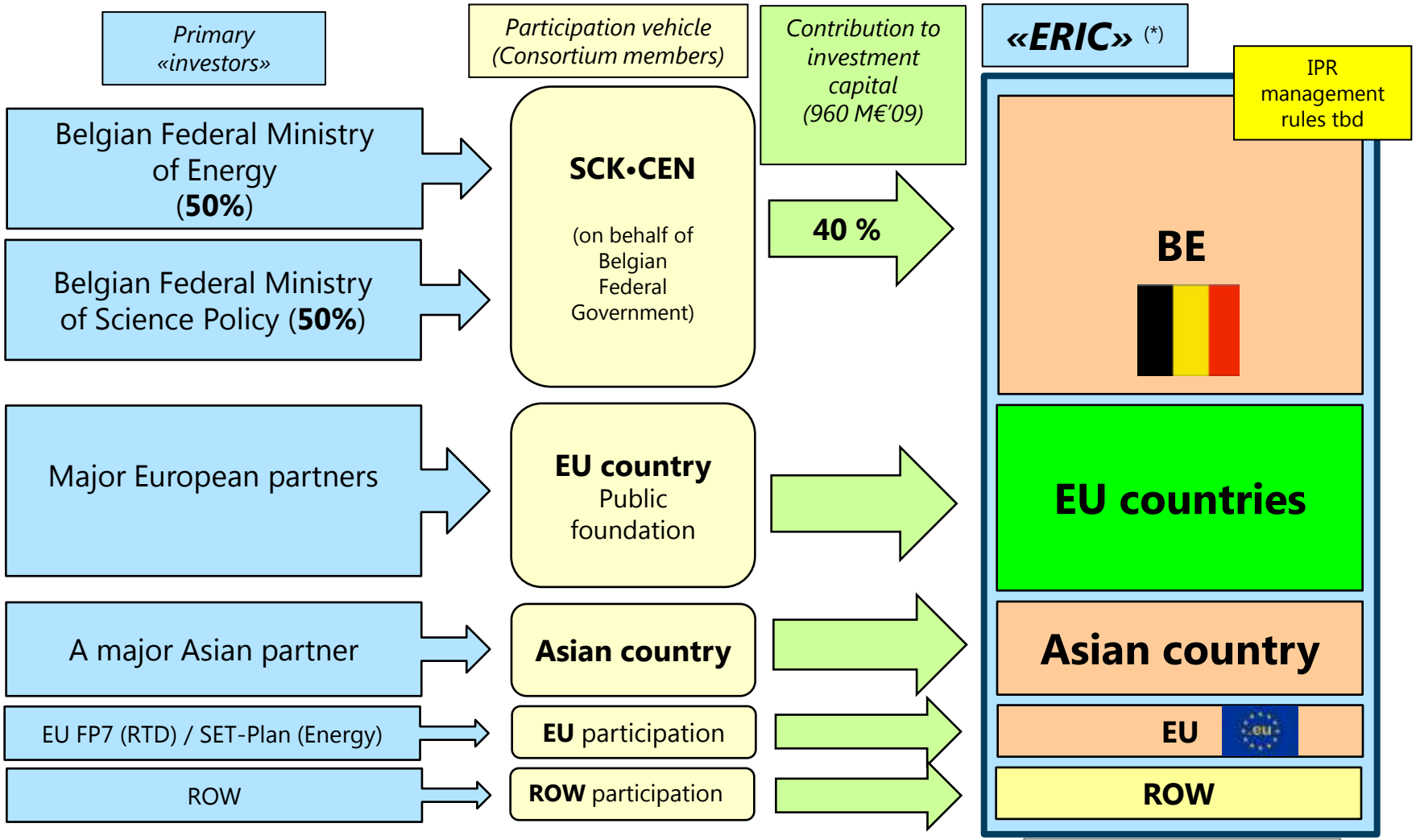
International Members Consortium – Phase 1
As of early 2012



(*) European Research Infrastructure Consortium

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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, our objectives are:
  - to sign **Memoranda of Understanding** for collaboration in MYRRHA with international partners (deadline mid 2014)
  - To finalise the **Consortium legal framework** (deadline end 2014)

