Fuel Cycle Closure including P&T & SMRs

A game changer for the future of nuclear energy?

MYRRHA

as a corner stone of such a strategy

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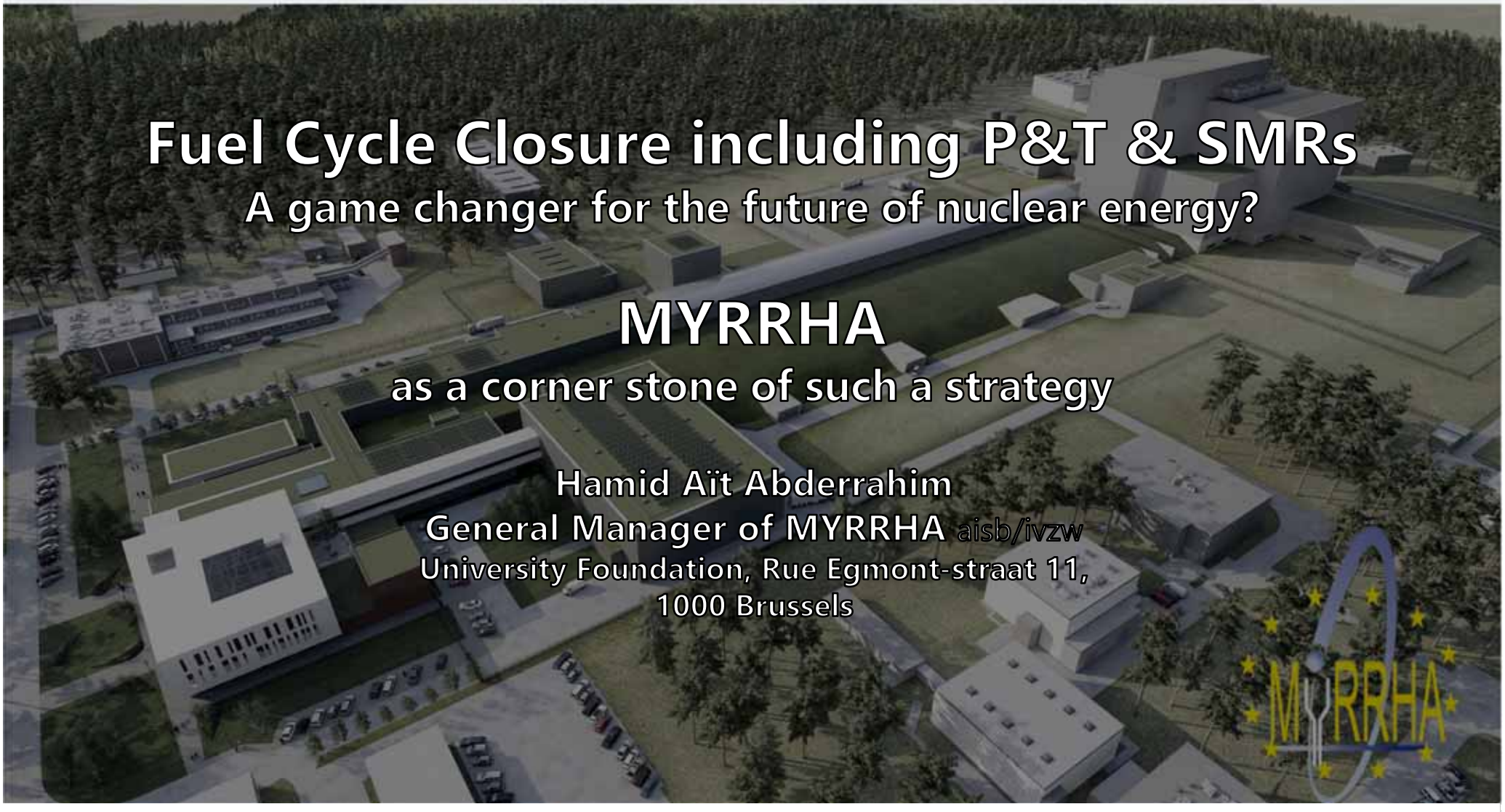


Meeting of the Energy Group of the European Physical Society- October 10-11, Brussels, Belgium

International context evolution
2015 -> Today

sing the fuel cycle and P&T beyond EU

- As a result of the NI2050 initiative launched in 2015 by the **OECD/NEA** for accelerating the innovation in the nuclear energy sector one of the subject retained is "**Demonstration of Fuel Cycle Closure Including Partitioning and Transmutation (P&T) Towards Industrialization by 2050 (TF-FCPT)"**
- A dedicated Task Force under the Nuclear Science Committee has been created beginning 2021 and has been given a mandate for issuing the "High level report" meant for governmental authorities and decision makers for **launching large scale demonstration programmes**
- The report of the Task Force is expected for **end-2022/beginning 2023**

Source:

Overview of the Task Force FCPT

Scope

- Existing and emerging **technologies** for **advanced transuranic (TRU) management strategies** – e.g. Pu multi-recycling and MA transmutation – such as advanced reprocessing and fuel fabrication, transmutation systems and cross-cutting issues

Main objectives

- Stress the need and the urgency to increase the Technology Readiness Level (TRL) in advanced fuel cycles and P&T technologies **to move from research and development (R&D) to pre-industrial scale demonstration**
- Identify **R&D and infrastructure needs and gaps** and provide recommendations on **priority actions** to be implemented
- Provide policy-makers with information for future decisions as regards technologies that would **enable the industrialisation** of fuel cycle closure and P&T **from 2050 on**
- **Provide guidance on establishing a Joint Undertaking on experimental demonstration**

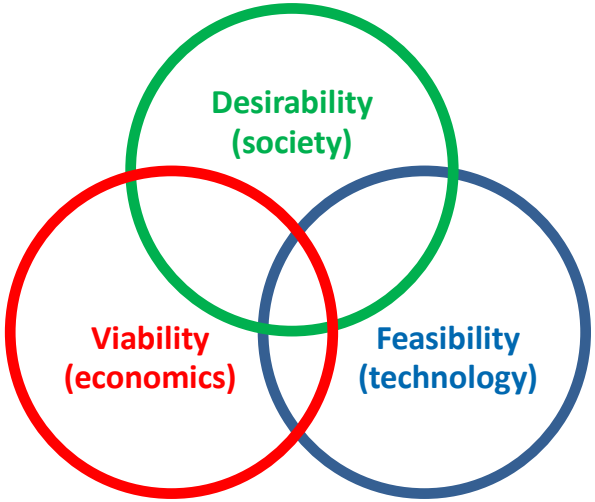
Deliverables

- A **"High-level Report"** aiming to be a comprehensive reference covering **technological, economic and societal aspects**
- A **library of documents** addressing the benefits of P&T, the technical challenges and developments in the field

Overview of the Task Force FCPT Report

Mandate and structure of the report

- Address the 3 dimensions that can be decisive for decision makers :
  1. Why ?
  2. What ?
  3. How much ?



