GEN IV International Forum℠

# MYRRHA
# AN ACCELERATOR DRIVEN SYSTEM BASED ON LFR TECHNOLOGY

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# Meet the presenter

**Prof. Dr. Hamid Aït Abderrahim** is the Deputy Director General of SCK•CEN, the Belgian nuclear research center. He is also professor of reactor physics and nuclear engineering at the "Université Catholique de Louvain" (UCL) at the Mechanical Engineering Department of the "Ecole Polytechnique de Louvain (EPL)".

Since 1998 he is the director of the MYRRHA project. He is partner and/or coordinator of various projects of the European Commission framework programme related to advanced nuclear systems or to partitioning and transmutation of high level nuclear waste management.

He chaired the Strategic Research Agenda (SRA) working group of the European Sustainable Nuclear Energy Technology Platform (SNETP, http://www.snetp.eu) from September 2007 to December 2011.Since 2015 he is the chairman of the Governing Board of SNETP.

He is the representative of Belgium in the Governing Board of the project JHR (Jules Horowitz Reactor). He has authored more than 100 scientific publications in peer review journals and international conferences.

In April 2014, he has been honoured by the King of Belgium who nominated him as “Grand Officer in the Crown Order” for his contributions in progressing science and knowledge in the field of nuclear engineering of innovative systems for High Level Waste management. On February 15, 2016 he received the title of Doctor Honoris Causa to the Kaunas University of Technology for his personal achievements and long term collaboration with Kaunas University, especially with the Baršauskas Ultrasound Research Institute.

# Innovation in Belgium for Europe for sustainable & innovative nuclear energy and applications

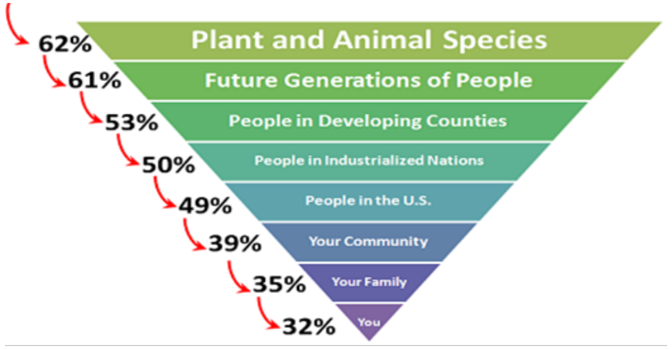
# Outline

- Worldwide energy facts
- SCK•CEN and MYRRHA backgrounds
- What is ADS & Why ADS for P&T
- MYRRHA Project at a Glance
  - MYRRHA Reactor
  - MYRRHA Accelerator
- MYRRHA Licensing
- MYRRHA implementation towards realization
- Conclusions

# Worldwide energy facts


Energy demand increases

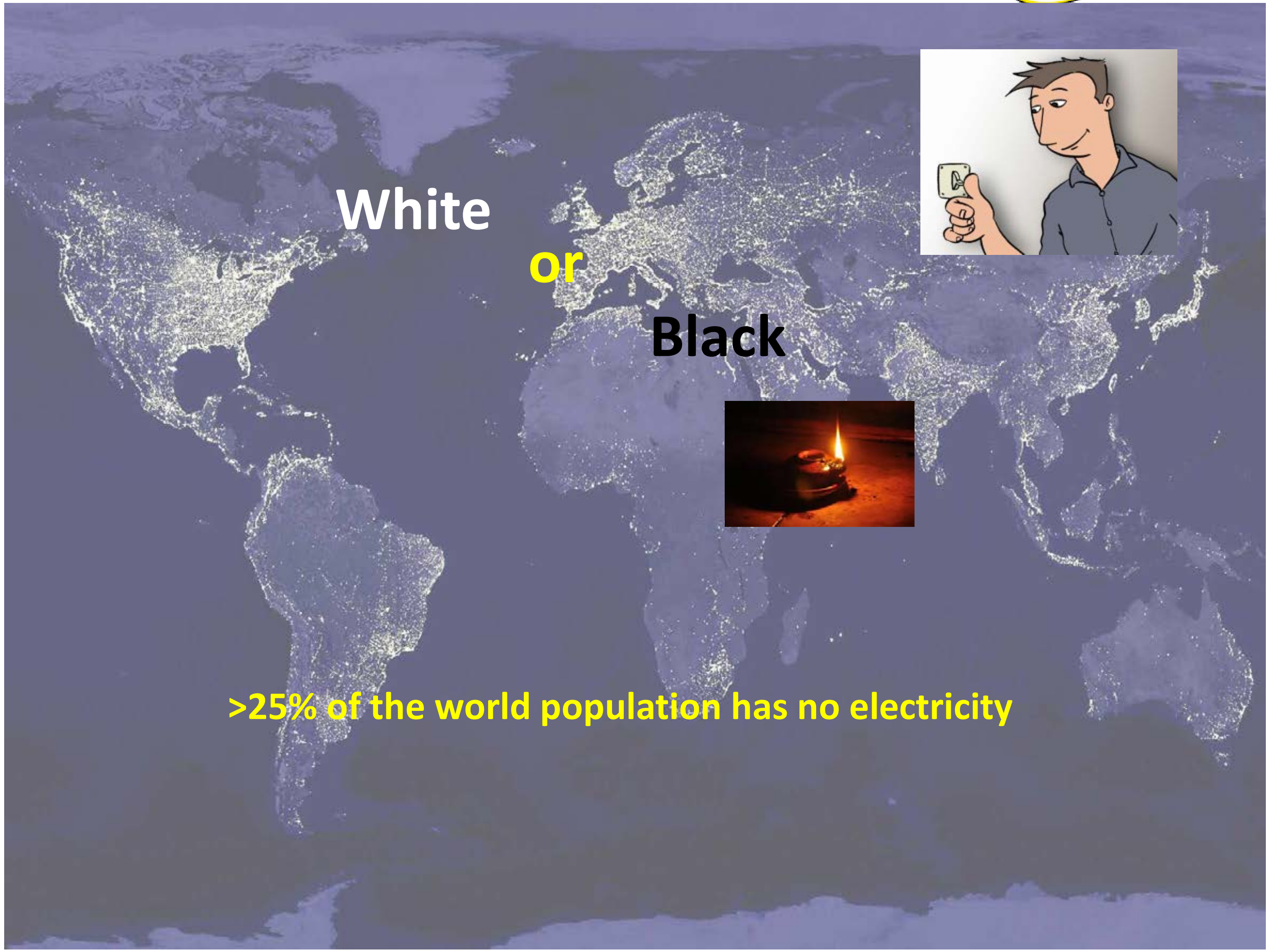
Energy and security




Energy and the environment

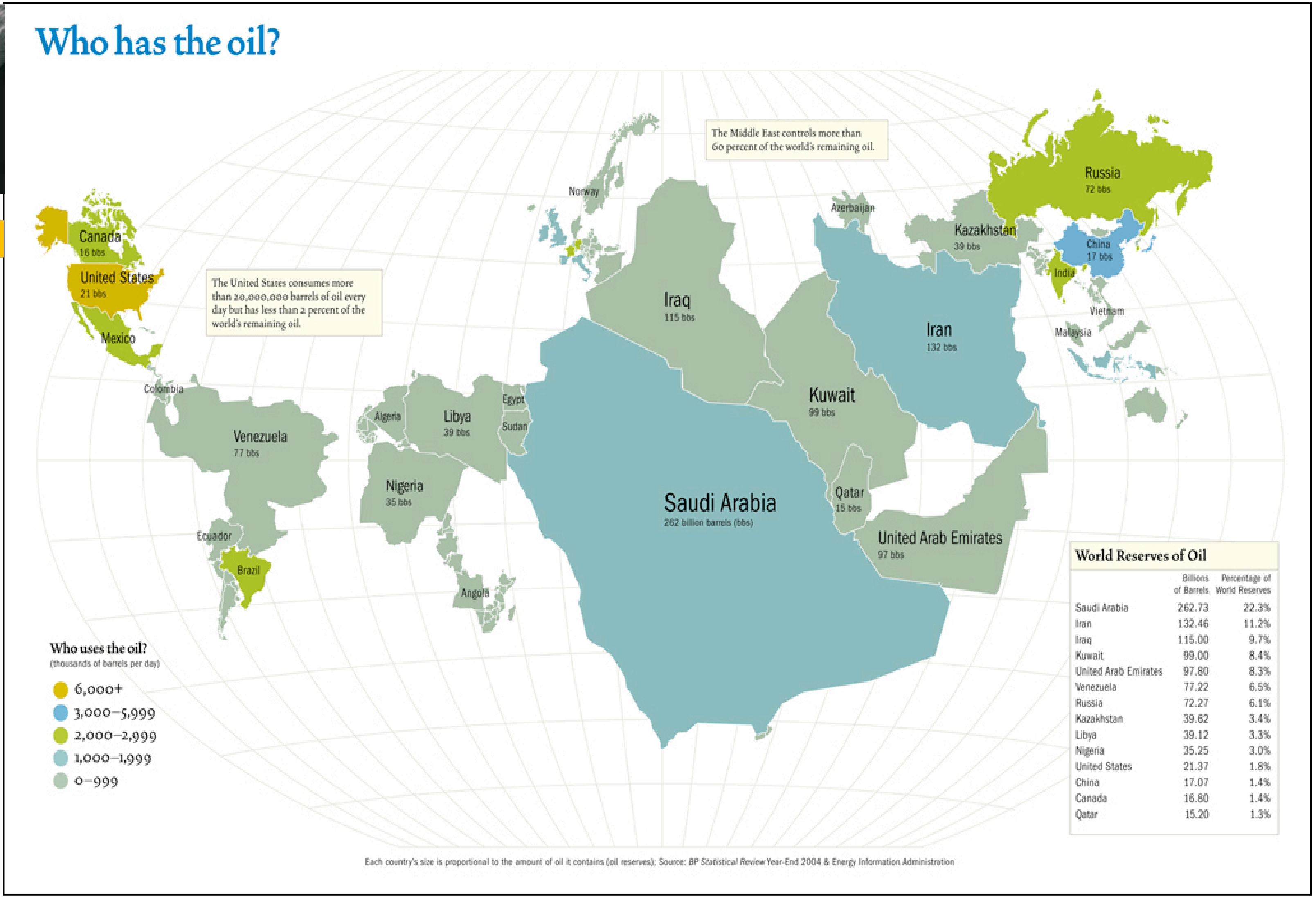
# Color of electricity? Green? Red? Blue?...


Energy demand increases



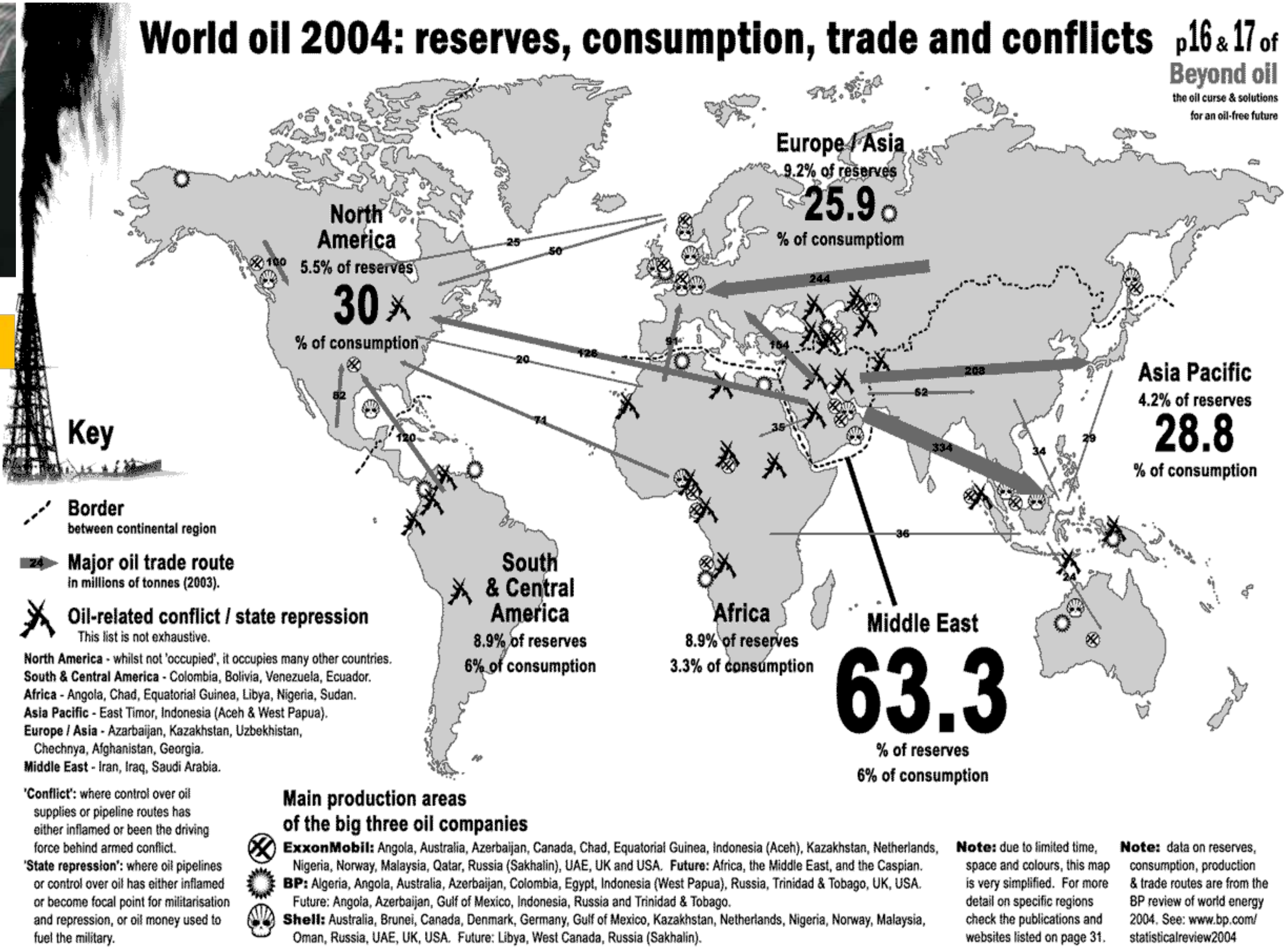
# Even with shale gas, geopolitics on oil & gas reserves