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Conclusions

- **MYRRHA As a Multipurpose Fast Spectrum irradiation facility selected by ESFRI (European Strategic Forum for Research Infrastructure), is responding to:**
  - The issue of addressing the nuclear waste legacy of present reactor technology through advance options (**ADS, P&T**)
  - The SNETP need for a **multipurpose research infrastructure** expressed in its Strategic Research Agenda whatever the considered technology for Gen.IV systems
  - The Objective of Belgium and SCK•CEN to **maintain a high level expertise in the country** in the nuclear safety, nuclear technology and nuclear competencies independently of the future of NE
  - The objective of the European Commission to make available a series of **relevant irradiations facilities for the fusion materia**l research community towards the DEMO construction
  - **Secure society needs** for RI for medical applications and Dopped-Si for renewable Energy

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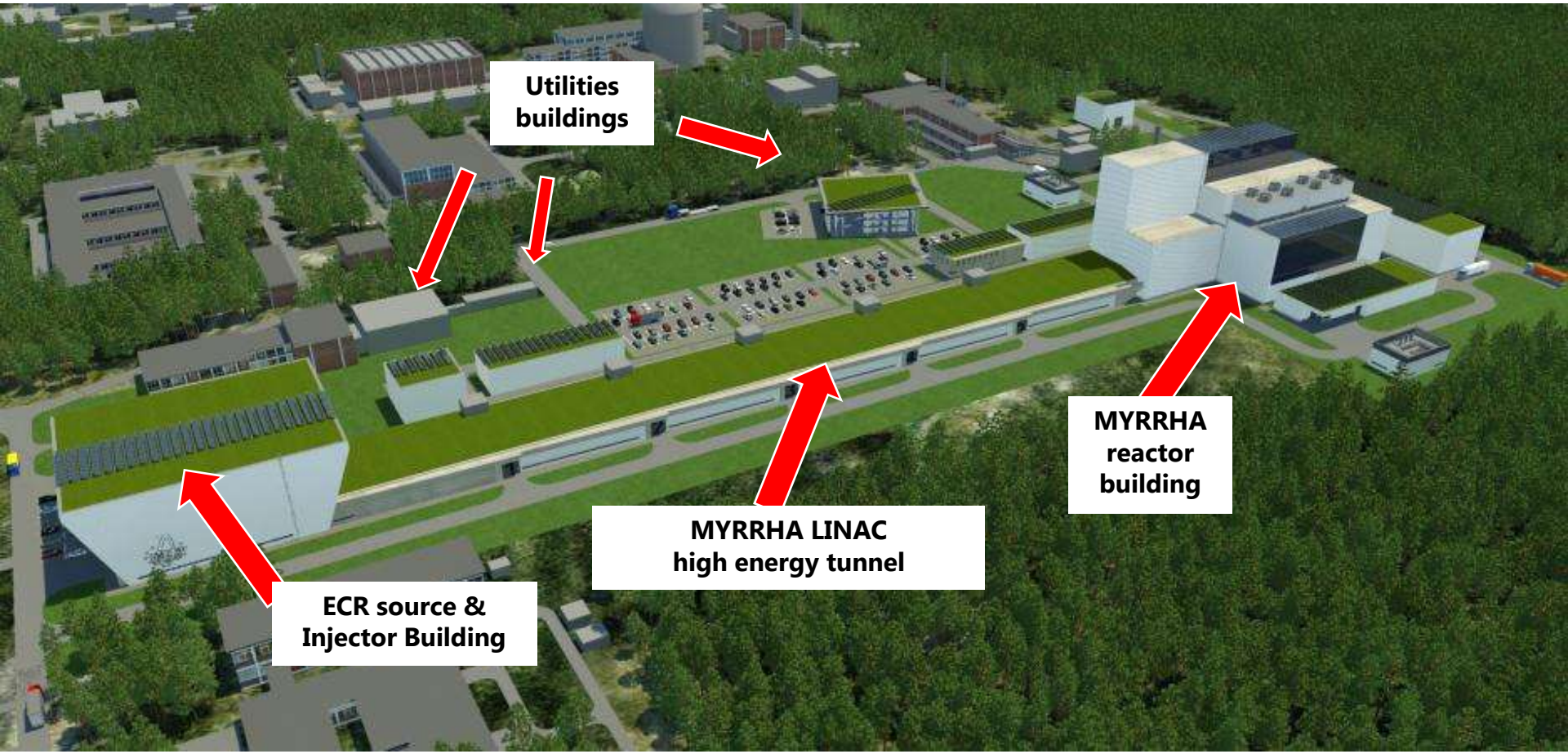
MYRRHA: EXPERIMENTAL ACCELERATOR DRIVEN SYSTEM
A pan-European, innovative and unique facility at Mol (BE)



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Centre d'Etude de l'Energie Nucléaire
Belgian Nuclear Research Centre

Stichting van Openbaar Nut
Fondation d'Utilité Publique
Foundation of Public Utility

Registered Office: Avenue Herrmann-Debrouxlaan 40 – BE-1160 BRUSSELS
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Some spare slides….