**Suspended following OECD Council's decision – effective 11 May 2022*

Content and structure of the "High-level Report"

#	Section
	Foreword
	Executive Summary
1	**Introduction**
2	**Advanced separation of conventional used fuels** *Beyond PUREX for spent fuels – including MOX – from current NPP fleets (PWR/BWR)*
3	**Advanced fuel fabrication and performance**
4	**Transmutation systems** *Ensure overall consistency among systems considered*
	- Liquid Metal Fast Reactors (LMFRs) (SFR and LFR)
	- Accelerator-driven systems (ADSs)
	- Molten Salt Reactors (MSRs)
5	**Advanced fuel reprocessing** *For transmutation fuels*
6	**Advanced fuel technological aspects** *Cross-cutting aspects: transportation, cooling, and handling*
7	**Economic aspects**
8	**Societal aspects**
9	**Recommendations and conclusions**
	Glossary
	Appendices *Including accessible introductions to the technical areas discussed*
	References

- Review technology "building blocks"
- Identify of R&D needs and priority actions to increase the TRL up to pre-industrial demonstration
- One specific working subgroup for each "building block" with topical leader(s) to coordinate work and ensure interconnection with other chapters

- Perform an economic analysis of the pre-industrial phase needed for the closure of the nuclear fuel cycle, focusing on the need for and the benefit of a pre-industrial demonstration (reducing uncertainties, and option value, informing a decision…)
- One specific working subgroup, gathering experts from NDC/NTE and Task Force members

- Provide an overview of societal aspects of the closure of the nuclear fuel cycle, addressing the public perception, worries and concerns, hence acting on decision-makers
- To be reviewed by the Forum on Stakeholder Confidence

Quantities at different stages for 1GWe PWR

220 t depl. UF_6 + 32 t enrich. UF_6

250 t nat. UF_6

45 to 50,000 t ore

24 t recover. UO_2 (1% ^{235}U)
230 kg Pu for recycling
750 Vitrified HLW (FPs & MAs)

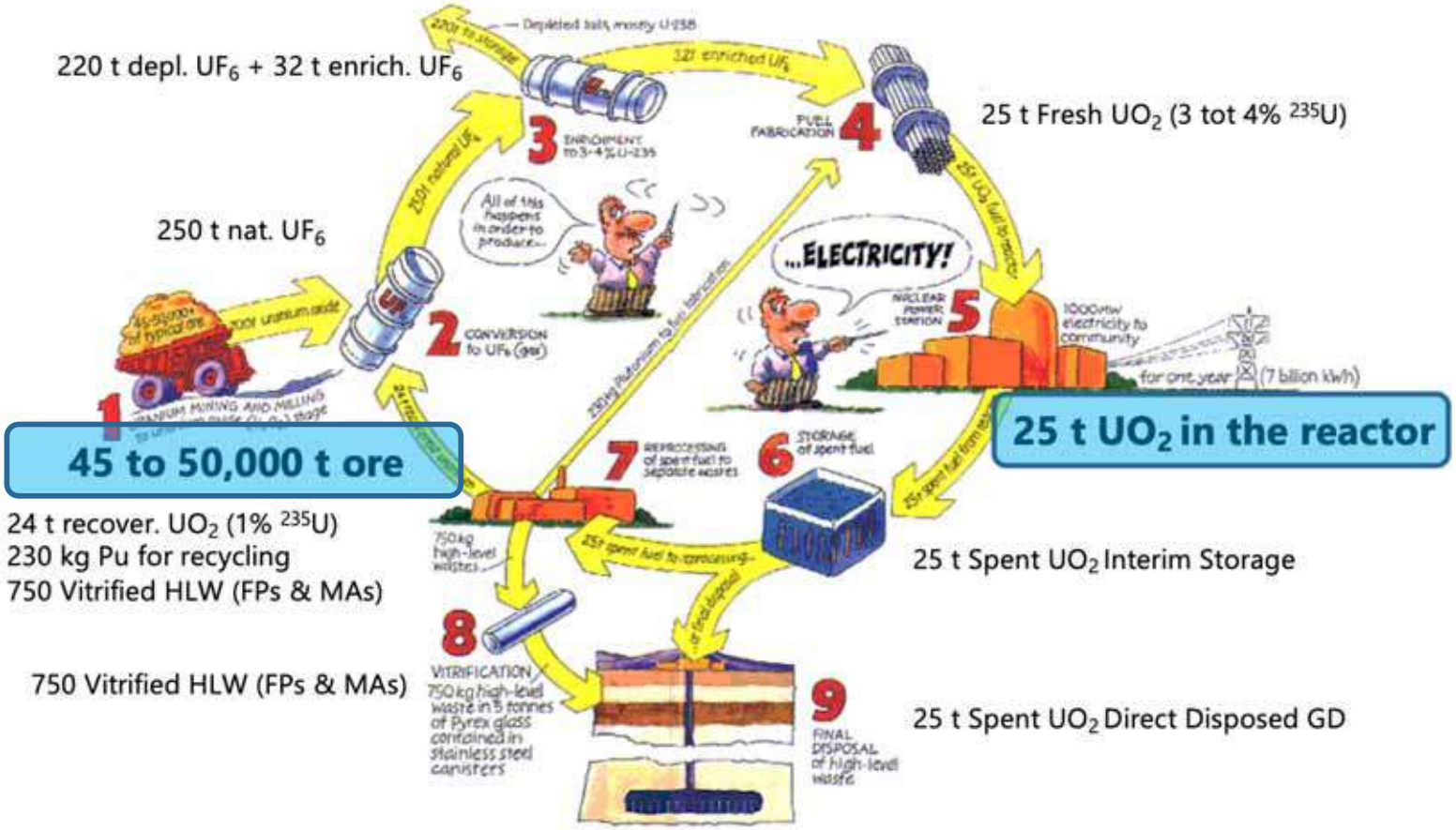
750 Vitrified HLW (FPs & MAs)

25 t Fresh UO_2 (3 tot 4% ^{235}U)