**Energy and security**

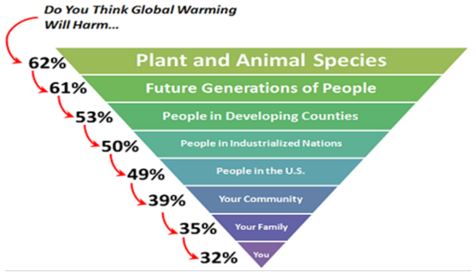


# Correlation between oil & wars

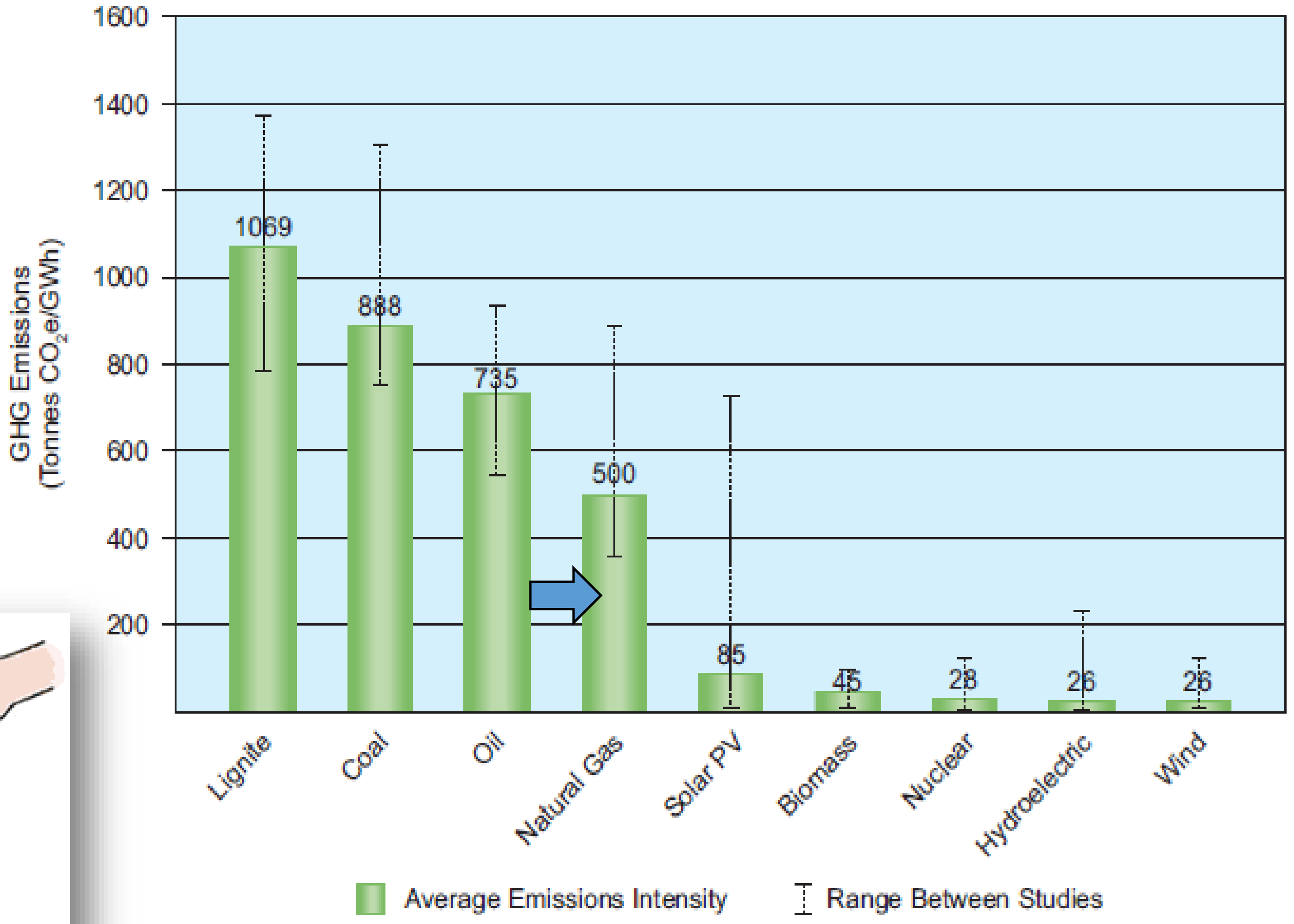
**Energy and security**

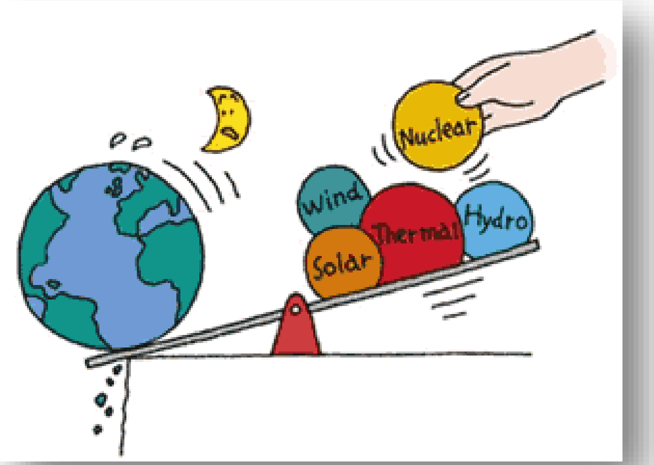


# Invest in all CO2-free energy sources

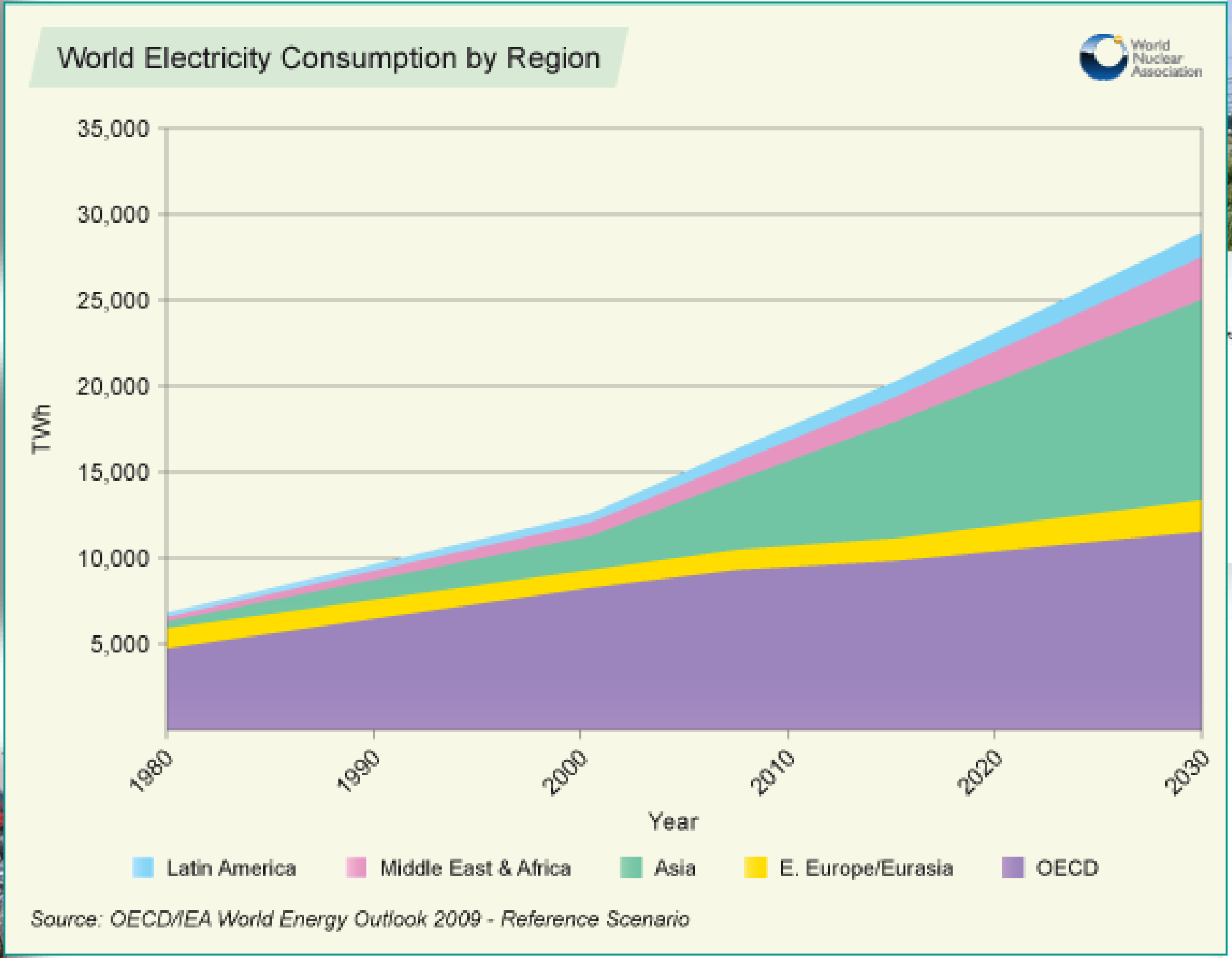


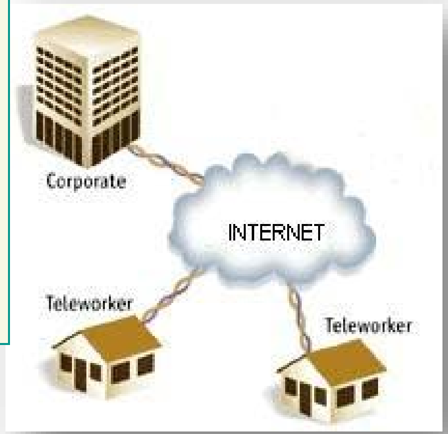

**Energy and the environment**



# Emit less $CO_2$ = need more electricity



# Clear thinking on nuclear energy

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“Science has spoken. There is no ambiguity in the message,” said the UN secretary general, Ban Ki-moon, attending what he described as the “historic” IPCC report launch.

“Stop all fossil energy production in favor of **renewables and nuclear energy**”

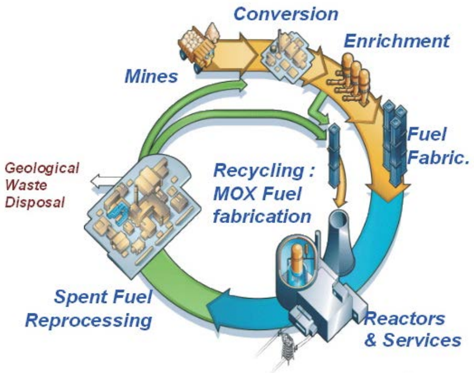
*Copenhagen, November 2, 2014*

# Global issues for nuclear fission

2011-2030
capacity increase

2030-2050
increase via
sustainability

1. enhance safety and security
2. maximise the use of proven technologies
3. reduce the legacy of the past
4. better use the resources



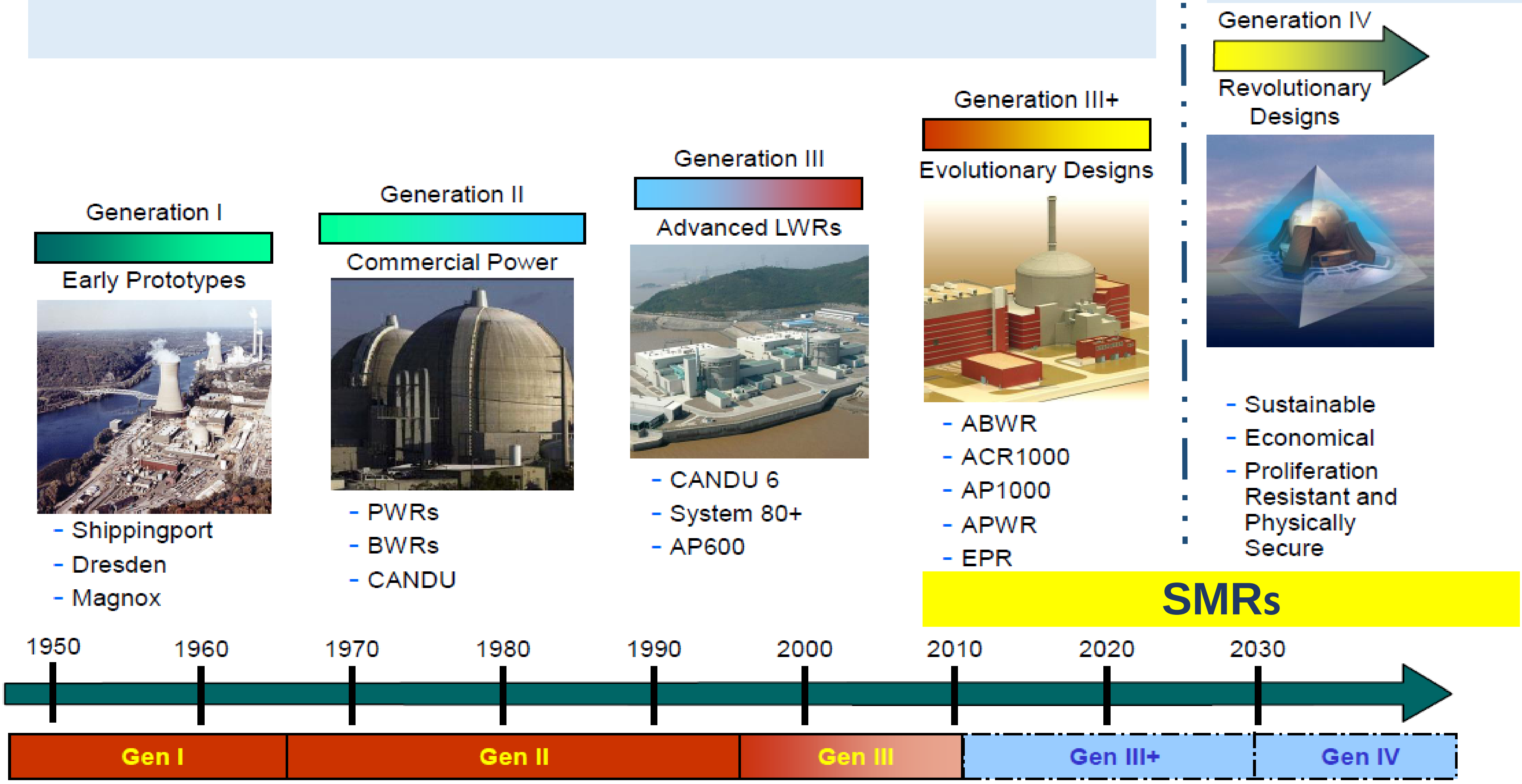
# The technologies of today and tomorrow

GEN II, III, III+ can fulfill the demand, safety and $CO_2$ job

- **nuclear** x **X**?: PLIM + reflect to 1980's ~20 plants/year
- but politics and industry must be able to act efficiently

GEN IV

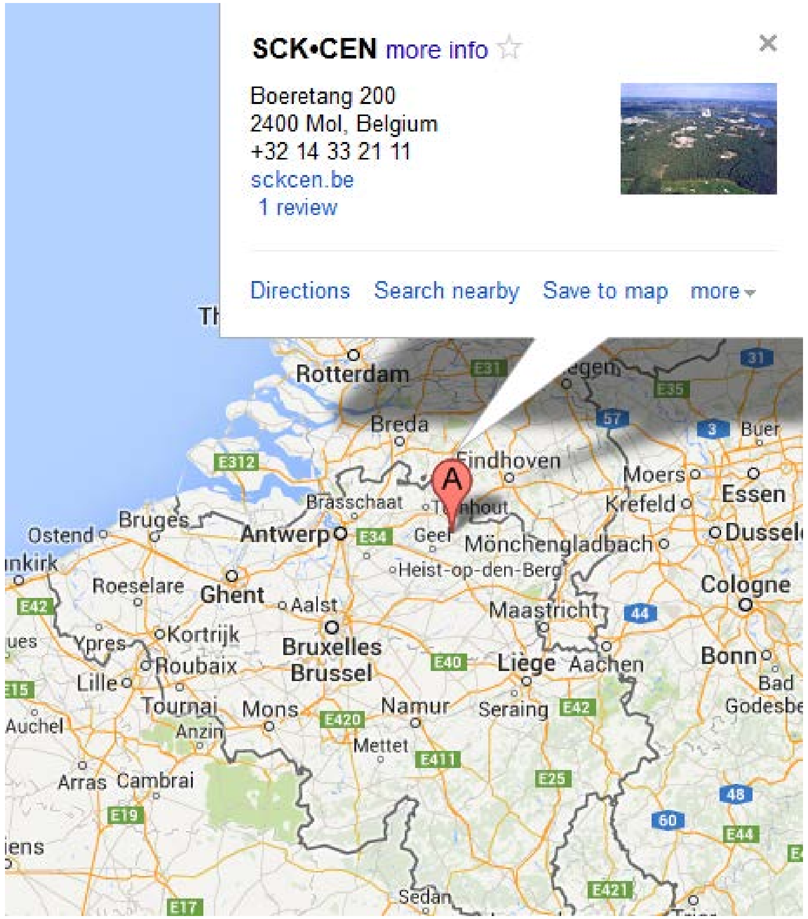
- sustainability
- legacy



# SCK•CEN a pioneering research organisation in nuclear

Studiecentrum voor Kernenergie -

Centre d'Étude de l'énergie Nucléaire




1st pressurized water reactor (PWR) outside USA (BR3)

Innovative nuclear fuel (MOX fuel)

Highest performing material testing reactor in Europe (BR2)

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

World first lead based ADS (GUINEVERE)

World premiere project for transmutation of nuclear waste

# Why MYRRHA at SCK•CEN? Continuity for SCK•CEN as an international nuclear CoE

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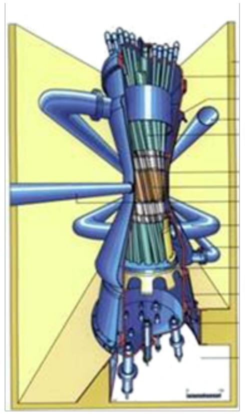
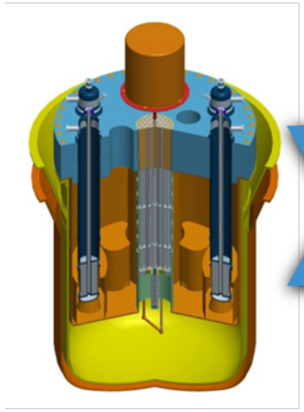


**Today BR2**

- Material Testing Reactor (fission)
- Fuel testing for LWR & GEN II/ GEN III
- Irradiation Services:
  - Medical RI
  - Fundamental research
  - Others

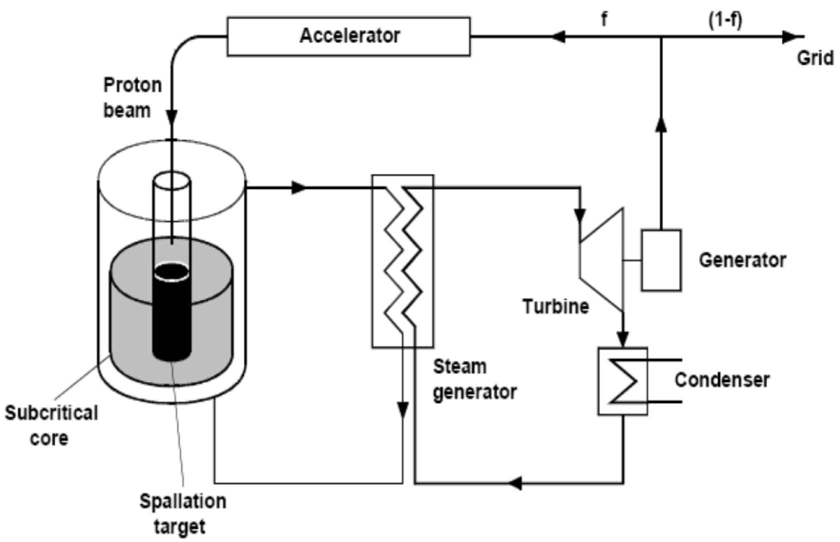


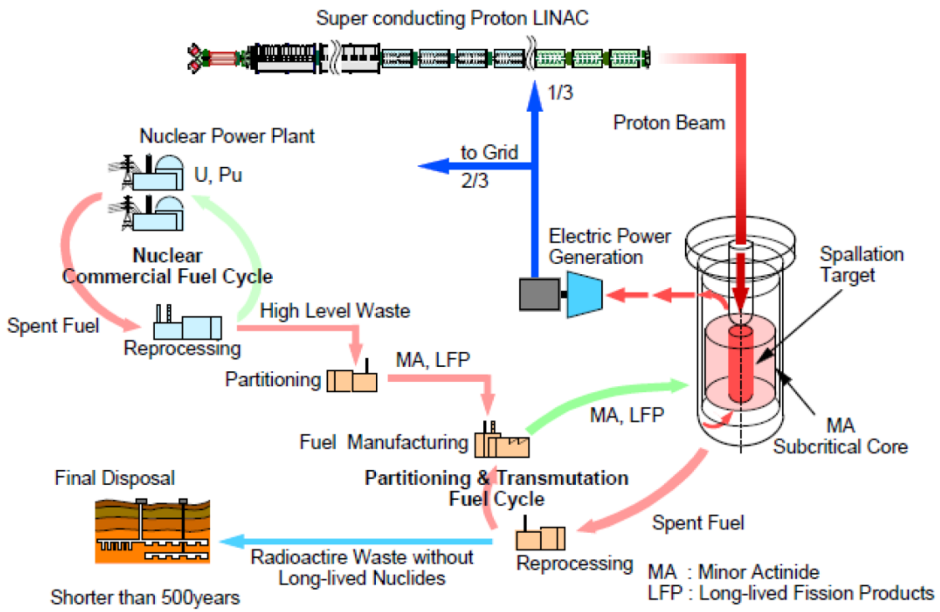
**Tomorrow MYRRHA**

- Fast Neutron Material Testing Reactor (fission + fusion)
- ADS-Demo + P&T Testing (Partitioning & Transmutation)
- Irradiation Services:
  - Medical RI
  - Fundamental research
  - Others
- Fuel testing for GEN IV
- LFR Experimental Technology Pilot Plant (ETPP)

# What is an ADS ?

Concept of an accelerator-driven system




An **Accelerator-Driven-System** is:

- a subcritical neutron multiplication assembly (nuclear reactor, keff<1),
- driven by an external neutron source,
- obtained through the spallation mechanism with high energy (~ 1GeV) protons,
- impinging on massive (high Z) target nuclei (Pb, Pb-Bi, W, Ta, U).