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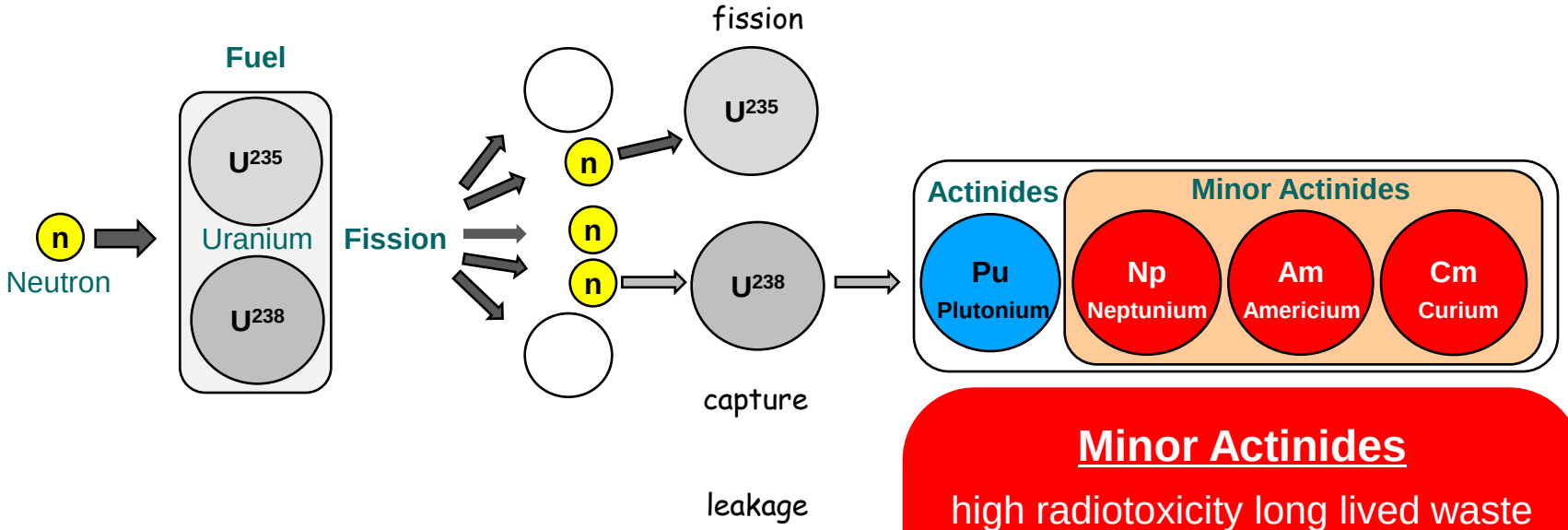
High Level Nuclear Waste



Minor Actinides

high radiotoxicity long lived waste that are difficult to store due to:

- **Long lived (>1,000 years)**
- **Highly radiotoxic**
- **Heat emitting**

$$n + U^{235} \Rightarrow 2\,FP + 2 \text{ or } 3\,n + 200MeV$$

(4 eV for combustion of C)