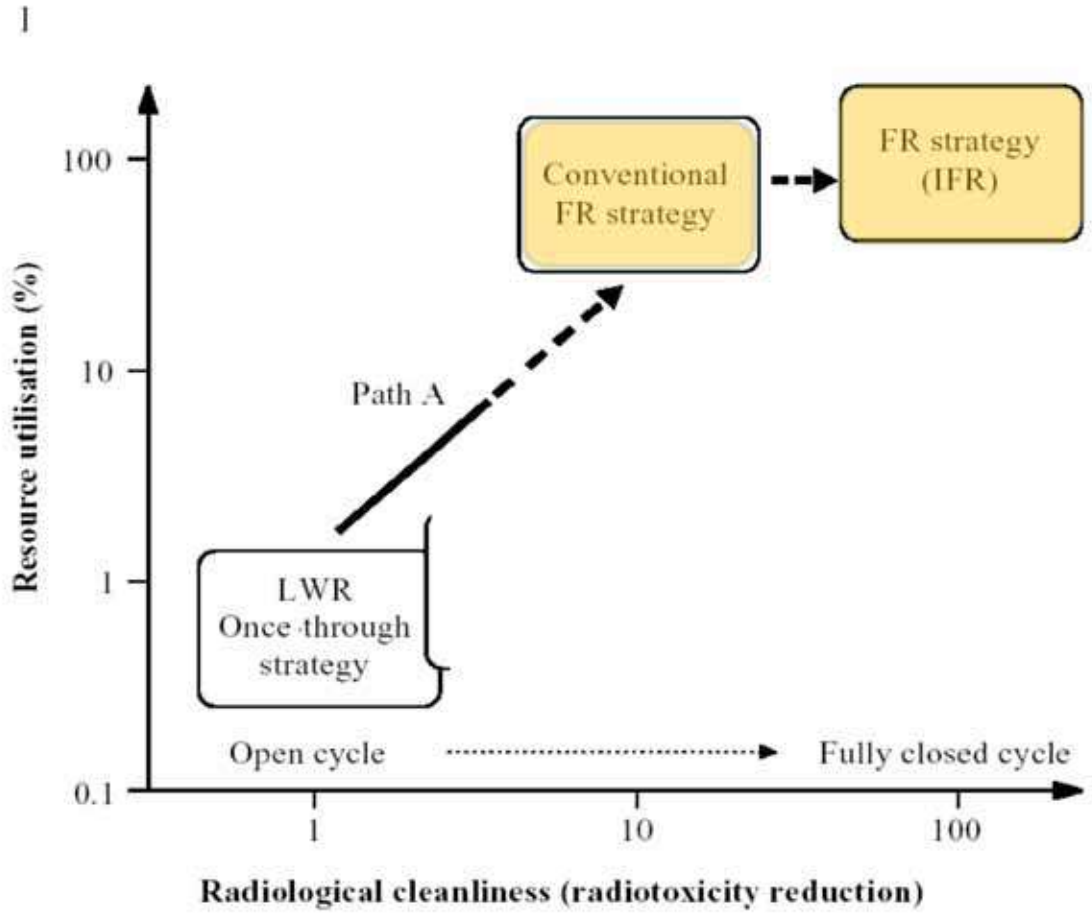
25 t UO_2 in the reactor

25 t Spent UO_2 Interim Storage

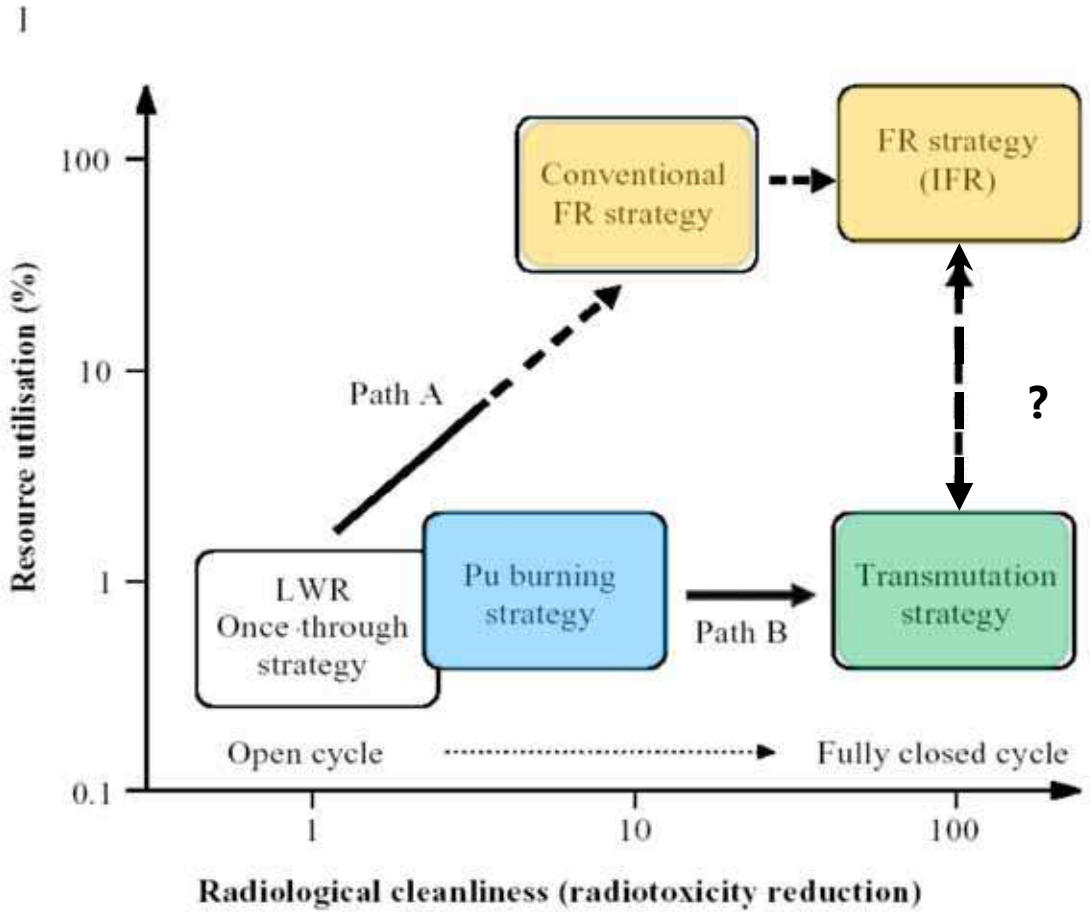
25 t Spent UO_2 Direct Disposed GD



Fuel Cycle or Fuel Cycles



Fuel Cycle or Fuel Cycles



Source:

What is the most important part of the fuel cycle for the NE environmental footprint?

DE LA RECHERCHE À L'INDUSTRIE

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www.cea.fr

SCK•CEN ACADEMY
FOR NUCLEAR SCIENCE AND TECHNOLOGY

Van Geen SCK-CEN chair

❺ Nuclear energy environmental footprint

Is nuclear energy so little environmental-friendly ?