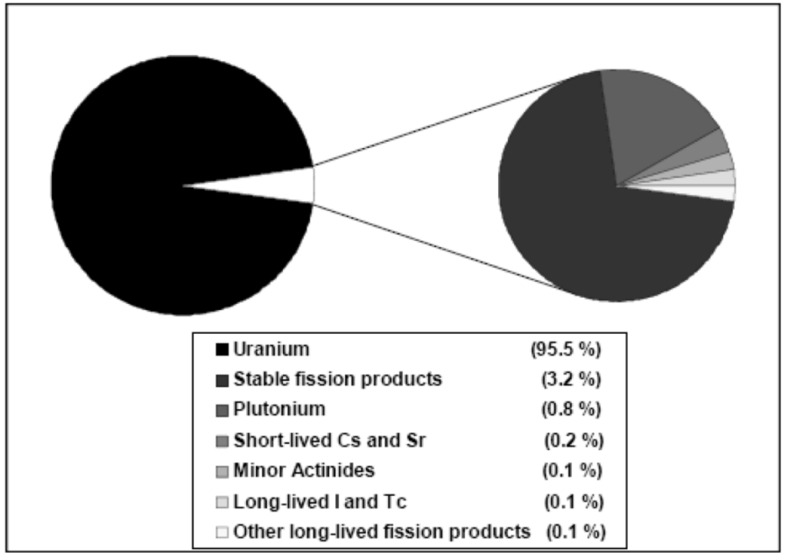
# Brief recent history of ADS activity in Europe

- 1993 C. Rubbia, energy amplifier (CERN)
- 1994 H. Aït Abderrahim & Y. Jongen, ADONIS (BE)
- **1995 M. Salvatores, MUSE experiments (FR)**
- **1995 C. Rubbia et al., FEAT/TARC experiments (CERN)**
- 1996 C. Rubbia et al., EA-80 ADS Demo joint programme ENEA, Ansaldo Nucleare, INFN (IT)
- 1998 H. Aït Abderrahim et al., MYRRHA (BE)
- 1999 B. Carluec & M. Salvatores et al., EFIT-Gas AREVA,-CEA (FR)
- 2001 C. Rubbia et al., TRADE ENEA-Casaccia (IT)
- **2001 A. Kievitskaya et al., YALINA experiments (Belarus)**
- 2002 V. Shvetsov et al., SAD facility in DUBNA (JINR/Russia)
- **2007 H. Aït Abderrahim et al., GUINEVERE (BE/FR)**
- **2010 H. Aït Abderrahim et al., MYRRHA in ESFRI & BE-Gov. Declaration support for contruction (BE)**
- 2011 A. Zelinsky et al., Neutron Source based ADS at KIPT (Ukraine)
- 2015 iThEC, iThEC ADS Project at INR in Troitsk (CH/RU)

*Source: SCK•CEN MYRRHA Project Team*

# Partitioning & Transmutation

Composition of spent nuclear fuel (standard PWR 33 GW/t, 10-year cooling)




1 tonne of SNF contains:
955.4 kg U
8.5 kg Pu

Minor actinides (MAs)
0.5 kg $^{237}Np$
0.6 kg Am
0.02 kg Cm

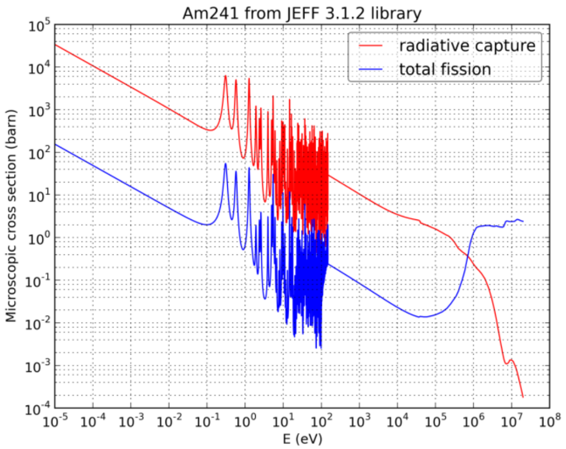
Long-lived fission products (LLFPs)
0.2 kg $^{129}I$
0.8 kg $^{99}Tc$
0.7 kg $^{93}Zr$
0.3 kg $^{135}Cs$

Short-lived fission products (SLFPs)
1 kg $^{137}Cs$
0.7 kg $^{90}Sr$

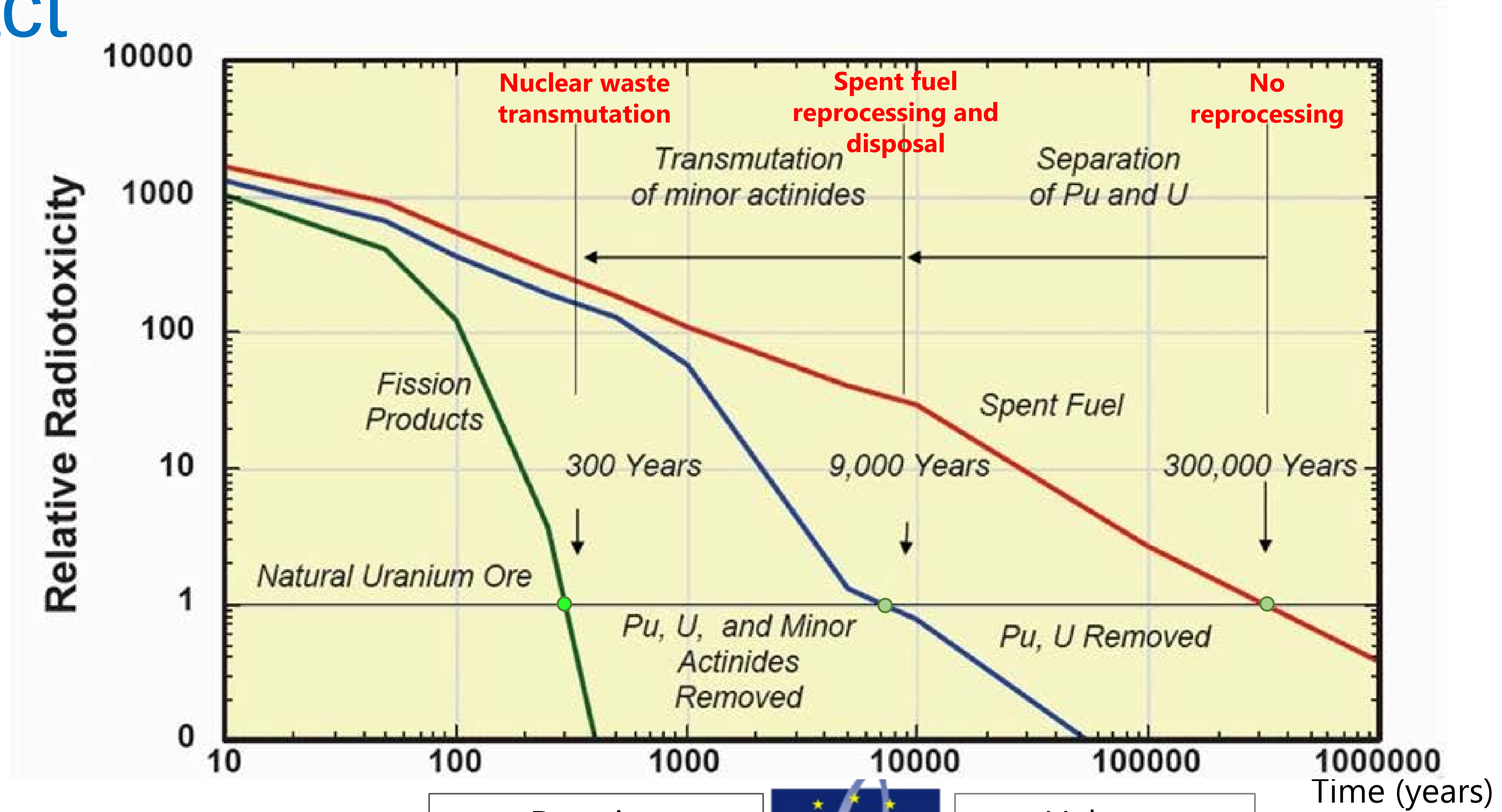
Stable isotopes
10.1 kg lanthanides
21.8 kg other stable

- Spent nuclear fuel current EU strategy is:
  - Onsite in-pool cooling (up to 10yrs)
  - Reprocessing in (few) centralized and dedicated plants (1yr): here U&Pu is removed from the spent fuel
  - Disposal:
    - Superficial for LLW and ILW (half lives ~$10^3$ yrs)
    - Geological for HLW (half lives ~ $10^6$ yrs)

- Storage (*"to wait"*) vs. treatment (*"to use nature against nature"*):
  - To reduce radiotoxicity of MAs, we can to fission them
  - The ratio Fission/Capture is more favorable with fast neutrons
  - To reduce radiotoxicity of LLFPs, they should undergo several neutron captures



# Nuclear waste: transmutation impact




*US DOE exstimation, LWR fuel, burn-up: 50 GWd/MT, 5 years in-pool cooling*

Duration Reduction: 1000x

Volume Reduction: 100x

# Critical and subcritical configuration

- The fission reaction chain can be obtained either in critical or subcritical configuration:

$$\phi(x,t) = \frac{p}{K_\infty \Sigma_a} \sum_{\substack{n=1 \\ (n\ \text{disp.})}}^{\infty} \left[ C_n e^{(K_n - 1)t/\ell_n} + \frac{K_n S_n}{(1-K_n)} \right] \cos\frac{n\pi x}{a}$$

Fourier's series

Example 1: solution for a thermal neutron flux in an infinte absorbing slab

# Critical and subcritical configuration

- The fission reaction chain can be obtained either in critical or subcritical configuration:

$$\phi(x,t) = \frac{p}{K_\infty \Sigma_a} \sum_{\substack{n=1 \\ (n \ \text{disp.})}}^{\infty} \left[ C_n e^{(K_n - 1)t/\ell_n} + \ldots \right] \cos \frac{n\pi x}{a}$$

Fourier's series

**$K_1 = 1$**
**CRITICAL CONFIGURATION**

Example 1: solution for a thermal neutron flux in an infinte absorbing slab

# Critical and subcritical configuration

- The fission reaction chain can be obtained either in critical or subcritical configuration:

$$\phi(x,t) = \frac{p}{K_\infty \Sigma_a} \sum_{\substack{n=1 \\ (n\ \text{disp.})}}^{\infty} \left[ C_n e^{\cdots t/\ell_n} + \frac{K_n S_n}{(1-K_n)} \right] \cos\frac{n\pi x}{a}$$

Fourier's series

**$K_1 < 1$, $S > 0$**
**SUBCRITICAL CONFIGURATION**

Example 1: solution for a thermal neutron flux in an infinte absorbing slab

# Intrinsic safety of the ADS

Example 2: Spherical reactor, two energetic groups of neutrons, static solution of diffusion equation

$$\begin{cases} \Phi_1(r) = \frac{1}{r}\sum_{n=1}^{\infty} \frac{s_n}{D_1} \frac{\left(\frac{n\pi}{R}\right)^2 - \delta}{\left[\left(\left(\frac{n\pi}{R}\right)^2 - \alpha\right)\left(\left(\frac{n\pi}{R}\right)^2 - \delta\right) - \xi\gamma\right]} \sin\frac{n\pi r}{R} \\ \Phi_2(r) = \frac{1}{r}\sum_{n=1}^{\infty} \frac{\gamma s_n}{D_1} \frac{1}{\left[\left(\left(\frac{n\pi}{R}\right)^2 - \alpha\right)\left(\left(\frac{n\pi}{R}\right)^2 - \delta\right) - \xi\gamma\right]} \sin\frac{n\pi r}{R} \end{cases}$$

$\Phi_1$: thermal neutron flux

$\Phi_2$ : fast neutron flux

accelerator off → reactor off !!

**Easy power control**

# ADS reactor: rather a necessity than a virtue

- Both **fast critical reactors** and **ADS** can be used as transmutation systems
- Nevertheless a big load of MAs can jeopardize the control of a critical reactor because of:

1) Reduced delayed neutron fractions, β (due also to the reduction of $^{238}U$) and reduced margin to prompt criticality ($\rho = \beta$)

$$\psi(\mathbf{r}, t) = \psi_o(\mathbf{r}) \sum_{m=0}^{M} A_m e^{\omega_m t}$$

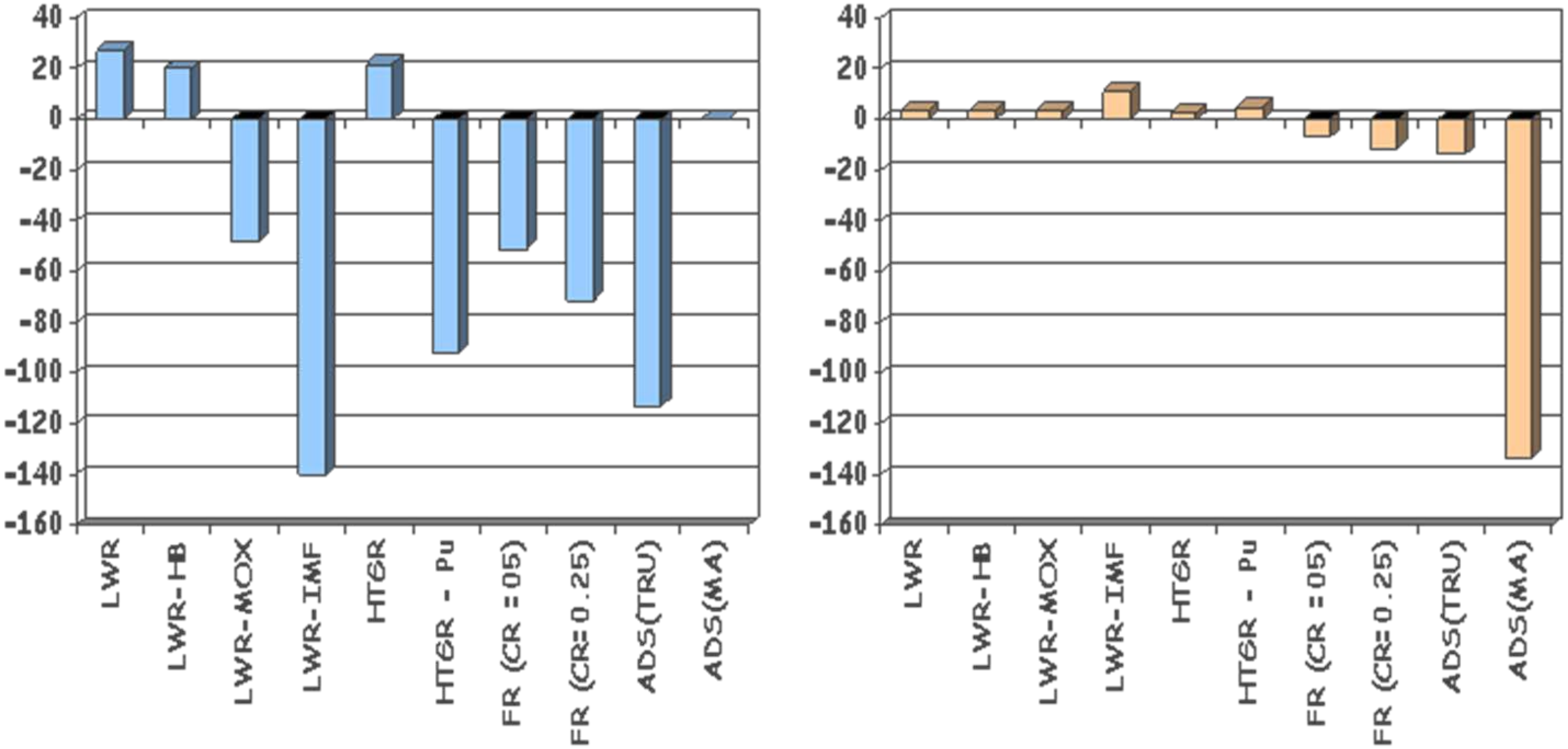
$$T = \frac{1}{\rho}\left[\frac{\ell}{K_{eff}} + \sum_{i=1}^{M} \frac{\beta_i}{\lambda_i}\right]$$