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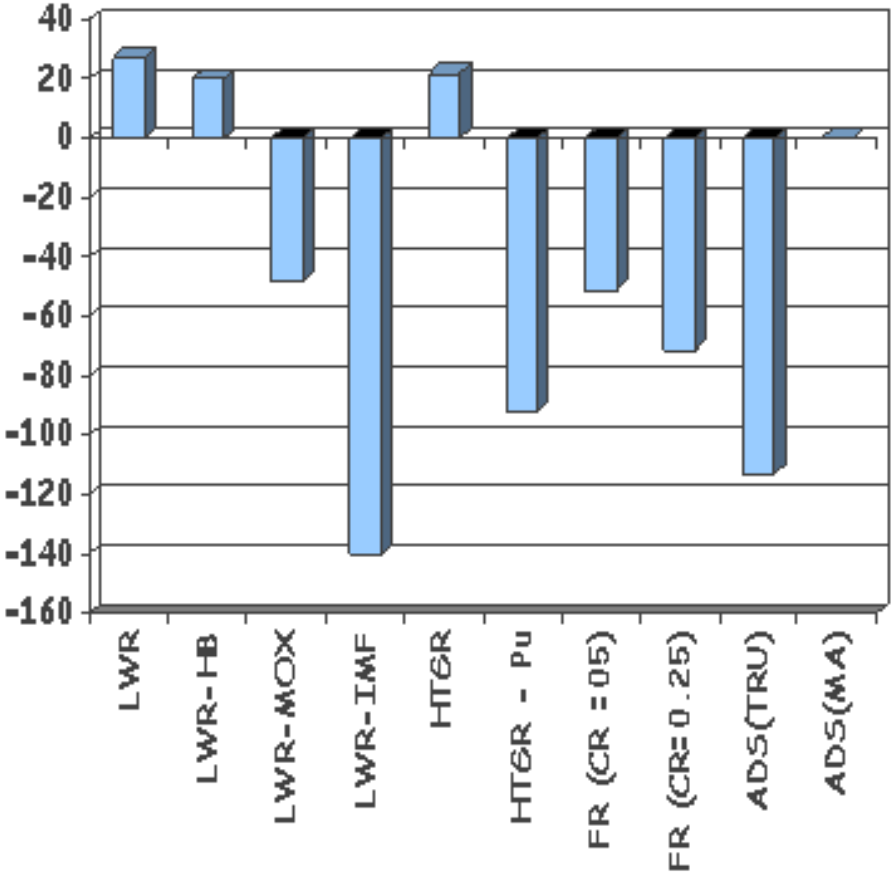
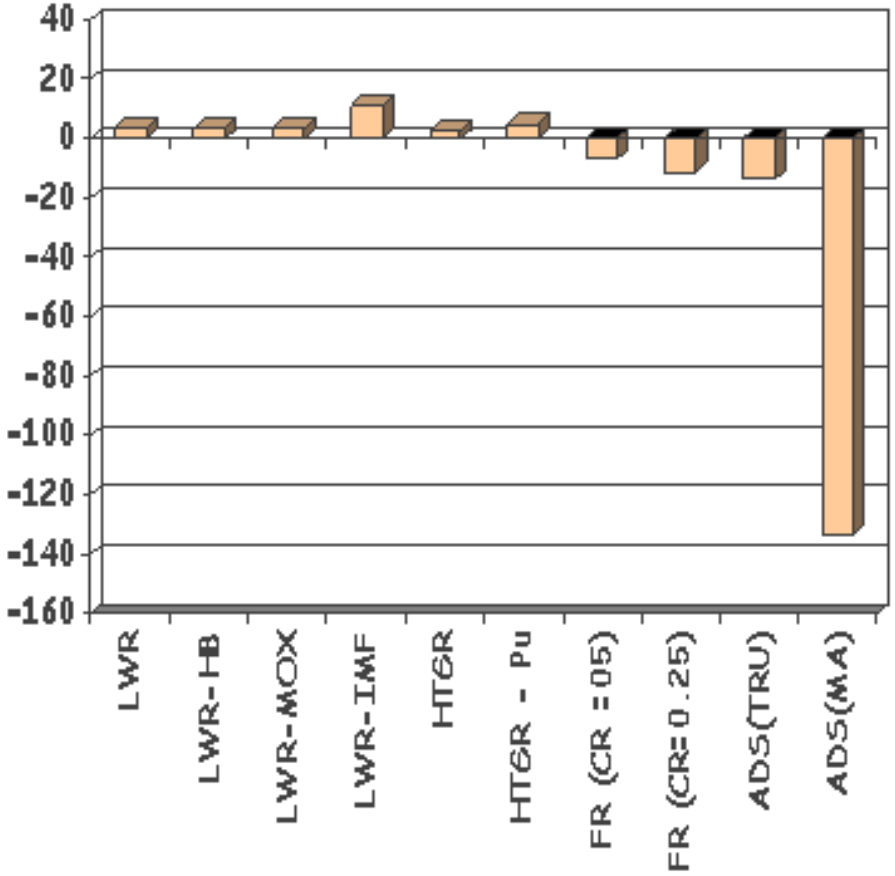
ADS is the most efficient system for burning MAs