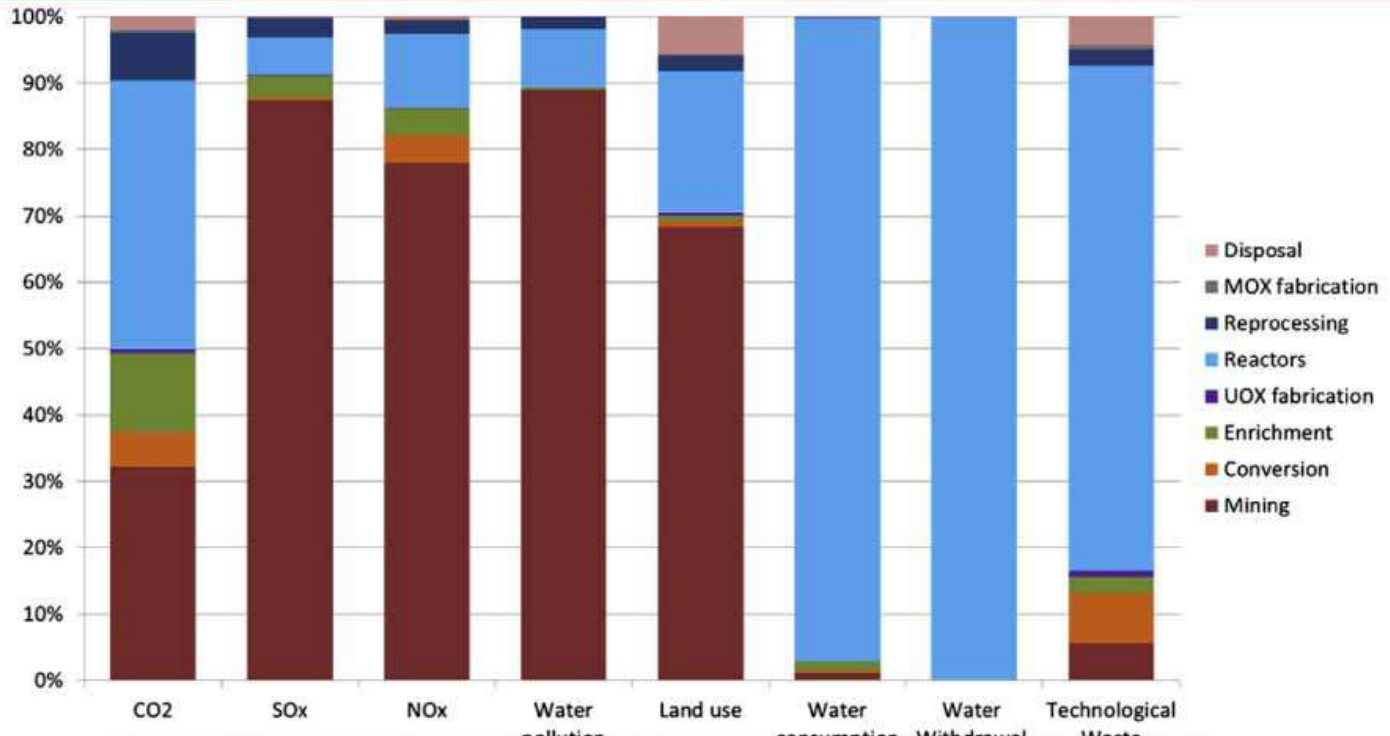
Prof. Christophe POINSSOT
Head of the Research Department on mining and fuel recycling processes, Nuclear Energy Division, CEA
Professor in Nuclear Chemistry, INSTN
christophe.poinssot@cea.fr

With the contribution of **Stéphane BOURG**

Source:

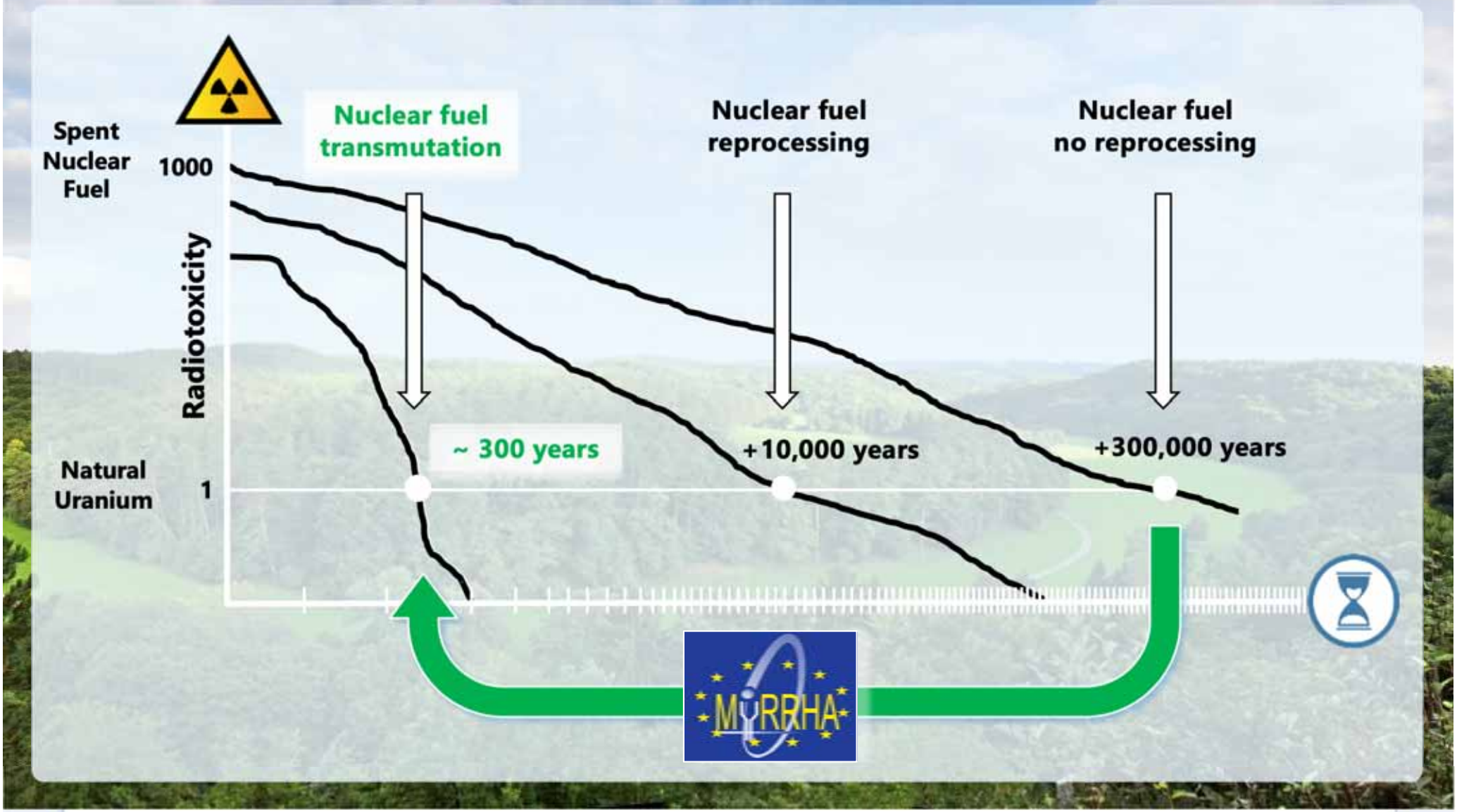
Chap.II – results of the current French cycle

The general environmental indicators of the TTC



	CO2	SOx	NOx	Water pollution	Land use	Water consumption	Water Withdrawal	Technological Waste
	(gCO_2 eq/kWh_e)	(mg/kWh_e)	(mg/kWh_e)	(mg/kWh_e)	(m^2/GWh_e)	(L/MWh_e)	(L/MWh_e)	(g/MWh_e)
	5,29	16,276	25,30	287,53	211,0	1507	72364	93,9

Source: Christophe POINSSOT (CEA)