Characteristic period of the reactor

2) Doppler feedback reduced with increasing amount of MAs

The ADS can transmute big loads of MAs without losing safety and this solution is needed for heavily MA loaded core (>10%)

# The ADS is the most efficient system in burning MAs

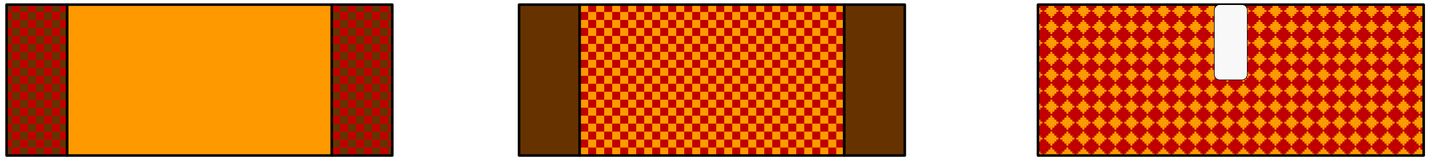



* Mike Cappiello, (LANL), "The Potential Role of Accelerator Driven Systems in the US", ICRS-10/RPS'2004, Madeira (PT), 2004

# Three options for Minor Actinide transmutation

EU is presently considering two approaches for transmutation: via FR or ADS

| FR heterogeneous | FR homogeneous | ADS |
|---|---|---|



| Driver fuel<br>Blanket with MA | Fuel with MA<br>Blanket | Fuel with MA |
|---|---|---|

Core safety parameters limit the amount of MA that can be loaded in the critical core for transmutation, leading to transmutation rates of:

- FR = 2 to 4 kg/TWh
- ADS = **35 kg/TWh** (based on a 400 $MW_{th}$ EFIT design)

# European Strategy for P&T (2005) with objective of possible industrialisation from 2030-35

**<u>EU P&T Strategy 2005:</u>** *"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"**:*

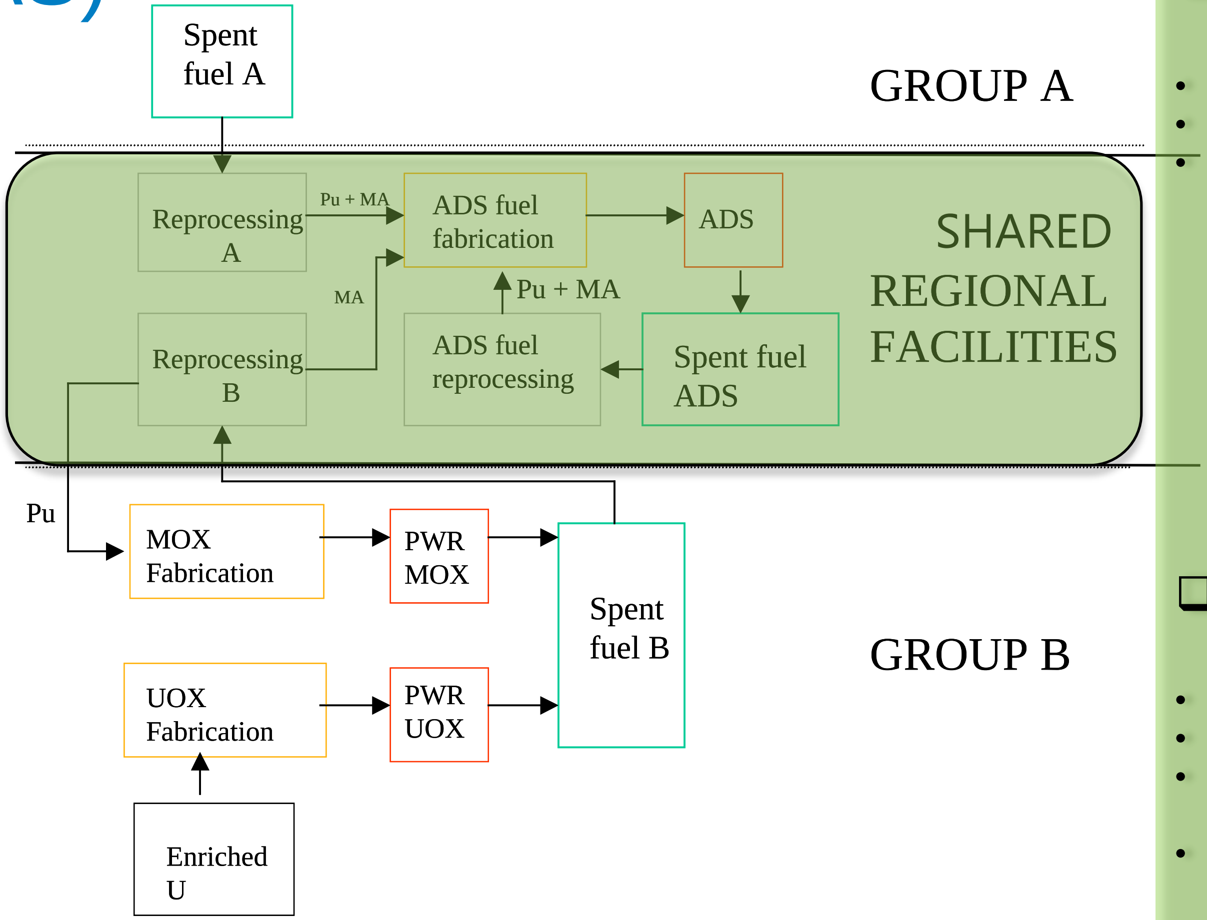
| P&T building blocks | Description | Name & Location |
|---|---|---|
| 1 **Advanced Partitioning** | ▪ Demonstrate capability to process a sizable amount of **spent fuel** from commercial Light Water Reactors to **separate** plutonium, uranium and minor actinides | ▪ Atalante (FR) |
| 2 **MA Fuel production** | ▪ Demonstrate the capability **to fabricate** at a semi-industrial level the **dedicated fuel with MA** needed to load in a dedicated transmuter | ▪ JRC-ITU (EU) |
| 3 **Transmutation** | ▪ **Design and construct one or more dedicated transmuters** | ▪ **MYRRHA (BE)** |
| 4 **MA Fuel Reprocessing** | ▪ Specific installation to process fuel unloaded from transmuter<br>▪ based on pyroreprocessing/electrorefining | |

The European Commission contributes to the 4 building blocks and fosters the national programmes towards this strategy for **demonstration at engineering level**.



*Source: European Commission Strategy Paper on Partitioning & Transmutation (2005)*

# Even with completely different national NE policies European solution for HLW works with ADS (FP7 ARCAS)




Scenario 1 objective: elimination of A's spent fuel by 2100
A = Countries Phasing Out, B = Countries Continuing

## ❑ Advantages for A

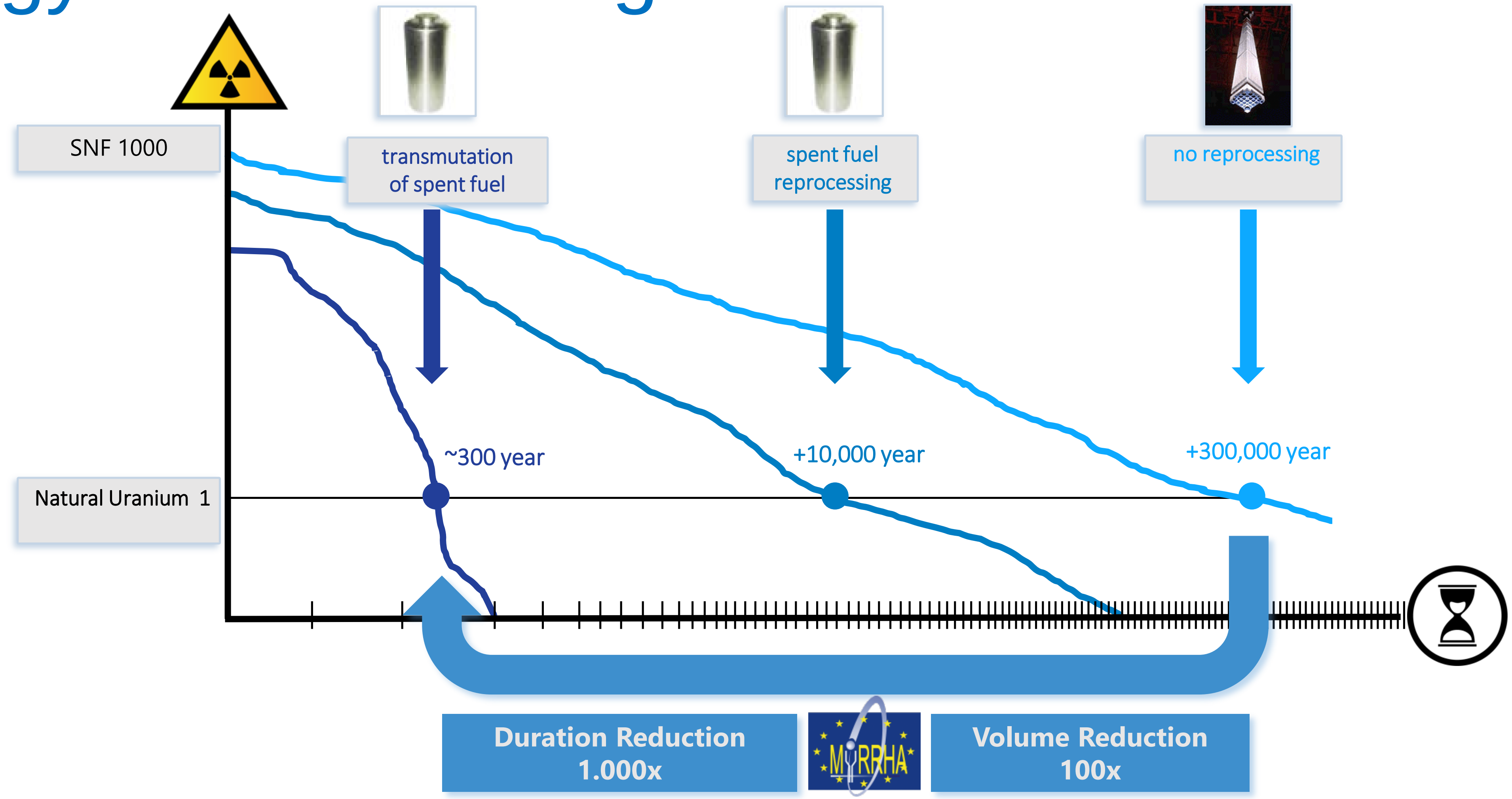
- ADS shared with B
- ADS burn A's Pu& MA
- Smaller Fu-Cycle units & shared

## ❑ 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

*Source: SCK•CEN MYRRHA Project Team, MYRRHA Business Plan*

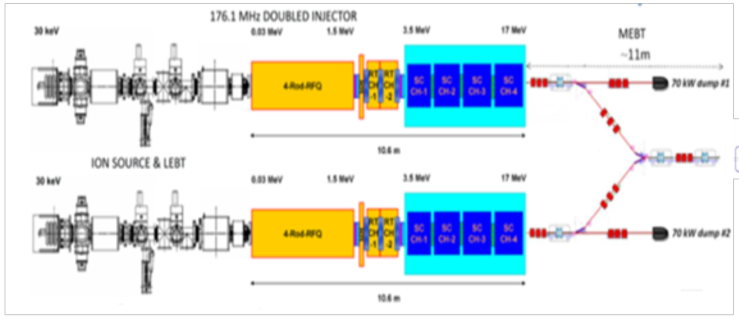
# MYRRHA crucial in this European strategy for P&T through ADS

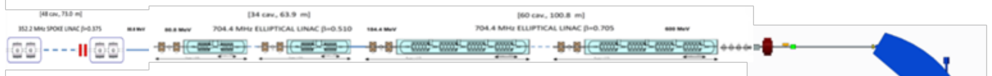



*Source: European Commission Strategy Paper on Partitioning & Transmutation (2005), SCK•CEN MYRRHA Project Team*

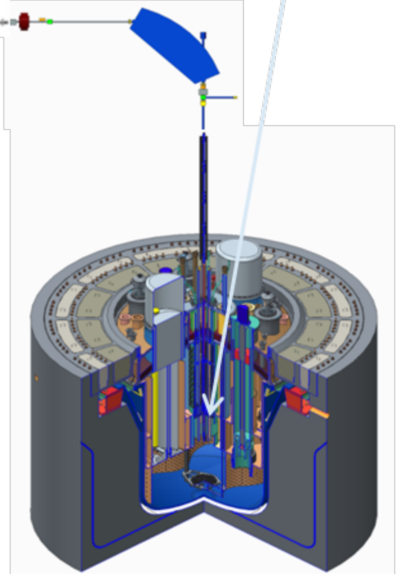
# Key technical objective of the MYRRHA-project: an Accelerator Driven System

- MYRRHA – An Accelerator Driven System
  - Demonstrate the ADS concept at pre-industrial scale
    - Can operate in critical and sub-critical modes
  - Demonstrate transmutation
  - Fast neutron source → multipurpose and flexible irradiation facility



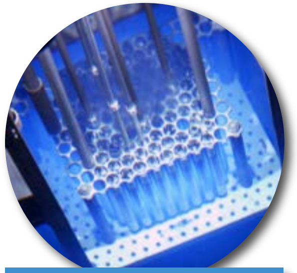
| Target | |
|---|---|
| *main reaction* | spallation |
| *output* | $2 \cdot 10^{17}$ n/s |
| *material* | LBE (coolant) |



| Accelerator | |
|---|---|
| *particles* | protons |
| *beam energy* | 600 MeV |
| *beam current* | 2.4 to 4 mA |

| Reactor | |
|---|---|
| *power* | 65 to 100 $MW_{th}$ |
| $k_{eff}$ | 0,95 |
| *spectrum* | fast |
| *coolant* | LBE |