Pu Production Rate (grams / GWh)



MA Production Rate (grams / GWh)

* Mike Cappiello, (LANL), "The Potential Role of Accelerator Driven Systems in the US", ICRS-10/RPS'2004, Madeira (PT), 2004

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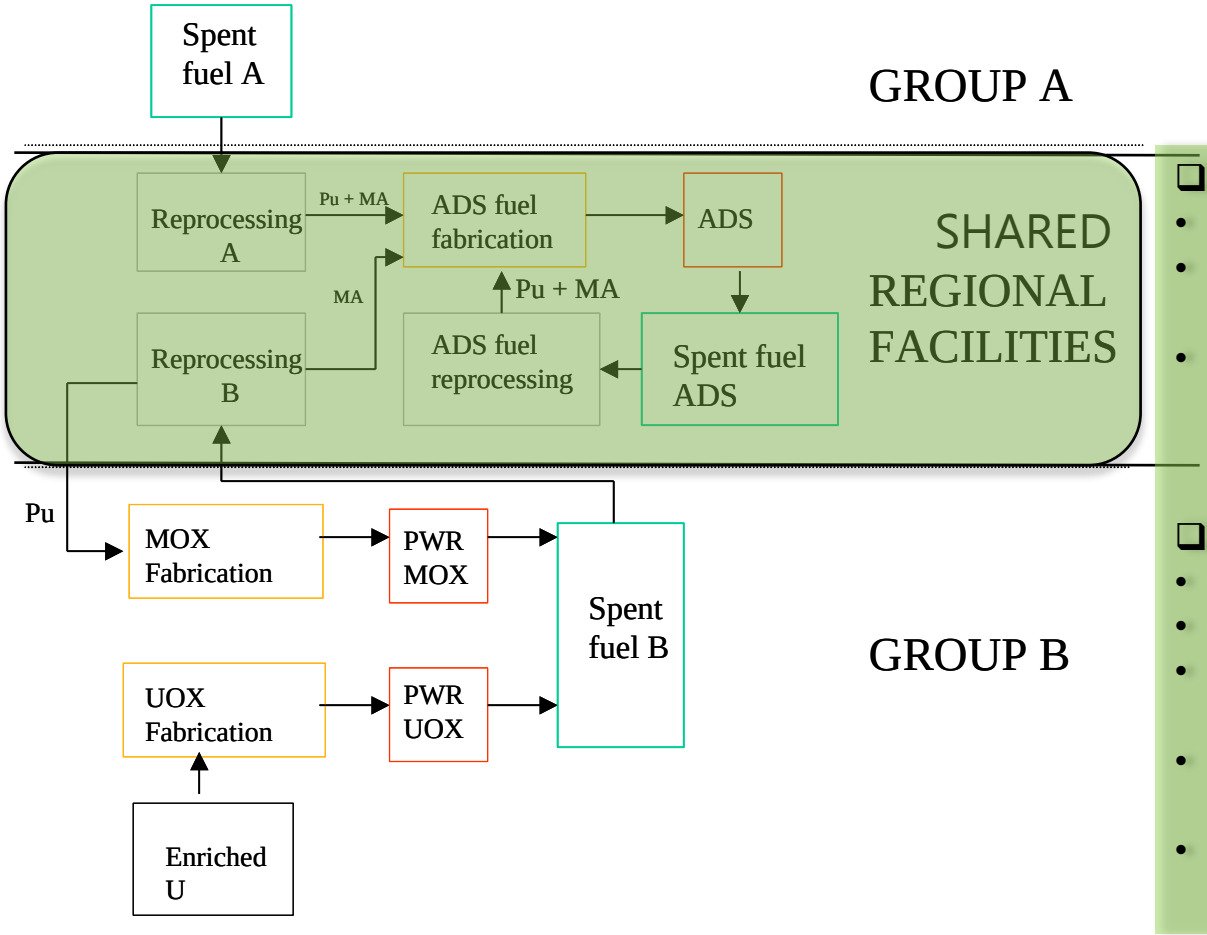
Even with completely different national NE policies European solution for HLW works with ADS



❑ **Advantages for A**
- ADS shared with B
- ADS burn A's Pu& MA
- Smaller Fu-Cycle units & shared