European Strategy for P&T (2005) with objective of possible industrialisation from 2040

rategy 2005: *"The **implementation of P&T** of a large part of the high-level nuclear wastes **in Europe needs the ion of its feasibility at an "engineering" level**. The respective **R&D** activities could be **arranged in four "building blocks"**:*

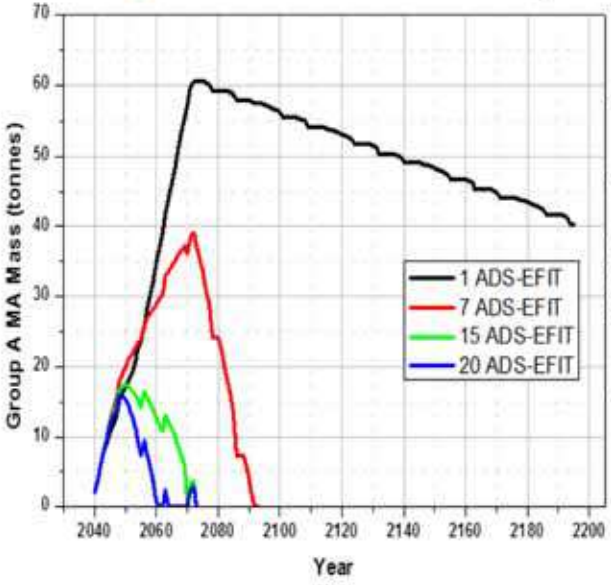
	P&T building blocks	Description	Name & Location
1	**Partitioning**	▪ Demonstrate capability to process a sizable amount of **spent fuel** from commercial Light Water Reactors to **separate** plutonium, uranium and minor actinides	▪ Atalante (FR)
2	**Fuel production**	▪ Demonstrate the capability **to fabricate** at a semi-industrial level the **dedicated fuel** needed to load in a dedicated transmuter	▪ JRC-ITU (EU)
3	**Transmutation**	▪ **Design and construct one or more dedicated transmuters**	▪ **MYRRHA (BE)** ▪ **ASTRID (FR)**
4	**MA Fuel Partitioning**	▪ Specific installation to process fuel unloaded from transmuter ▪ Not necessarily the same as type to process original spent fuel unloaded from commercial power plants	

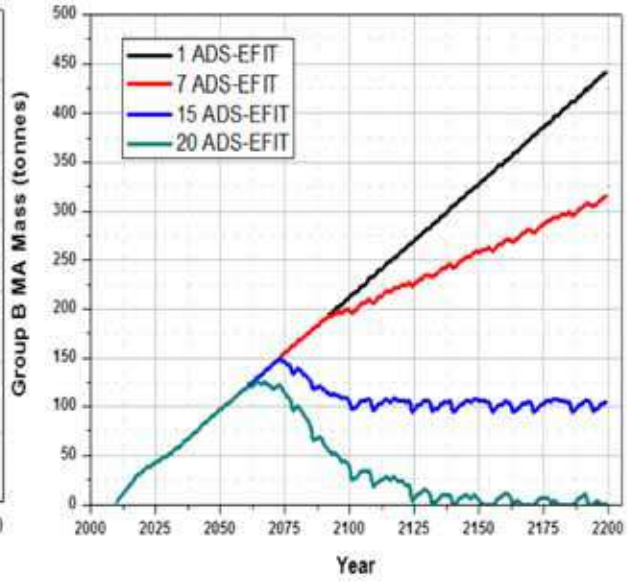
The European Commission contributes to the 4 building blocks and fosters the national programmes towards this strategy for **demonstration at engineering level**.

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

Shared & efficient solution for Minor Actinides management
EU case with 144 power reactors using EFIT 400 MWth

- **Europe should go for a regional approach** (see PATEROS, ARCAS)
- **Countries with different nuclear energy policies to collaborate together**
  - Countries willing to continue Nuclear Energy
  - Countries willing to develop fast reactor systems
  - Countries in nuclear phase out, interested in Partitioning &Transmutation (P&T)





Source: [TBD]

15 EFIT * 400 MWth = 6000 MWth
For all EU HLW treatment

Doel (BE) = 9000 MWth
Tihange (BE) = 9000 MWth

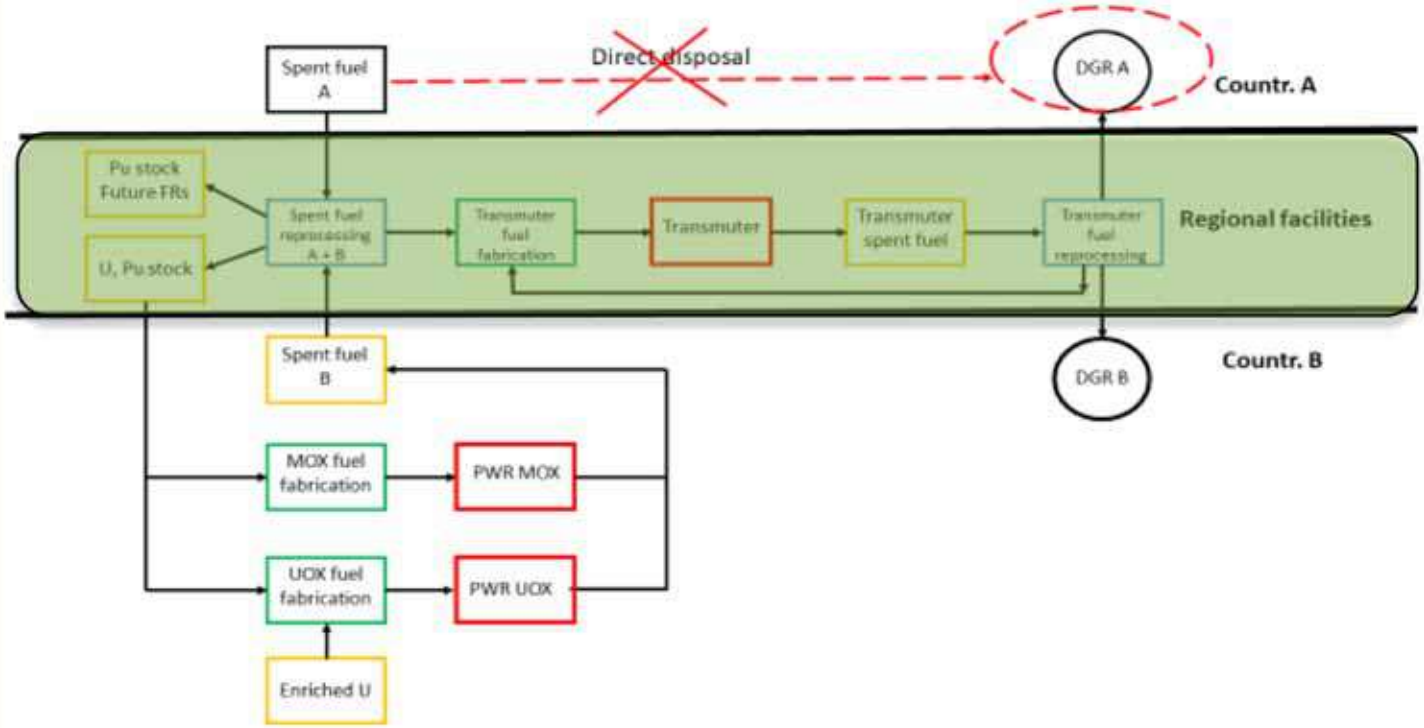
Gravelines (FR) = 17118 MWth

Zaporizhzhya (UA) = 18000 MWth

Bruce (CND) = 18702 MWth

Kashiwazaki-Kariwa = 23895 MWth

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

FP6 PATEROS project: Scenario 1 objective: elimination of A's spent fuel by 2100
A = Countries Phasing Out, B = Countries Continuing