# MYRRHA application portfolio



**Fission GEN IV**

**SNF*/ Waste**

**Radio-isotopes**

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

**Fusion**

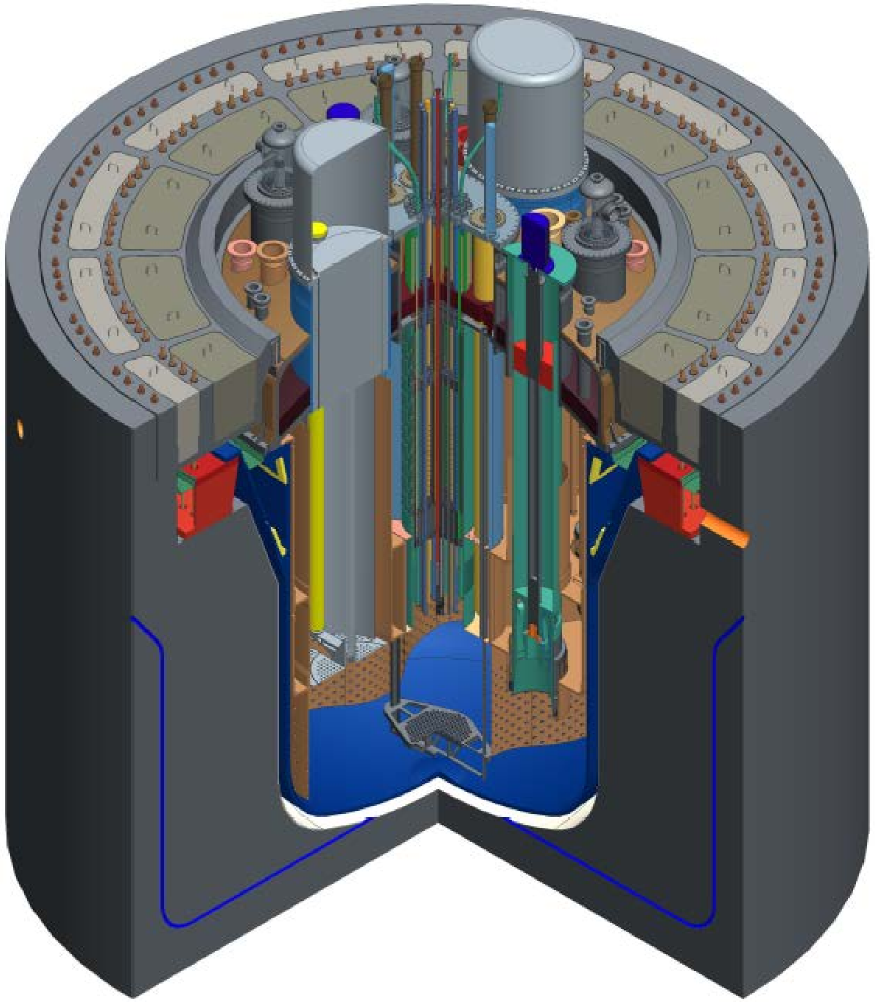
**Fundamental research**

**SMR LFR**

*SNF = Spent Nuclear Fuel

*Source: SCK•CEN MYRRHA Project Team, MYRRHA Business Plan*

# Reactor Pool-type: MYRRHA rev. 1.6 at the End of 2014



*Source: SCK•CEN MYRRHA Project Team*

- Size reduction
- Po issue
- $O_2$ concentration control

**Optimisation requested**

# Reactor: Comparative study for MYRRHA rev. 1.7 in 2015

## Primary system design options

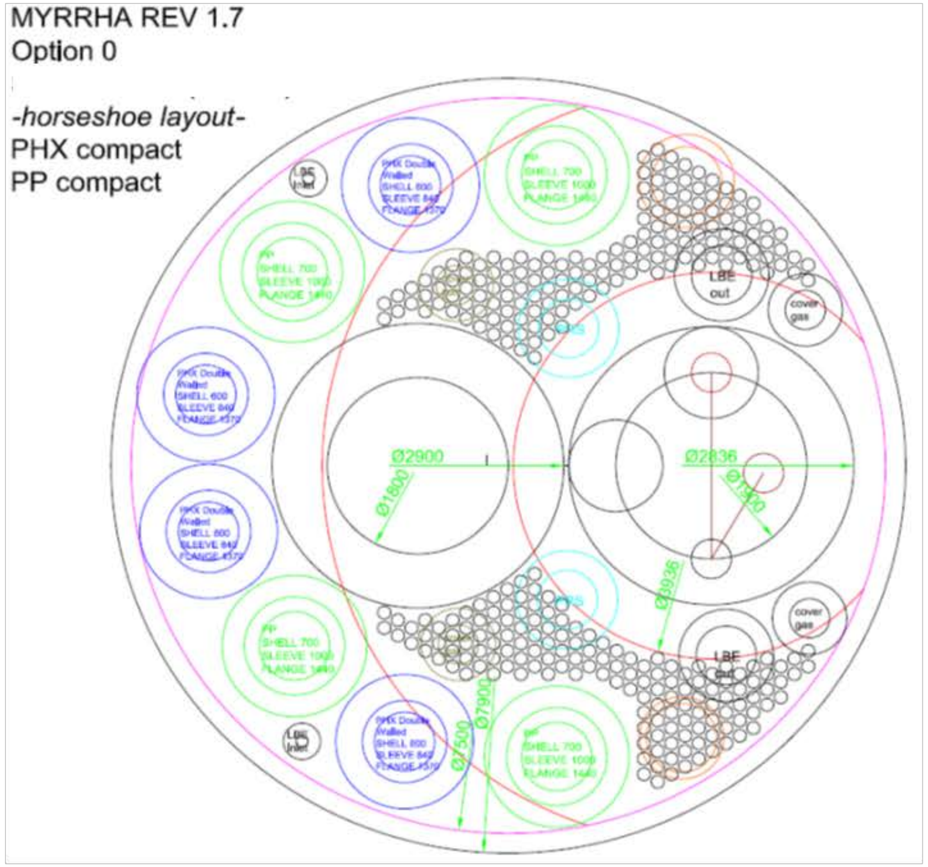
- Option 0: Updated rev. 1.6
  - Innovative double walled heat exchangers
  - One innovative IVFHM
- Option 1: Innovative Pool-type focused on size limitation
- Option 2: Loop-type bottom-loading with conservative technical choices
  - External double walled heat exchangers
  - One existing IVFHM
- Option 3: Loop-type top-loading
  - Top-loading system



*Source: SCK•CEN MYRRHA Project Team*

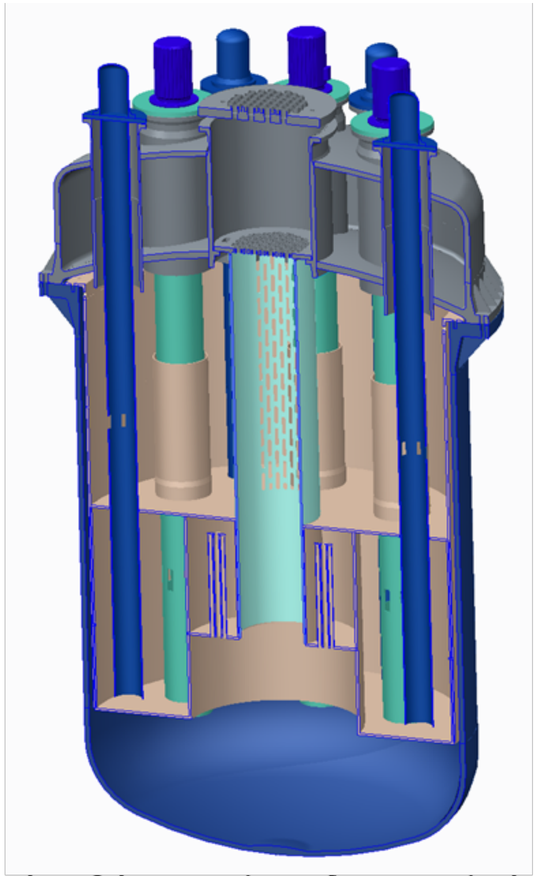
# Reactor Option 0-D: evolution of existing design with innovative HX and one IVFHM

- Layout of main components




Source: SCK•CEN MYRRHA Project Team

# MYRRHA reactor design update



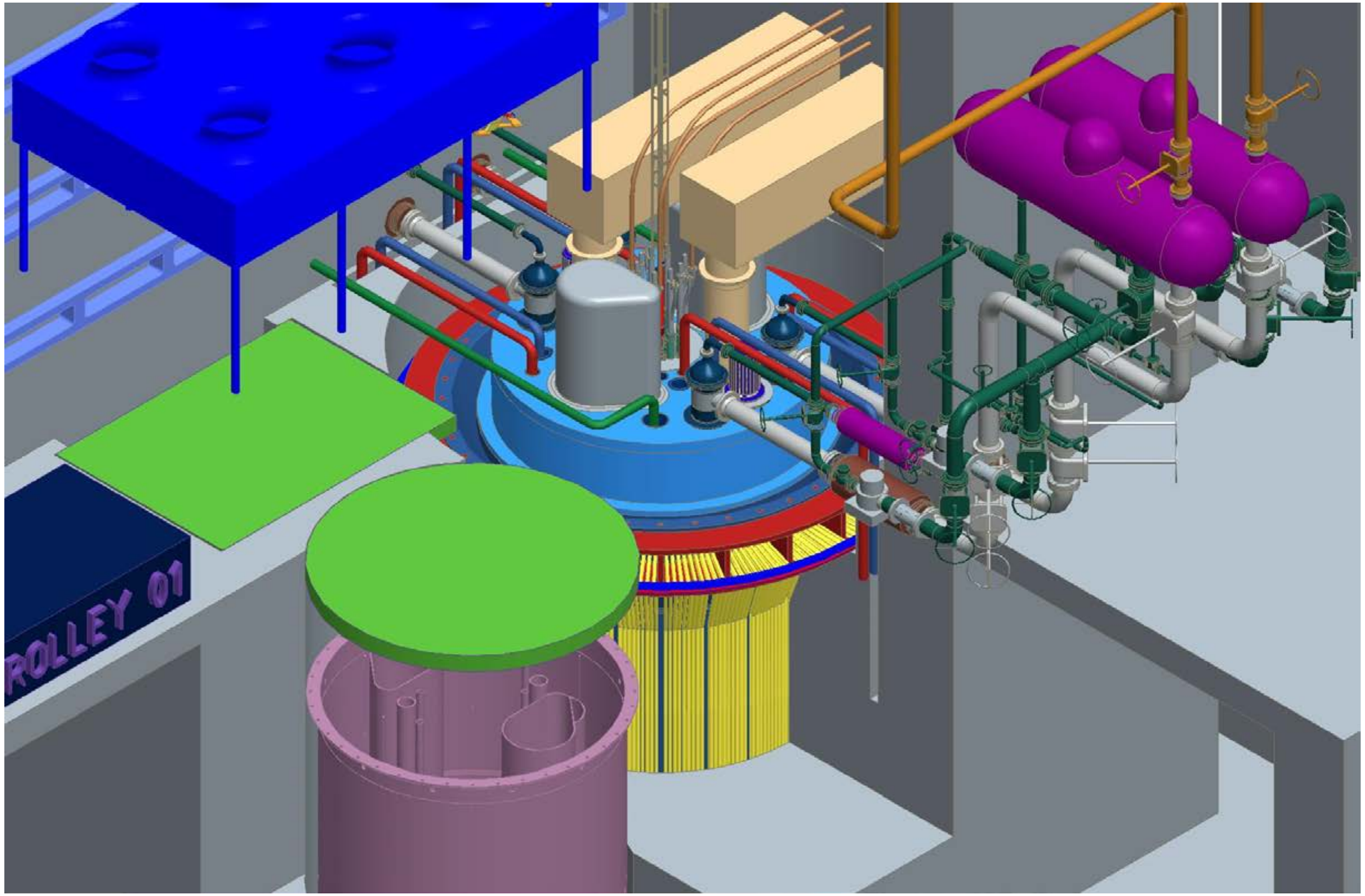
Option 0 is now the reference design under further optimisation

Four MYRRHA primary system design options investigated to reduce the dimension of the reactor vessel (& associated cost)

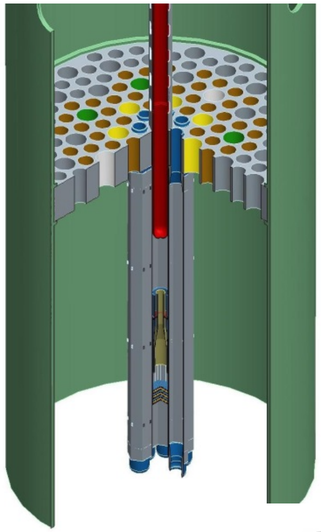
| Option | Reactor type | Description |
|---|---|---|
| 0 | Pool | Updated rev. 1.6<br>Innovative IVFHM & double-walled PHX |
| 1 | Pool | Reduced size<br>Innovative IVFHM & double-walled PHX |
| 2 | Loop | Bottom loading<br>Existing IVFHM concept & external double-walled PHX |
| 3 | Loop | Top loading |

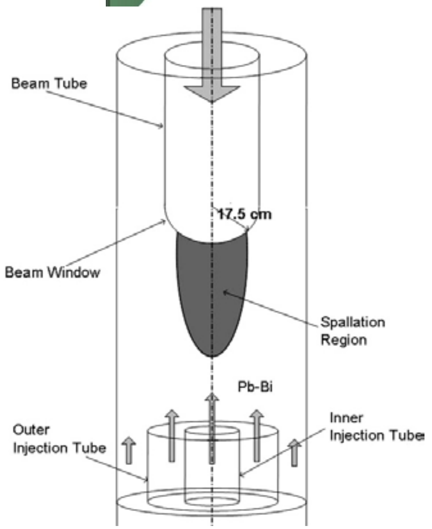
*Source: SCK•CEN MYRRHA Project Team*

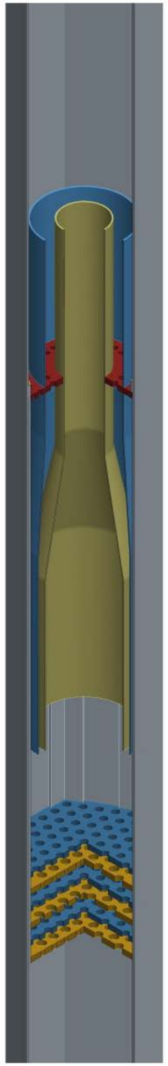
# MYRRHA reactor cooling systems



# Spallation target window in the reactor core



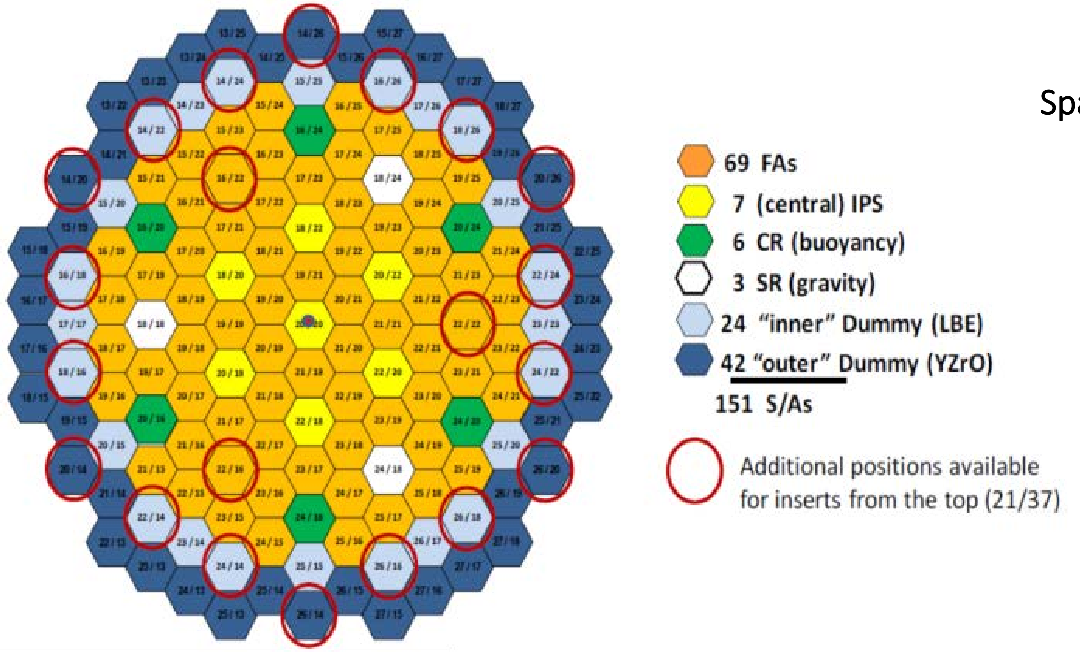


- Produces about $10^{17}$ neutrons/s at the reactor mid-plane to feed subcritical core @ keff=0.95
- Fits into a central hole in core
  - Compact target
  - Remove produced heat
- Accepts megawatt proton beam
  - 600 MeV, 3.5 mA → ~2.1 MW heat
  - Cooling of window is feasible
- Material challenges
  - Preferential working temperature: 450 – 500° C
  - Service life of at least 3 full power months (1 cycle) is achievable