❑ **Advantages for B**
- ADS shared with B
- ADS burn B's MA
- A's uses B's Pu (part) as resource in FR
- FR fleet not contam with MA's
- Smaller Fu-Cycle units & shared

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

A = Countries Phasing Out, B = Countries Continuing

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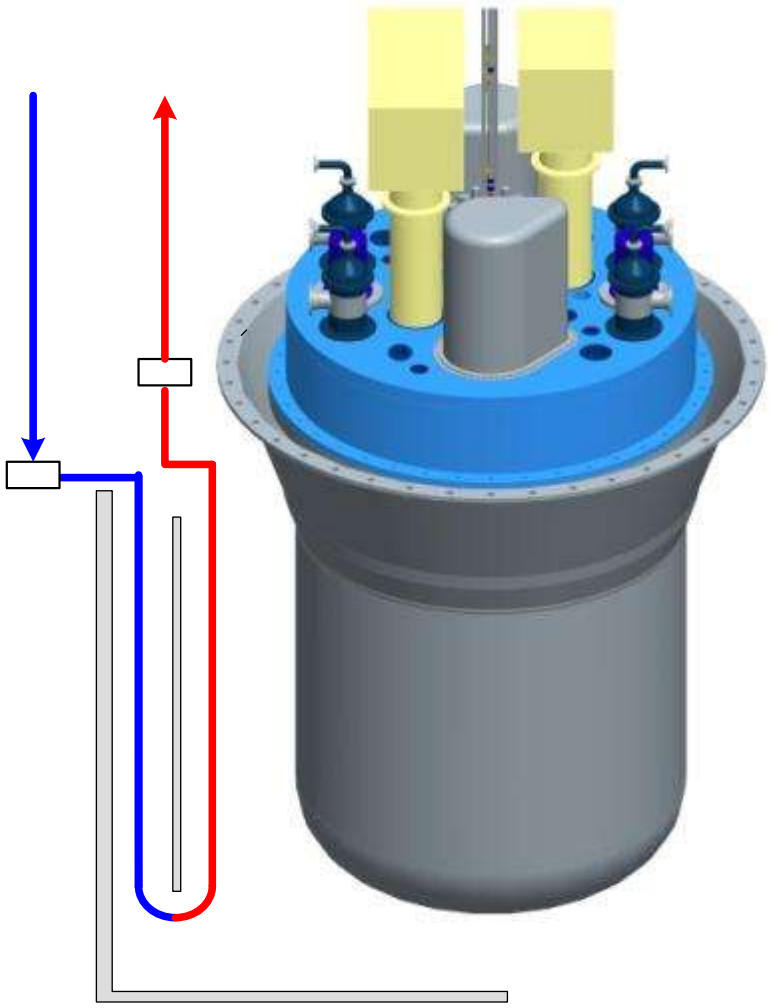
Cooling systems

- 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)