MYRRHA: ACCELERATOR DRIVEN SYSTEM

PHASE 1

100 MeV

LINEAR ACCELERATOR

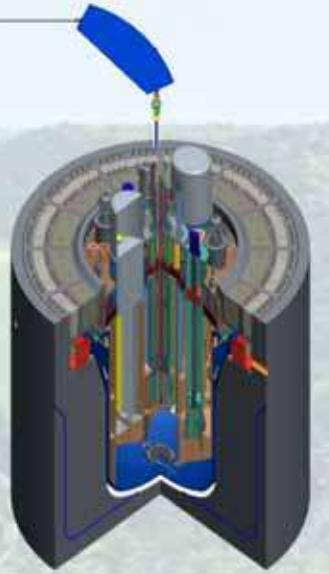
PHASE 2

600 MeV

- ✓ TRANSMUTATION DEMONSTRATION
- ✓ ADS AT PRE-INDUSTRIAL SCALE
- ✓ FLEXIBLE IRRADIATION FACILITY

PHASE 3

REACTOR



Accelerator Driven System: intrinsic safety

Belgian Government decision of 7 September 2018

Confirmed on 23 July 2021
(+ creation of MYRRHA NPO)

Decision to build MYRRHA as large new research infrastructure in Mol, Belgium

Belgium **allocates** € 558 m for 2019-2038

- **2019-2026: construction of MINERVA (linac 100 MeV + PTF & FPF)**
- 2019-2026: design, R&D and licensing for Phases 2 (extended linac 600 MeV) & Phase 3 (reactor)
- **2027-2038: MINERVA operations costs**

Establishment of **international non-profit organisation**

MYRRHA AISBL/IVZW

Decided 23.07.2021
Created 17.09.2021

Government support for establishing MYRRHA partnerships

Belgium appoints tutorship ministers to promote and negotiate international partnerships

Source: Belgian minister of Energy, Environment & Sustainable Development

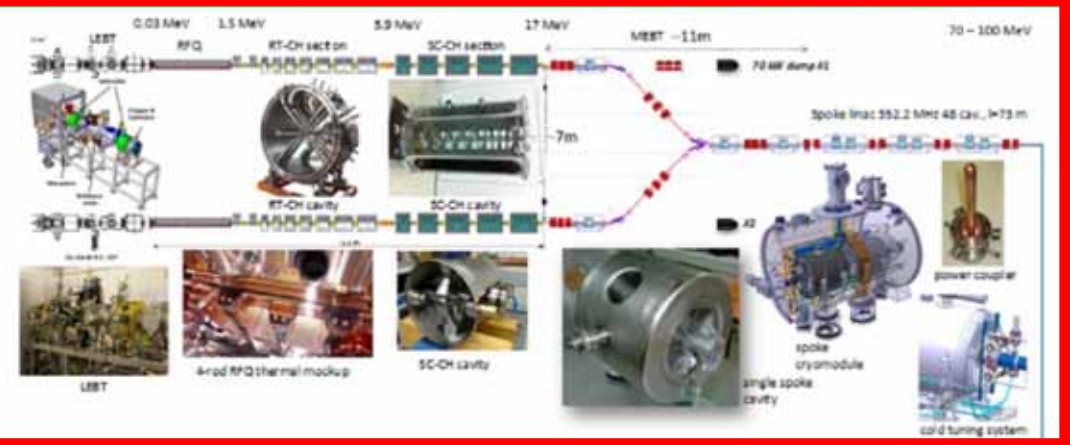
MYRRHA'S PHASED IMPLEMENTATION STRATEGY

Benefits of the phased approach:

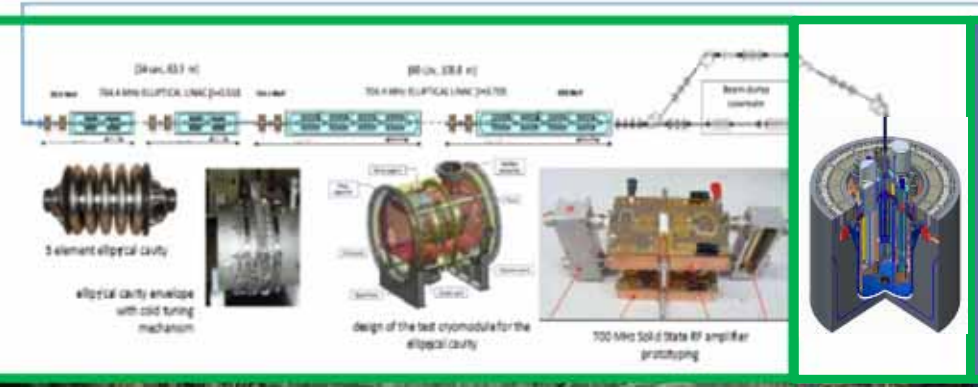
- already a first operational facility available in Mol at **end of 2026**
- spreading the investment costs
- successful milestone then next step >> reducing technical & financial risks