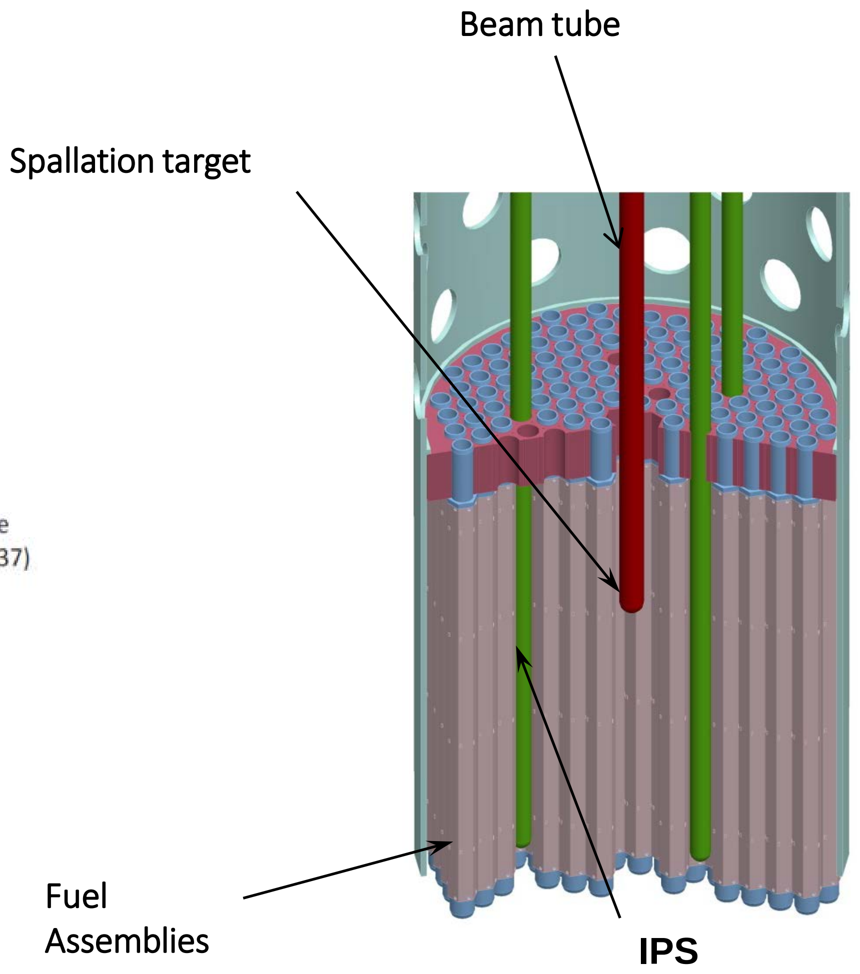
# MYRRHA Core and fuel

- 151 positions
- 37 multifunctional plugs

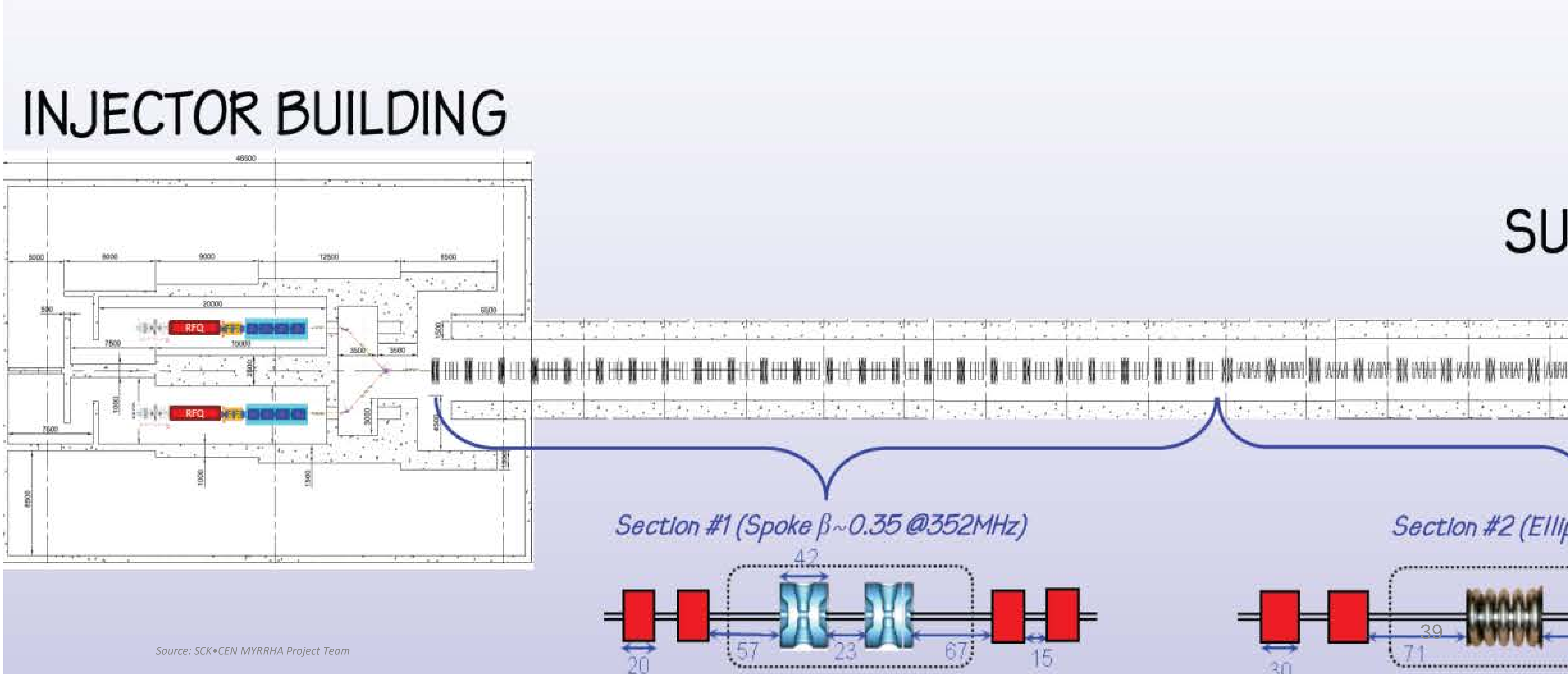



Both critical and subcritical configuration:

- Critical: 100 MWth
- Subcritical 65-75 MWth
- MOX driver fuel (~30%)

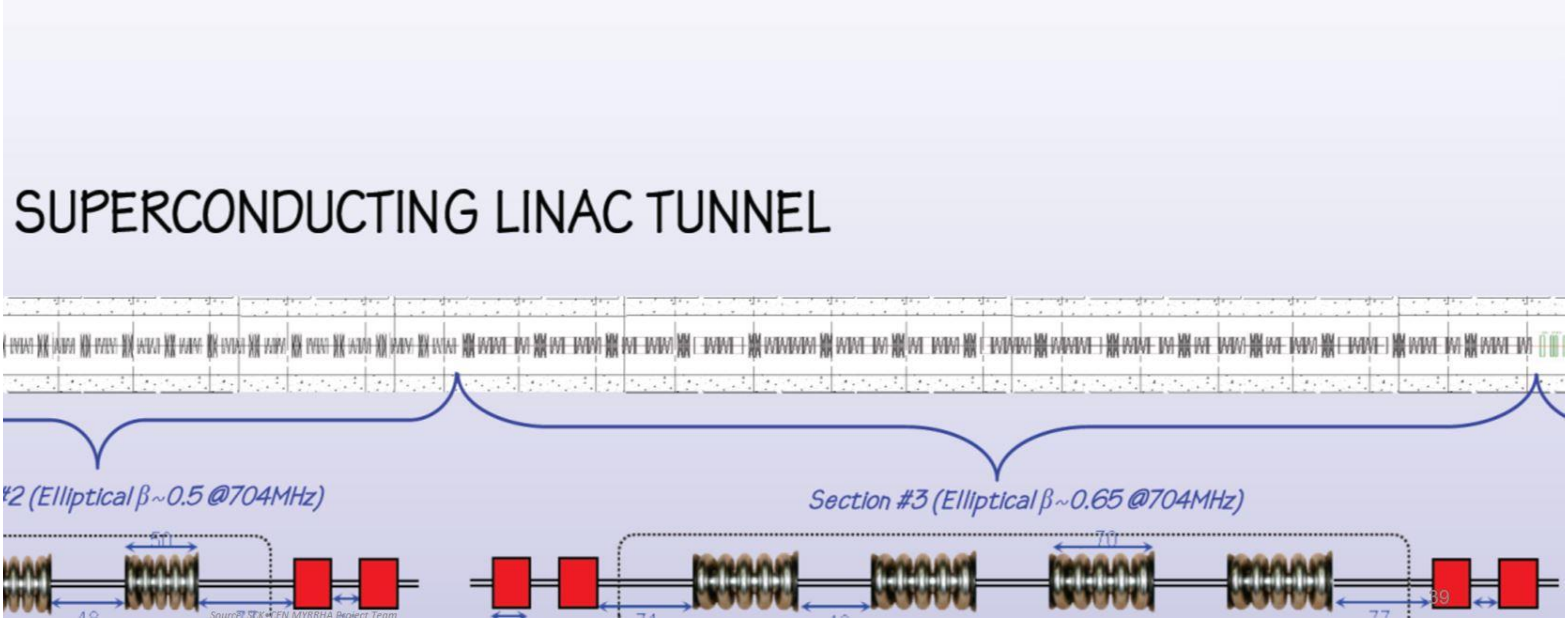


# MYRRHA linac: Design frozen since 2014 under prototyping




*Source: SCK•CEN MYRRHA Project Team*

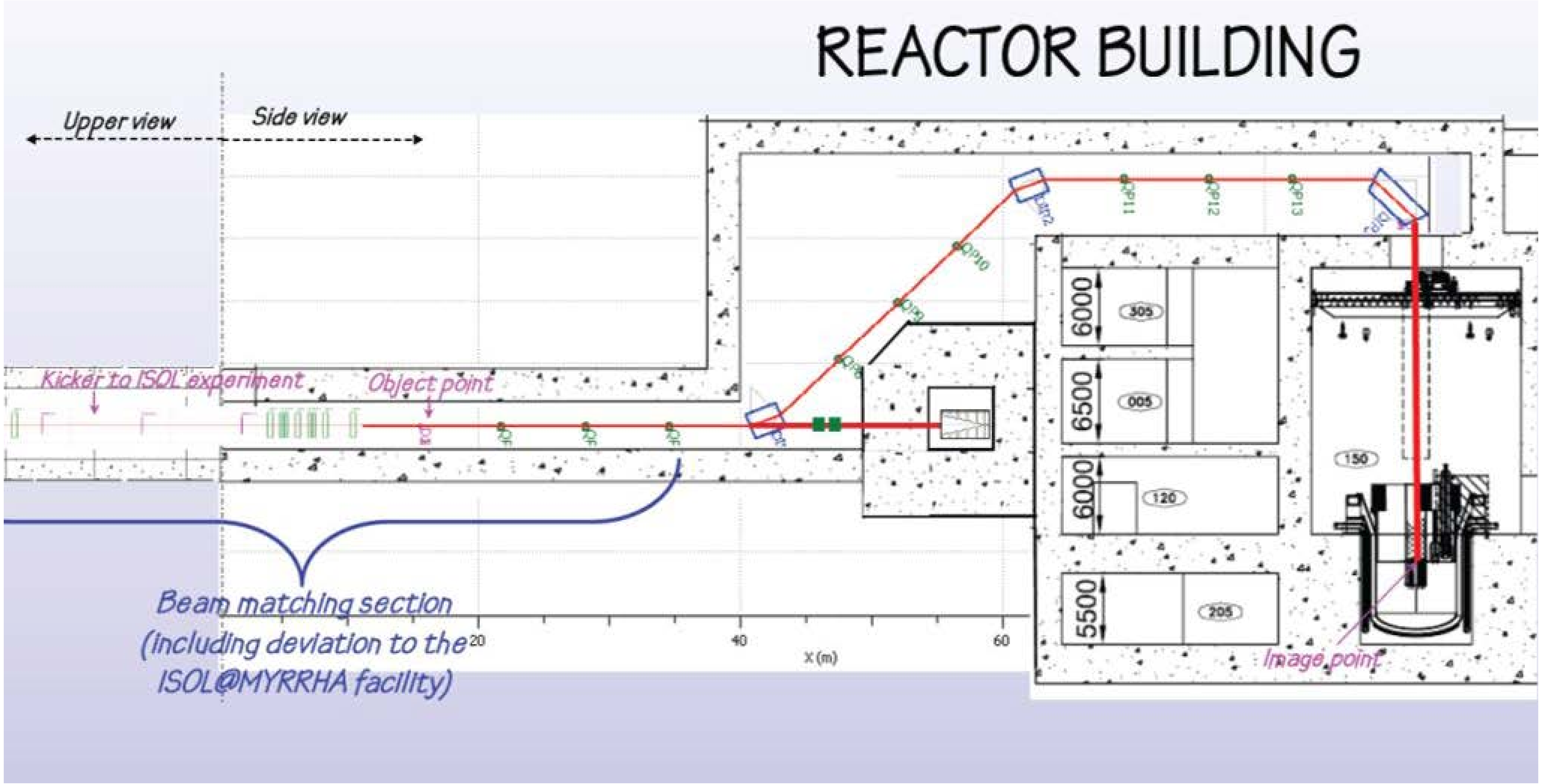
# MYRRHA linac: Design frozen since 2014 under prototyping






Source: SCK•CEN MYRRHA Project Team

# MYRRHA linac: Design frozen since 2014 under prototyping




Source: SCK•CEN MYRRHA Project Team

# Accelerator: Specific requirements of MYRRHA

**→ High power proton beam (up to 2.4 MW)**

| | |
|---|---|
| Proton energy | 600 MeV |
| Beam current | 0.1 to 4.0 mA |
| Repetition rate | CW, 250 Hz |
| Beam duty cycle | $10^{-4}$ to 1 |
| Beam power stability | < ± 2% on a time scale of 100ms |
| Beam footprint on reactor window | Circular ∅85mm |
| Beam footprint stability | < ± 10% on a time scale of 1s |
| # of allowed beam trips on reactor longer than 3 sec | 10 maximum per 3-month operation period |
| # of allowed beam trips on reactor longer than 0.1 sec | 100 maximum per day |
| # of allowed beam trips on reactor shorter than 0.1 sec | unlimited |

**→ Extreme reliability level: MTBF > 250 hrs**

*Source: SCK•CEN MYRRHA Project Team*

# Accelerator: Roadmap to Reliability

**Design**

- **Major accelerator labs** in Europe as well as specific **industrial partners**
- **Incorporating fault tolerant** schemes
- **Validation** with reliability model
- **Reviewed by panel of international** accelerator peers

**Prototyping**

- **Key elements:** Ion source, LEBT, RFQ, CH cavities, etc.
- **Set-up of an experimental test-bench**: 5.9MeV accelerator @CRC, UCL in LLN
- **Hands-on experience** for the team, **return on experience** for manufacturing phase, start of **engineering work** in view of the construction and integration

**Scenario 1 100MeV**

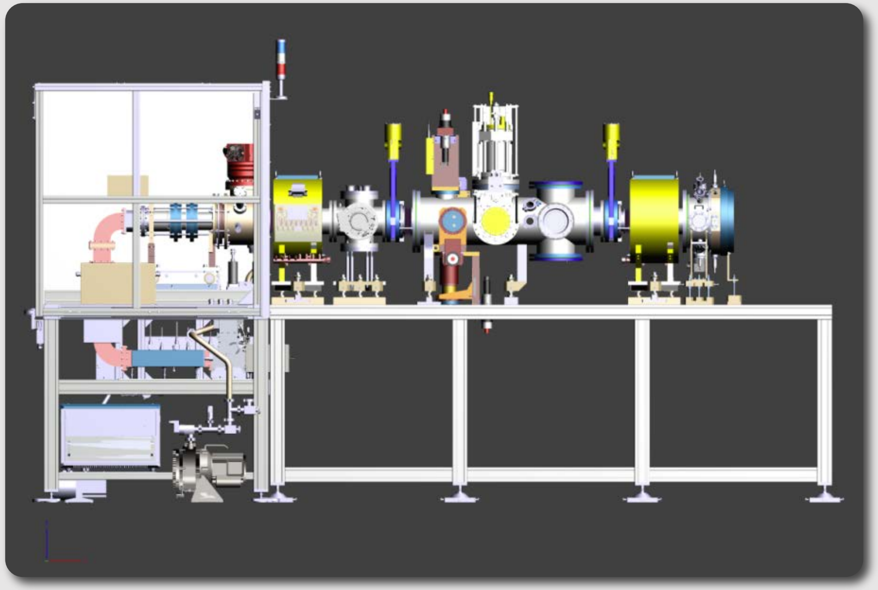
- **Representative unit** in view of the 600MeV
- **Implementation** of fault tolerant schemes
- **Testing and validation** of technological choices
- **Evaluation of the reliability goal** for the full MYRRHA Linac
- **Applications** (Lucia's presentation)

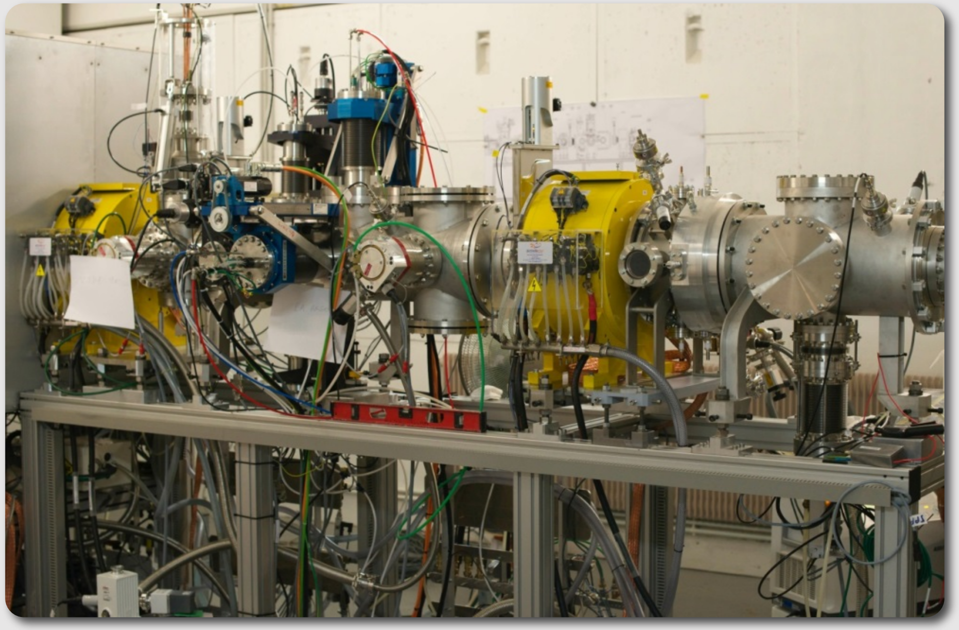
*Source: SCK•CEN MYRRHA Project Team*

# Accelerator components

- Ion source
- LEBT
- Chopper
- RFQ
- CH NC cavities
- Single spoke cryomodules
- Elliptical cryomodules