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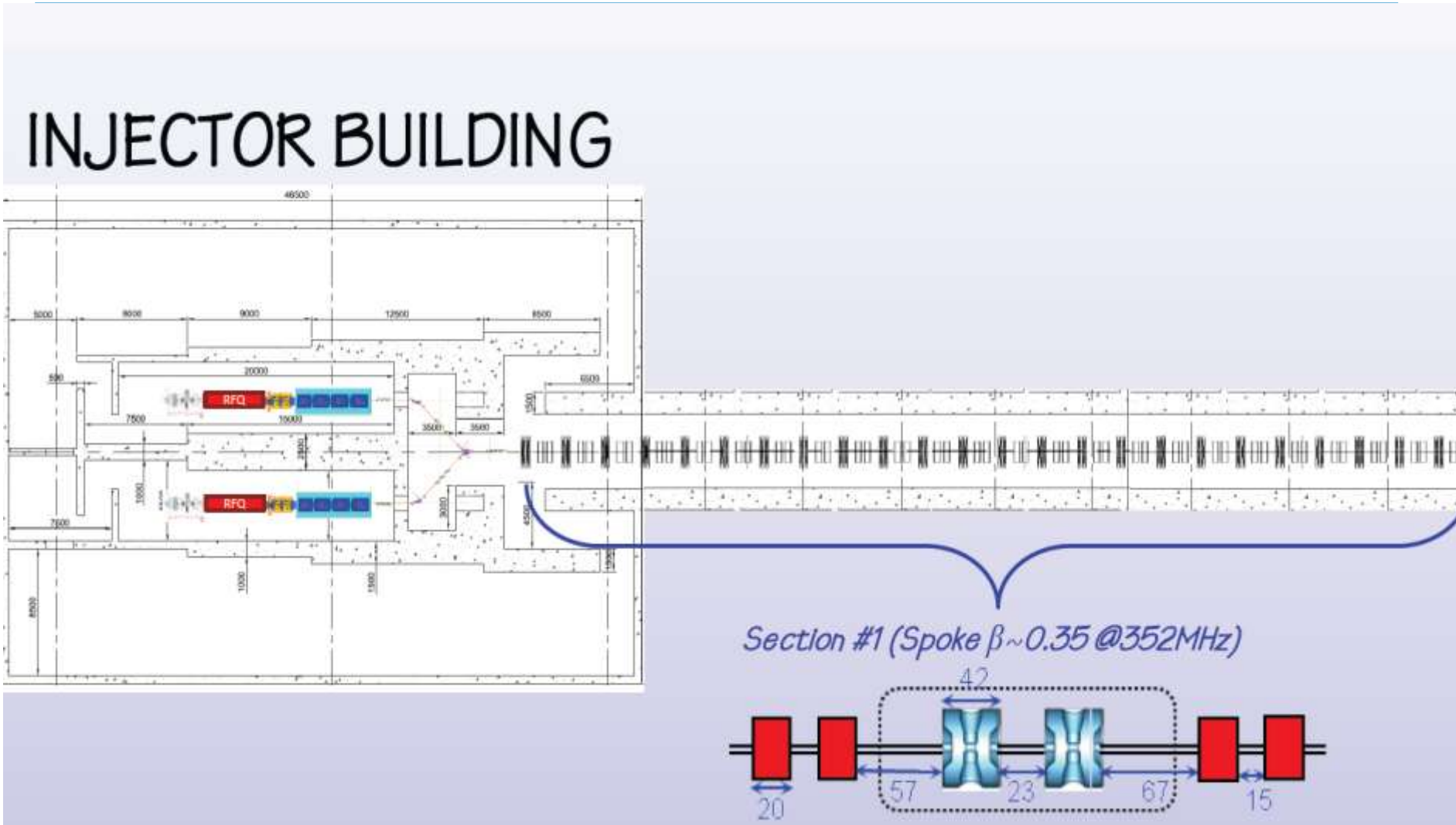
MYRRHA linac



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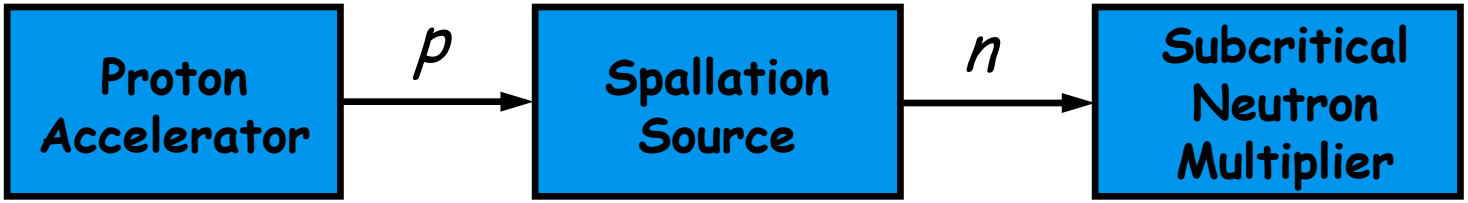
Why sub-criticality is needed



- ADS is presently studied for the MAs transmutation due to their smaller fraction of delayed neutrons and their impact of the kinetics parameters of the reactor

^{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

If one wants to have a heavily loaded core (>10%), one needs to consider ADS

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European Context

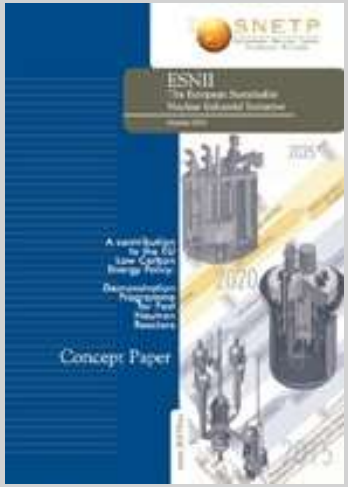
ESFRI
European
Strategic
Forum for
Research
Infrastructure