UNDER CONSTRUCTION

Phase 1 – 100 MeV + Proton Target Facility



Phase 2 – 600 MeV



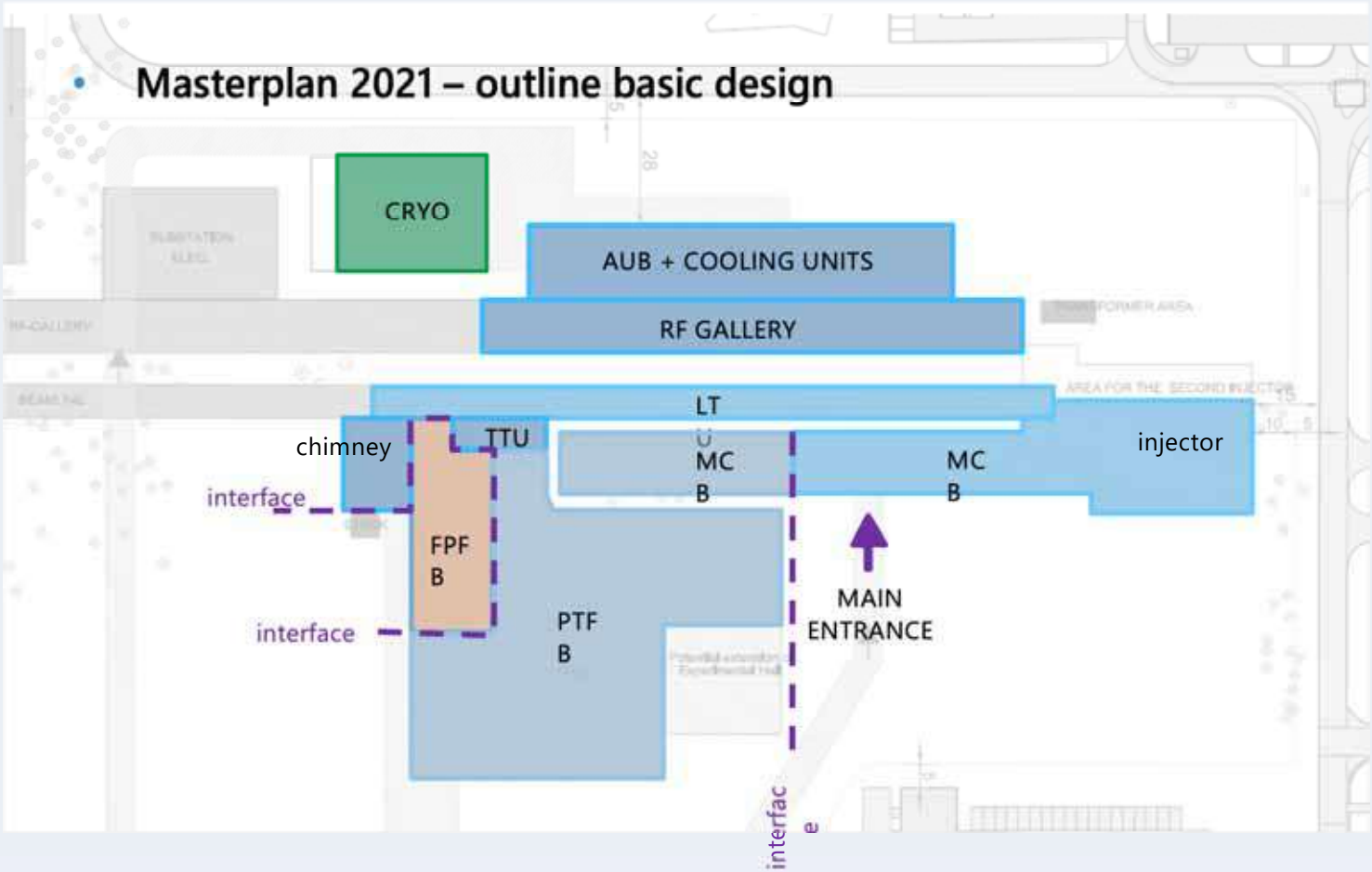
Phase 3 – Reactor

Source: SCK CEN MYRRHA Project Team

MINERVA implementation by 2027

- Overall architecture frozen, main internal floor plan decisions taken
- PTF design close to level of ACC, FPF catching up

Design status



= ACC

= PTF

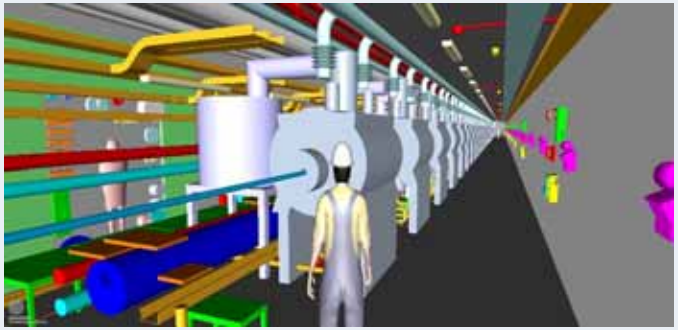
= FPF

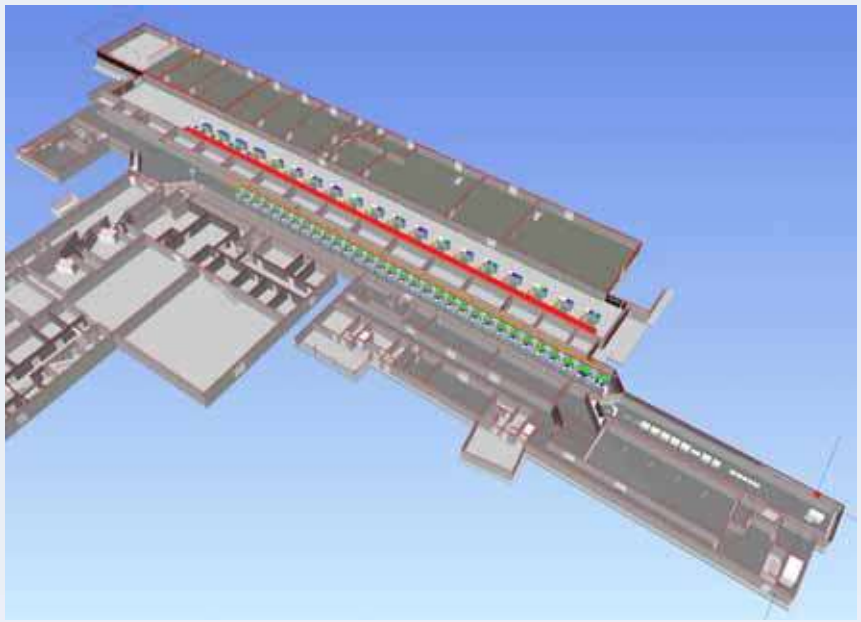
= AUXILIARY

PTFB: PTF Building
FPFB: FPF Building
TTU: Transfer TUnnel
MCB: MINERVA Central Building
FEB: Front-End Building
LTU: LINAC TUnnel
CRYO: Cryo-plant
AUB: Accelerator Utilities Building

NF ACC

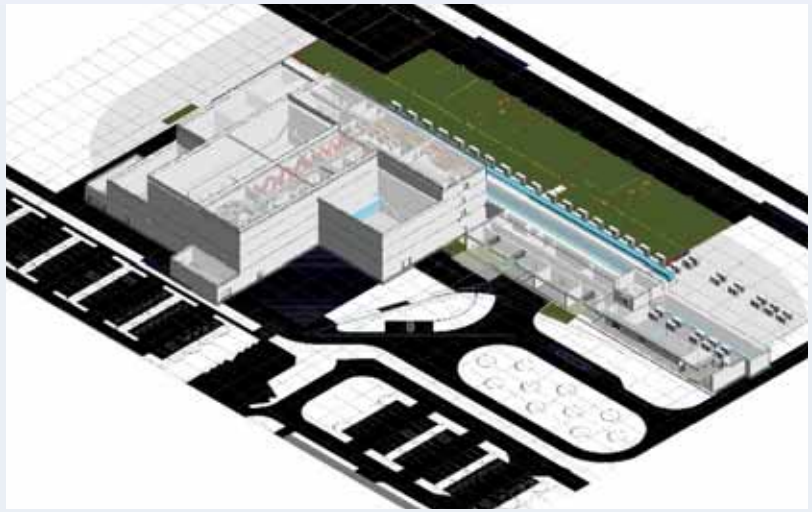
- **Outline Basic Design phase**
  - 3D data model
    - determines minimum level of detail (LOD 100) of all SSC
    - links ‘all’ information
    - tool for integration of SSC