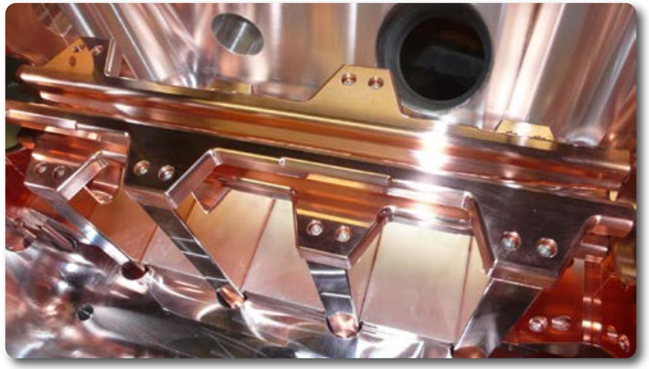
# Ion source – LEBT – Chopper

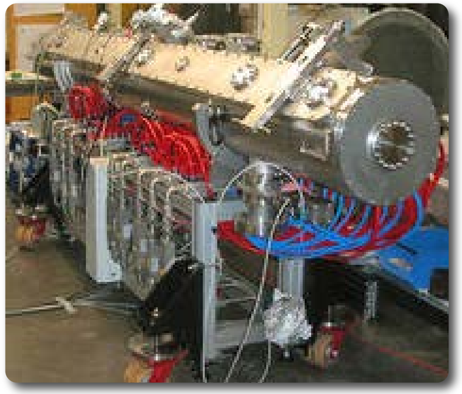


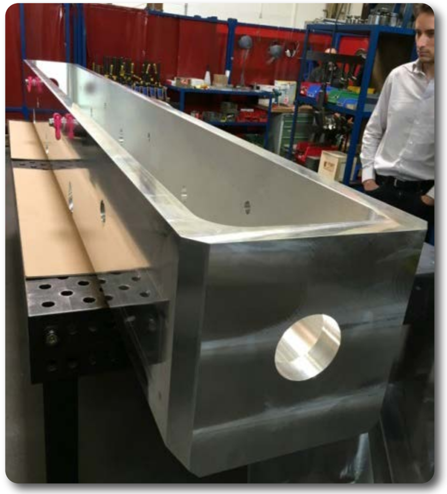


# RFQ – Radiofrequency quadrupole

- First accelerating structure
  - 4—rod
  - 30keV → 1.5MeV
  - 176.1MHz
  - 4m long aluminum structure
  - Stems:
    - OFHC Copper &Thick copper plating
    - Complex water cooling system



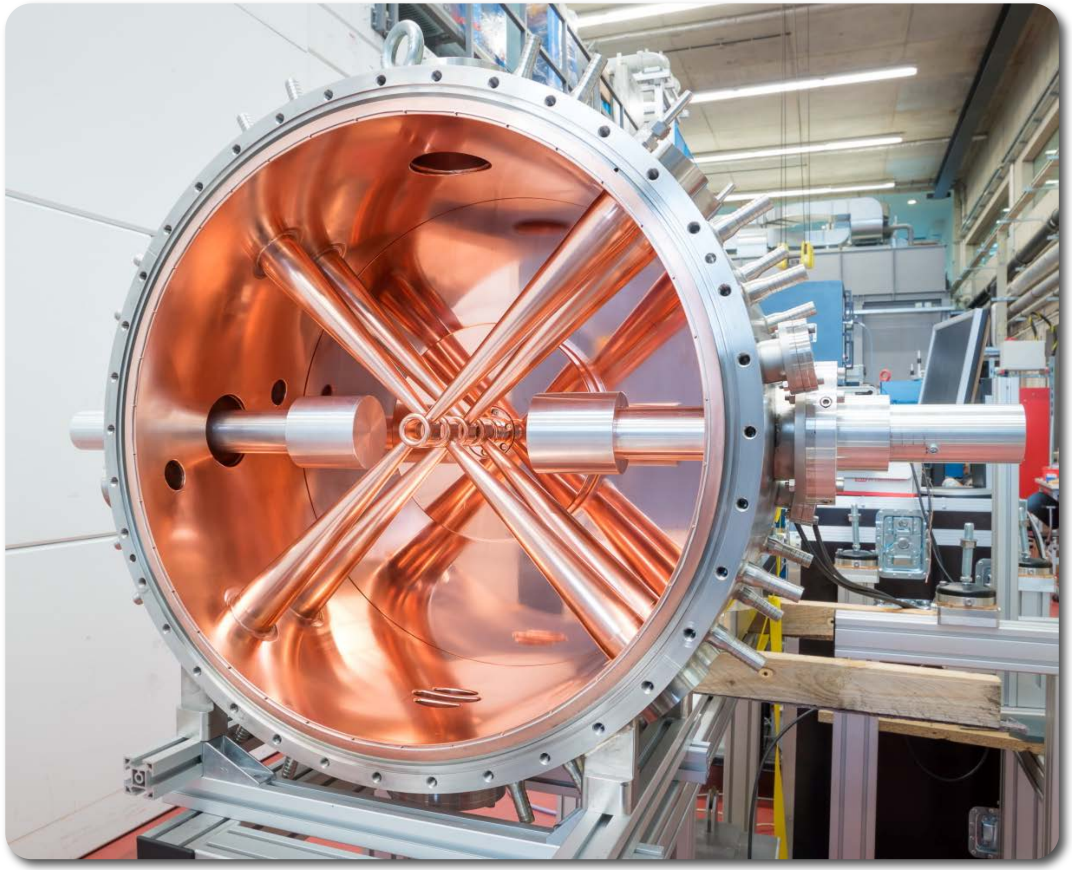




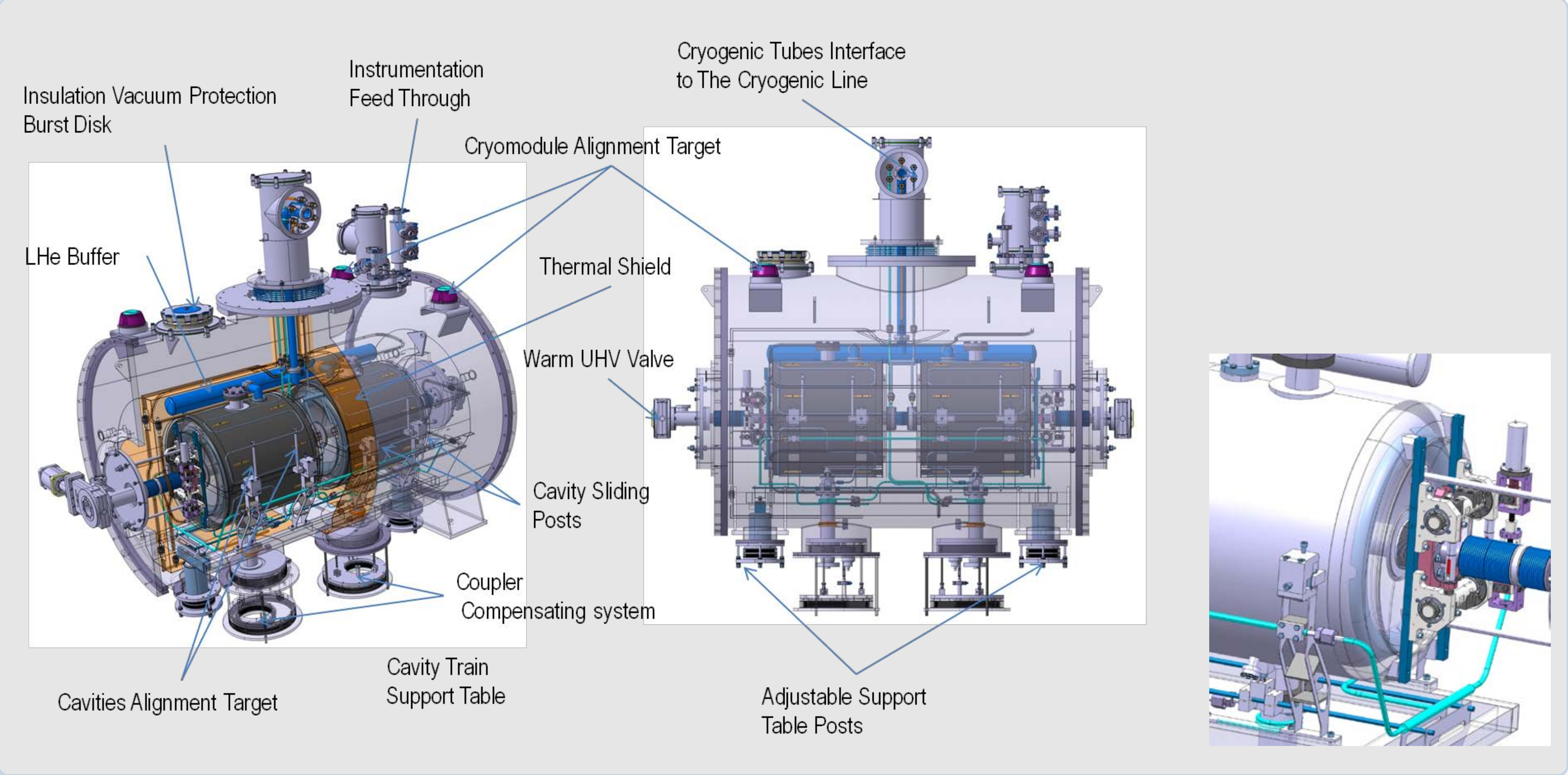
# CH room temperature cavities

- Second accelerating section
  - 1.5MeV → 17MeV
  - 176.1MHz

- Stainless steel structures
  - Thin copper plating



# Single spoke cavity cryomodules



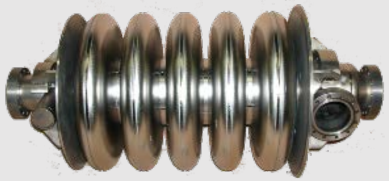
# Single spoke cavity

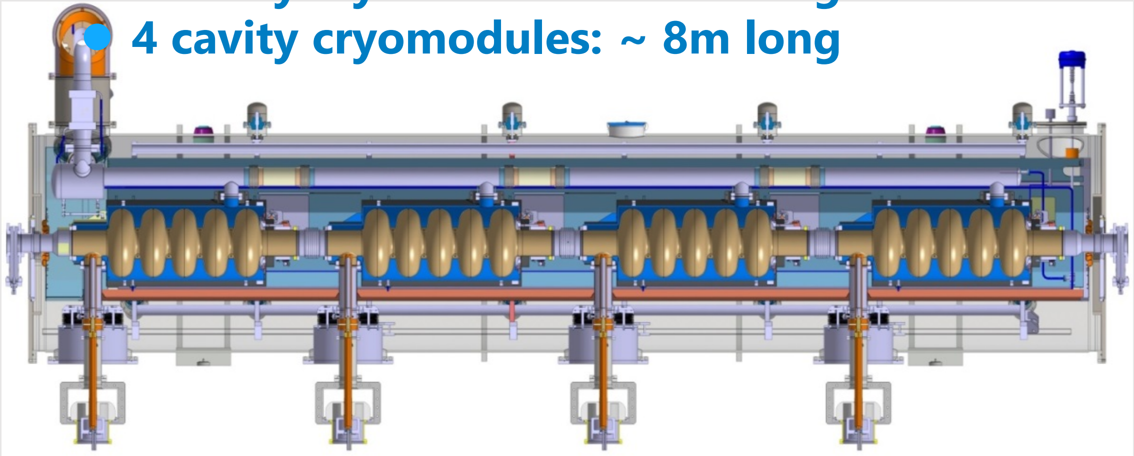
AMELIA
(ZA01)

VIRGINIA
(ZA02)

# Elliptical cavity cryomodules

- **Fourth and fifth accelerating section**
  - **100MeV – 600MeV**
  - **Superconducting RF structures**
    - 100 – 200MeV: double spoke or elliptical cavities (352.2 or 704.4MHz)
    - 200 – 600MeV: elliptical cavities (704.4MHz)
  - **2 cavity cryomodules: ~ 3m long**
  - **4 cavity cryomodules: ~ 8m long**





# Licensing: Approach

- Pre-licensing phase
  - For a complex nuclear installation relying on new technologies like MYRRHA
  - To timely communicate on design development and its expectations in terms of nuclear safety and security requirements, and safeguards provision
  - By implementing instruments providing guidance to the owner/designer

- Approach
  - Identification and evaluation of “Focus Points” (FPs), new or not mature enough issues specific to MYRRHA that may have an impact on the safety of the facility by jeopardizing any of the safety functions
  - Elaboration of a Design Options and Provisions File (DOPF) = pre-PSAR

# Licensing: Design Options and Provisions File

- Volume 1: Purpose and description of the MYRRHA installation
  - Facility system components, modes of operation, codes & standards, and other operational aspects. Interaction with site & environment
- Volume 2: Approach to the nuclear safety
  - Rules for safety demonstration and for determining the radiological consequences of accidents (check compliance with safety demo criteria)
- Volume 3: Design options, selected provisions and their justification
  - Initiating events and their categorization into plant states, main design options and their justification, preliminary safety analyses
- Volume 4: Management system for safety of the installation
  - For the time being, only restricted to the design phase. To be extended later on for the construction and operation phases
- Volume 5: Security and Safeguards Integrated Approach

# Status | FPs (mid 2017)

- 46 deliverables have been accepted
- 50 deliverables are still in evaluation or in Q&A iterations
- 5 deliverables should still be delivered this year
- 69 deliverables are scheduled to be issued after 2017

# Licensing: Conclusions

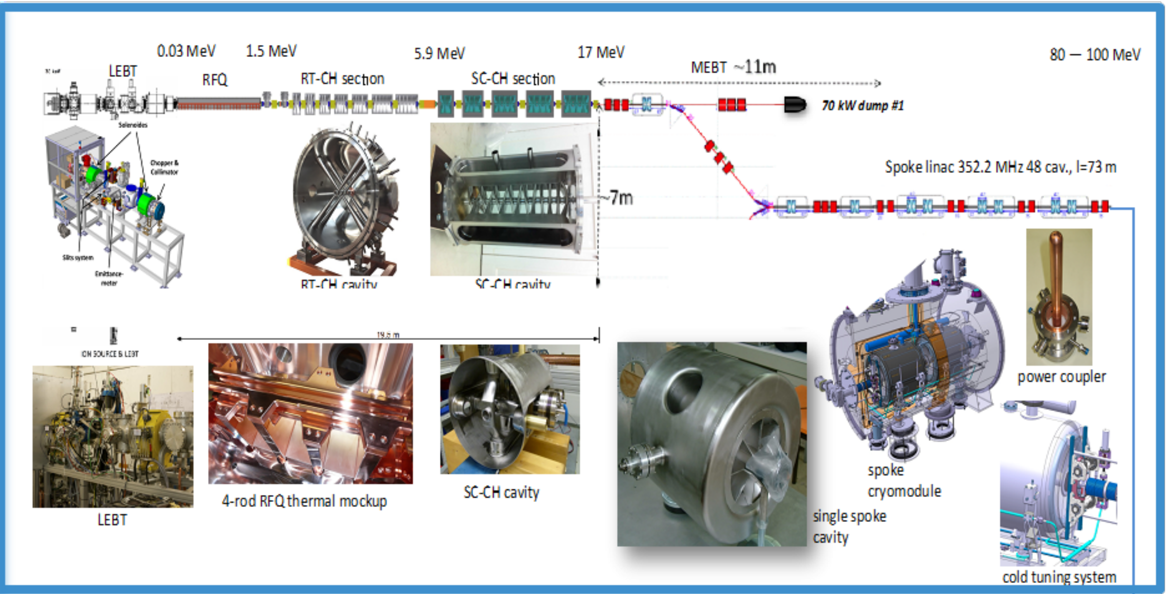
- A fully consistent and coherent design of the MYRRHA primary system was obtained
- Focus is shifting towards realization of prototypes of (sub-) components
- A large MYRRHA R&D supporting programme (with the support and in-kind contribution of international partners) generated between 2010 and 2017 important results
- Significant progress has been achieved in the pre-licensing framework with the Belgian Safety Authorities
- First opinion on licensability (of full MYRRHA) received in 2017
- Licensing of MYRRHA Accelerator 100 MeV started in 2016

# MYRRHA's phased implementation strategy

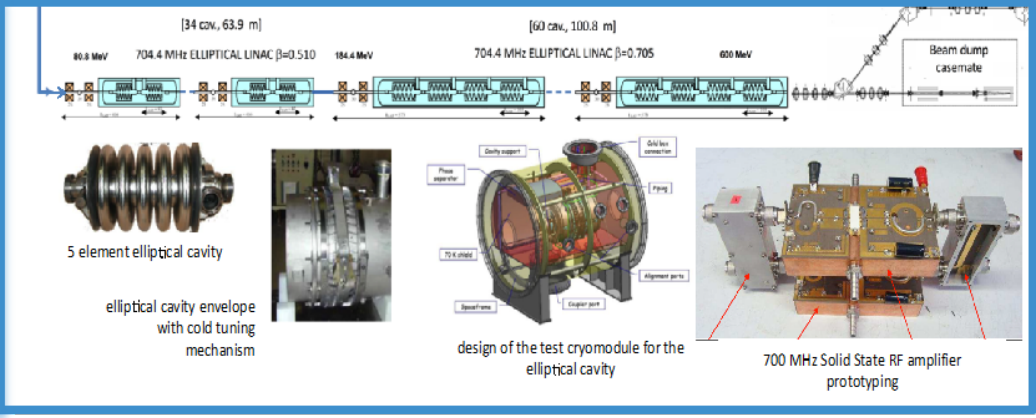
Benefits of phased approach:

- Reducing technical risk
- Spreading investment cost
- First R&D facility available in Mol end of 2024

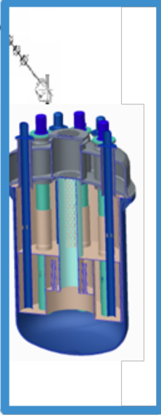
**Phase 1 – 100 MeV**




**Phase 2 – 600 MeV**

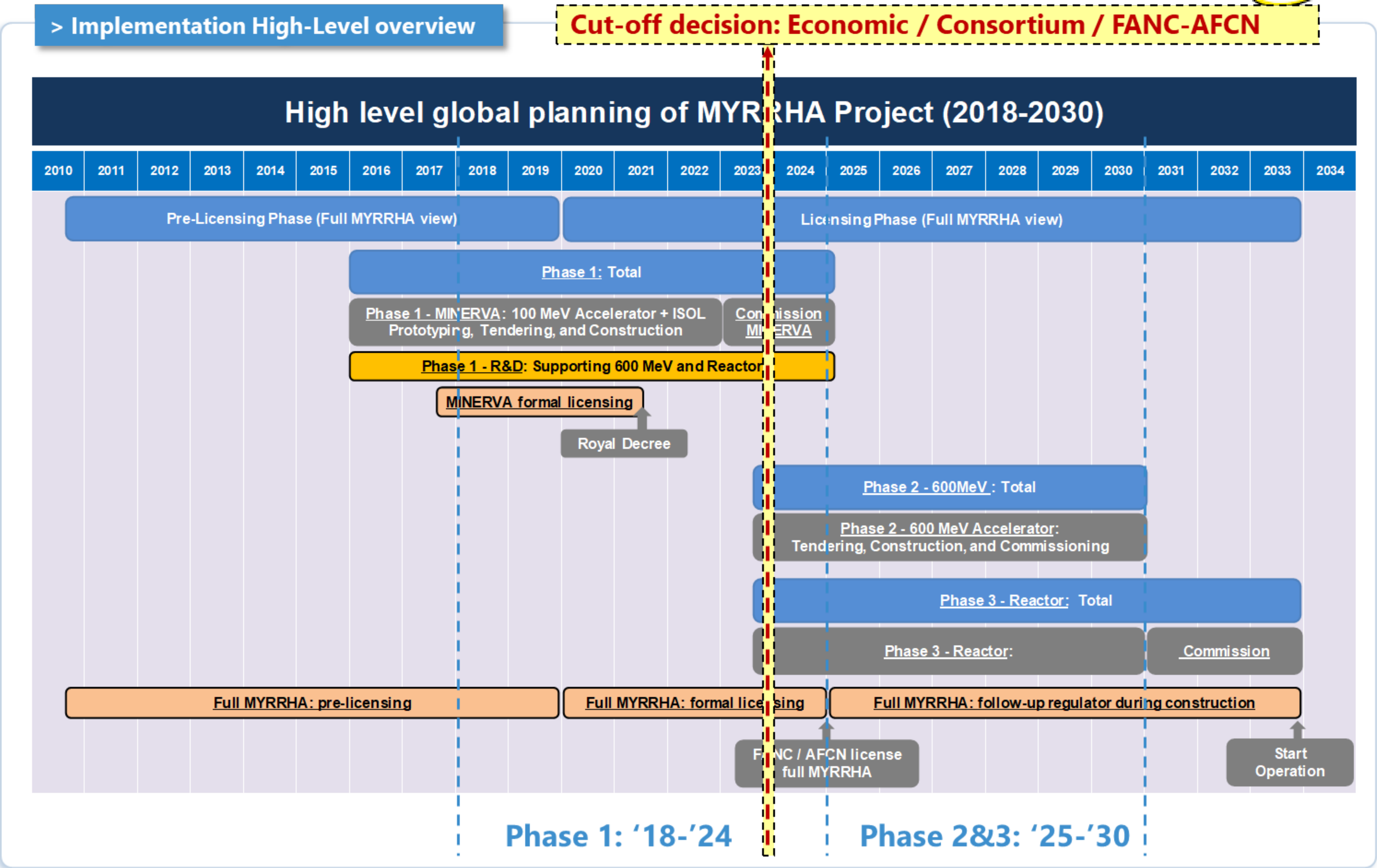



**Phase 3 – Reactor**



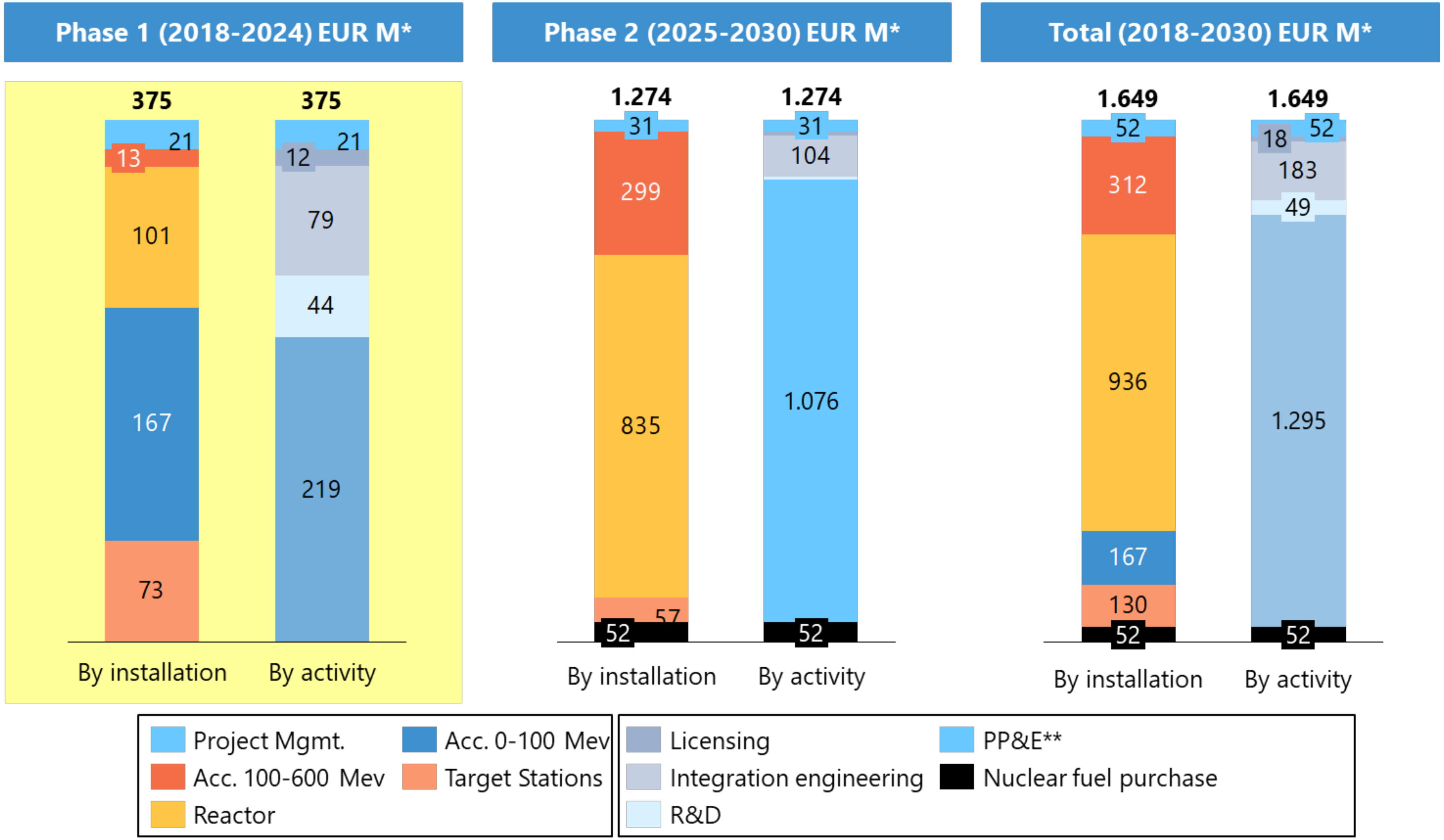
Source:SCK•CEN MYRRHA Project Team

# Phased implementation plan MYRRHA Project (2018-2030)




Source: SCK•CEN MYRRHA Project Team

# CapEx: MYRRHA Total investment budget (Summary)




Notes: *All numbers expressed in constant 2018 EUR  **PP&E = Property, Plant & Equipment
Source: SCK•CEN MYRRHA Project Team, MYRRHA Business Plan

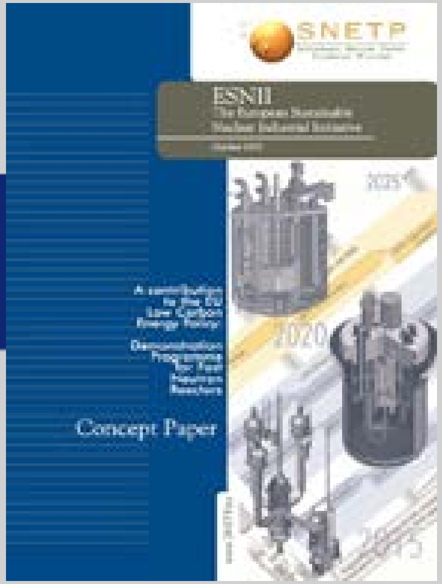
# MYRRHA is recognized in Europe to contribute to strategic objectives of both Energy and Knowledge economy

**Knowledge Economy**

**ESFRI**
European Strategic Forum for Research Infrastructure


MYRRHA

**Energy Independence**




**SET Plan**
European Strategic Energy Technologies Plan

| | |
|---|---|
| EIB InnovFin | MYRRHA is selected by the **European Investment Bank (EIB)** as a potential project for financing and benefits from advisory services from EIB InnovFin |
| Juncker Plan | MYRRHA is on the list of projects candidate to be financed by the **European Fund for Strategic Investments** (**EFSI**, also called **“Juncker plan”**) |

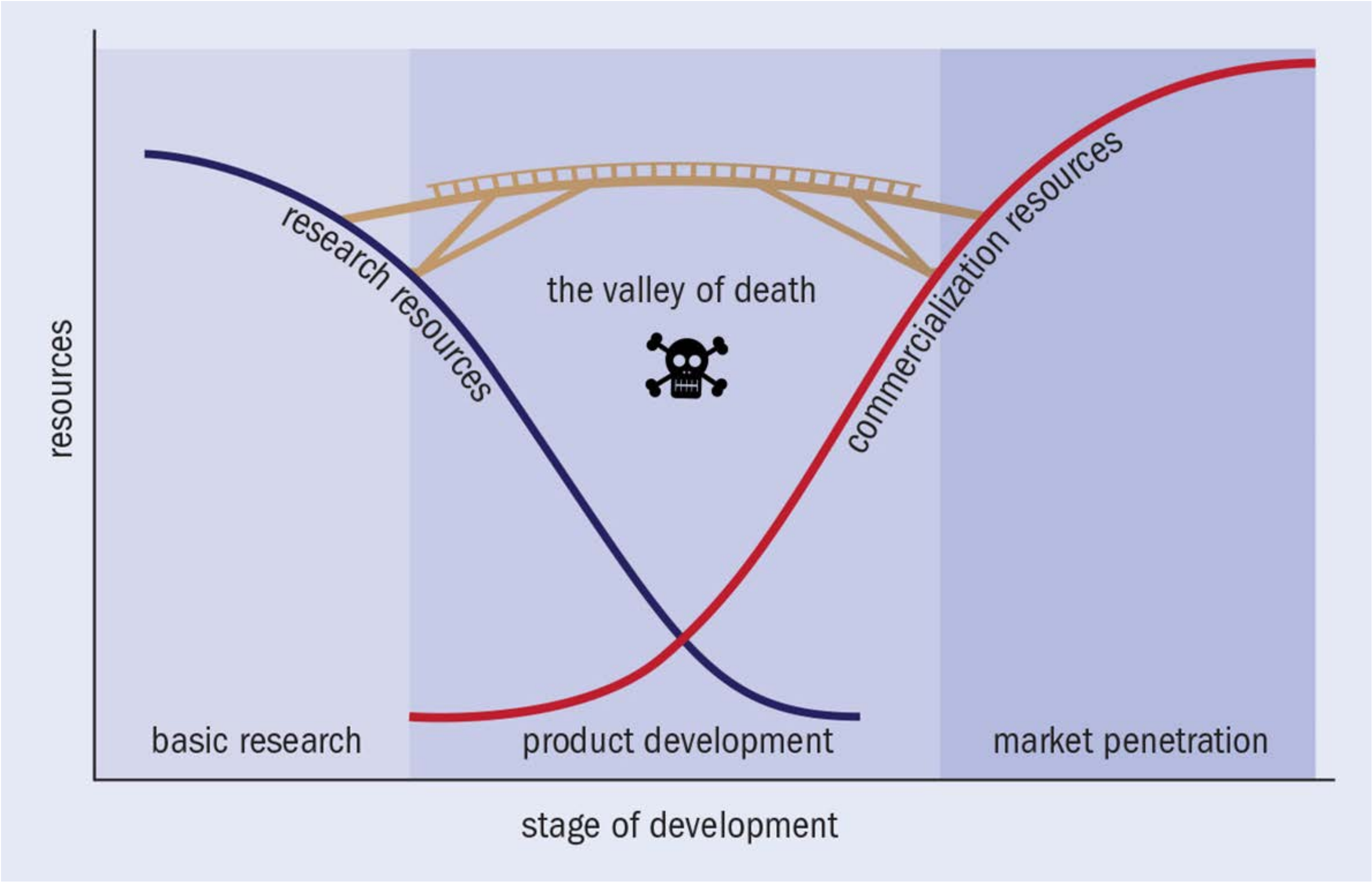
*Source: European Strategy Forum on Research Infrastructures (ESFRI), European Strategic Energy Plan (SET), EIB InnovFin, SCK•CEN MYRRHA Project Team*

# MYRRHA is embedded in an international R&D network

# Conclusions

- ADS is not anymore an “Emerging Nuclear Energy System”
- It has accomplished many impressive progresses in various fields:
  - Accelerator technology
  - Pb and Pb-Bi technology (many loops in BE, JP, IT, DE, ROK, CN, USA, …)
  - HLM instrumentation ($O_2$-meters, Flow meters, US-Visu, Sub-criticality monitoring, etc…)
  - Material behavior in HLM (corrosion, erosion LME, etc…)
  - ZPR experiments (FEAT/TARC, MUSE, YALINA, GUINEVERE, KUCA…)
  - Large Scale HLM reactor mock-ups (ESCAPE, CLEAR-S)
- What is then the danger for this technology ?
- **Succeed to cross the death-valley for moving from R&D enthusiasm compensating small money to pre-industrial scale needing large money, rigorous industrial approach and severe safety and licensing judgement**

# The valley of death for innovation




Not to succeed to cross the valley of death for moving from R&D enthusiasm compensating small money to pre-industrial scale needing large money, rigorous industrial approach and severe safety and licensing judgement

Innovation in Belgium for Europe and beyond
For sustainable & innovative nuclear energy and applications


Belgium decided to support MYRRHA at 40% and opens MYRRHA for international partnership

**SCK•CEN**
Studiecentrum voor Kernenergie
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
Operational Office: Boeretang 200 – BE-2400 MOL

# $4^{th}$ GIF Symposium

## 16-17 October 2018

at the $8^{th}$ edition of Atoms for the Future
UIC Paris, France

GEN IV International Forum℠

http://gifsymposium2018.gen-4.org/

Call for abstracts  Extended Deadline  - 31 March 2018

Track 1 & 2: Progress on Gen IV systems
Track 3: Human capital development
Track 4: Research infrastructures
Track 5: Safety and security
Track 6: Fuels and materials
Track 7: Advanced components and systems for Gen IV reactors
Track 8: Integration of nuclear reactors in low carbon energy systems
Track 9: Decommissioning & Waste Management
Track 10: Operation, Maintenance, Simulation & Training
Track 11: Construction of nuclear reactors

The symposium has **two major objectives**:

- to review the progress achieved for each system against the R&D goals of the 2014 Technology Roadmap Update.
- to identify the remaining challenges and associated R&D goals for the next decade necessary for the demonstration and/or deployment of the Gen IV systems, and the goal of establishing nuclear energy as a necessary element in the world's long-term sustainable carbon-free energy mix.



**MSc and PhD students, young professionals, policy makers and nuclear stakeholders are encouraged to participate**

GEN IV International Forum[SM]

# Upcoming webinars

| | | |
|---|---|---|
| 23 May 2018 | Proliferation resistance of Gen IV systems | Dr. Robert Bari, Brookhaven National Laboratory, USA |
| 07 June 2018 | Molten Salt Actinide Recycle and Transforming System with and without Th-U support: MOSART | Dr. Viktor Ignatiev, Kurchatov Institute, Russia |