SET Plan
European
Strategic
Energy Plan

Knowledge Economy

MYRRHA

Energy Independence



27.11.2010
Confirmed on ESFRI priority list projects

15.11.2010
in ESNII
(SNETP goals)

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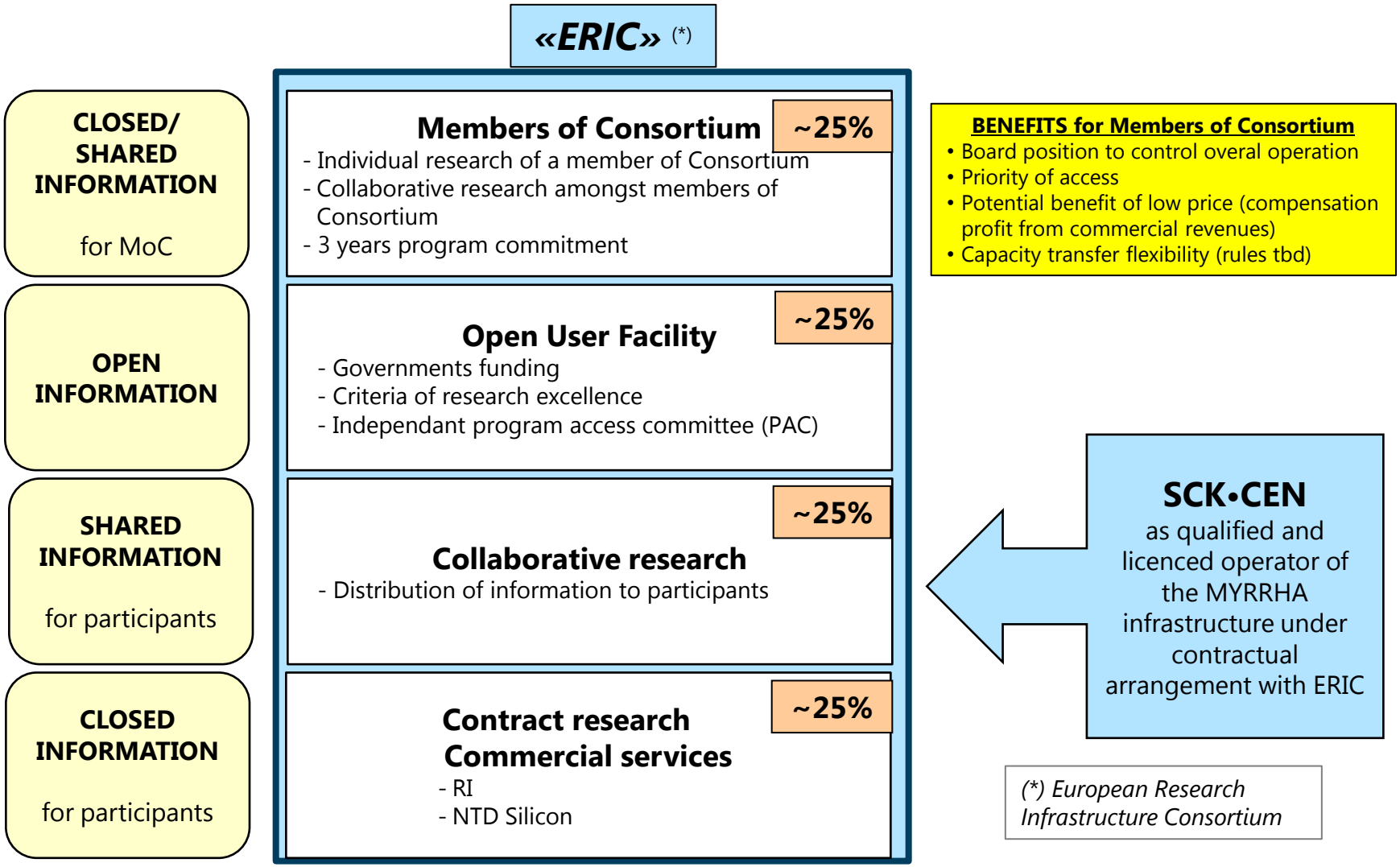
International Members Consortium - Phase 2



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