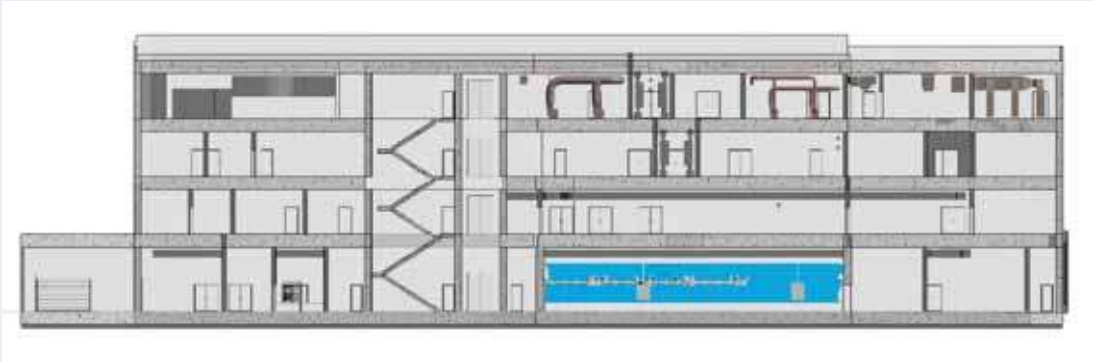


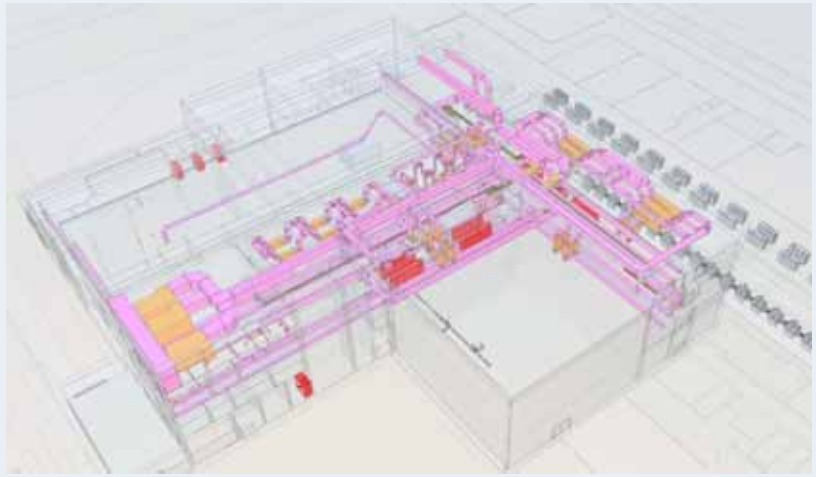


NF PTF

- **Conceptual Design phase**
  - 3D data model
    - minimum LOD 100, higher level reached
    - primary systems included







MYRRHA Reactor: implementation in 2036

Objectives = transmutation + radioisotopes + fusion material R&D + Fission technology platform

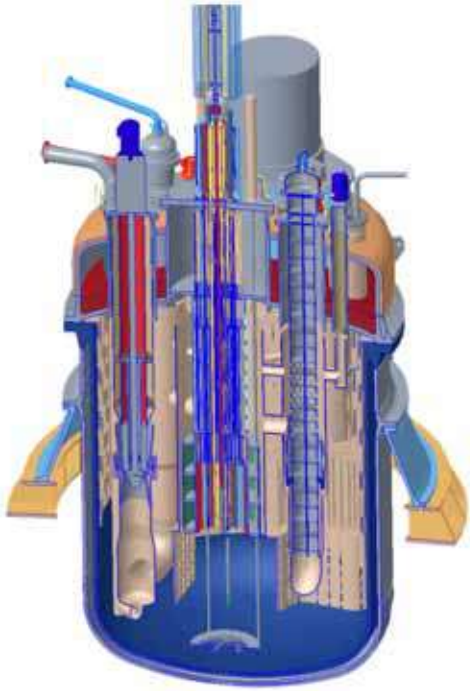
Source:

MYRRHA REACTOR HIGHLIGHTS

MYRRHA reactor primary design Rev. 1.8, frozen end 2020

- Integrated Pool-type concept with LBE coolant
- Fuel assemblies: hexagonal bundles of cylindrical wire-spaced fuel pins (MOX fuel 30wt.% Pu)
- 4x heat exchangers: double-walled with leak detection; water/steam on secondary side
- 2x primary pumps: vertical shaft mixed-flow design
- Bottom core loading: single in-vessel fuel handling machine (IVFHM)
- Safety vessel integrated into the primary vessel

Parameter	Unit	Value
Maximum core power	MW_{th}	64
Maximum heat sink rated power	MW_{th}	70
Shutdown state LBE temperature	°C	200
Maximum core inlet LBE temperature	°C	220
Maximum average hot plenum LBE temperature	°C	270



MYRRHA International nonprofit organisation

MYRRHA AISBL: separate legal entity needed to find external partners/investors

Responsability:

SCK CEN

- Design & build MINERVA
- Conduct R&D for phases 2 ACC-600 & 3 MYRRHA Reactor
- Obtain licenses for Phase 1 and later on for Phases 2 & 3
- Being the nuclear operator of MYRRHA/MINERVA

MYRRHA

- Establish the MYRRHA International Consortium
- Guarding the overall scope of MYRRHA programme
- Receiving & managing funds for the realization of MYRRHA/MINERVA

MYRRHA AISBL/IVZW: Membership

Member categories

- **Founding members**: Belgian State and SCK CEN
- **Contributing members** open for:
  - Countries
  - National Research Organisations, industries of a country (2021)
  - International Institutions or Associations (2021)

Rights & Obligations

- Contribution in-cash or in-kind to become contributing member
- from 40 M€ contribution:
  - 1 Director in the Board of Directors (overall maximum of 4)
  - 1 Voting right in the General Assembly per 40 M€ contribution
- Annual membership fee <100 k€ on proposal of BoD (right to nominate a representative in the MYRRHA **I**nternational **S**cientific and **T**echnical **A**dvisory **B**oard (ISTAB)

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Where is the link to SMRs ?

- **SMR-SFR**
- **SMR-LFR**
- **Link ADS ⇔ SMR-LFR**
- **SMR-MSR**

Link ADS ⇔ SMR-LFR in Belgium
celebration of 70th anniversary of SCK CEN on May 24, 2022

Source:

Let's create a better tomorrow!

SCK CEN
Belgian Nuclear Research Centre

Stichting van Openbaar Nut
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