Nuclear energy contribution to energy transition
Role of MYRRHA in this perspective

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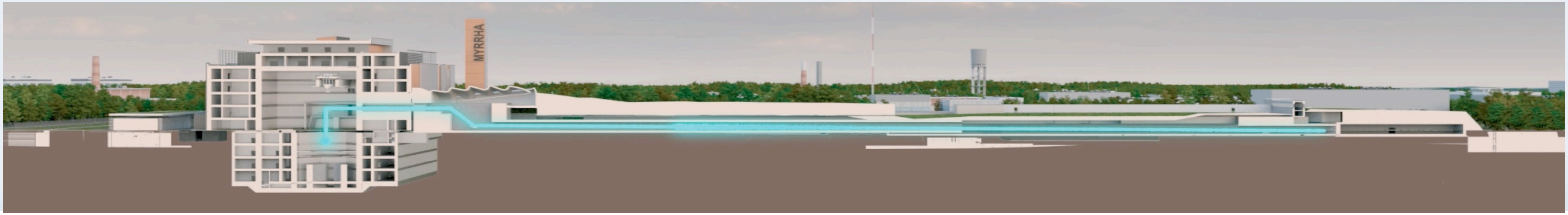


Workshop «Transizione energetica e sviluppi tecnologici: a che punto siamo?», NFN Laboratori Nazionali del Sud, Catania (IT), 21-22 February 2024

Introduction

- Nuclear energy as part of the energy mix to achieve the energy transition towards CO_2 neutral society by 2050 is regularly mentioned in the IPCC, IAEA and IEA reports **but rarely said in the general media (nuclear bashing ??).**
- Average lifecycle GHG emissions for electricity production from nuclear energy (6-10 g CO_2[eq]/kWh):
  - comparable to the values of hydropower and windmills.
  - about 20 times less than natural gas
  - and 30 to 40 times less than coal.
  - Therefore, we declare that nuclear energy can be part of the future energy-mix but we need rapidly to improve the paradigm
- End 2022, 443 nuclear reactors are in operation in 32 countries and 52 are under construction. Nuclear electricity represents 10% worldwide, 19,4% for USA and more than 25% for EU, 48% for BE (01.2023).
- In the last COP28 in Dubai, finally 22 countries declared openly to commit towards nuclear energy as part of their energy mix for mitigating climate change & Global warming (x3 installed nuclear power by 2050 !!)

Source:

At the Spring Annual Meeting (April 17-21, 2023) of American Physical Society it was said :

- We need to go towards SMRs and come with acceptable solutions for nuclear waste
- To have the innovative nuclear energy systems (SMRs) achieving industrial deployment we need:
  - **Establishing an economic viability & competitiveness**
  - **Guaranteeing the safety of the innovative system**
  - Creating a nuclear supply chain including for fuel (HALEU)
  - Delivering beyond present electricity application (Heat, H_2, fresh H_2O)
  - **Reestablishing capabilities and competences of Large projects Mgt**
  - **Establishing a new regulatory Framework**
  - **Showing societal acceptation**
  - **Meeting security and safeguard regulations & requirements**
  - **Dealing with the nuclear waste in agreement with the citizens**
  - Establishing a world market

Source:

Aspects related to Fuel Cycle and P&T

Fuel Cycle or Fuel Cycles

U_{nat} = 99,3% ^{238}U + 0,7 % ^{235}U

Full Fuel Recycling ➔ 100/0,7

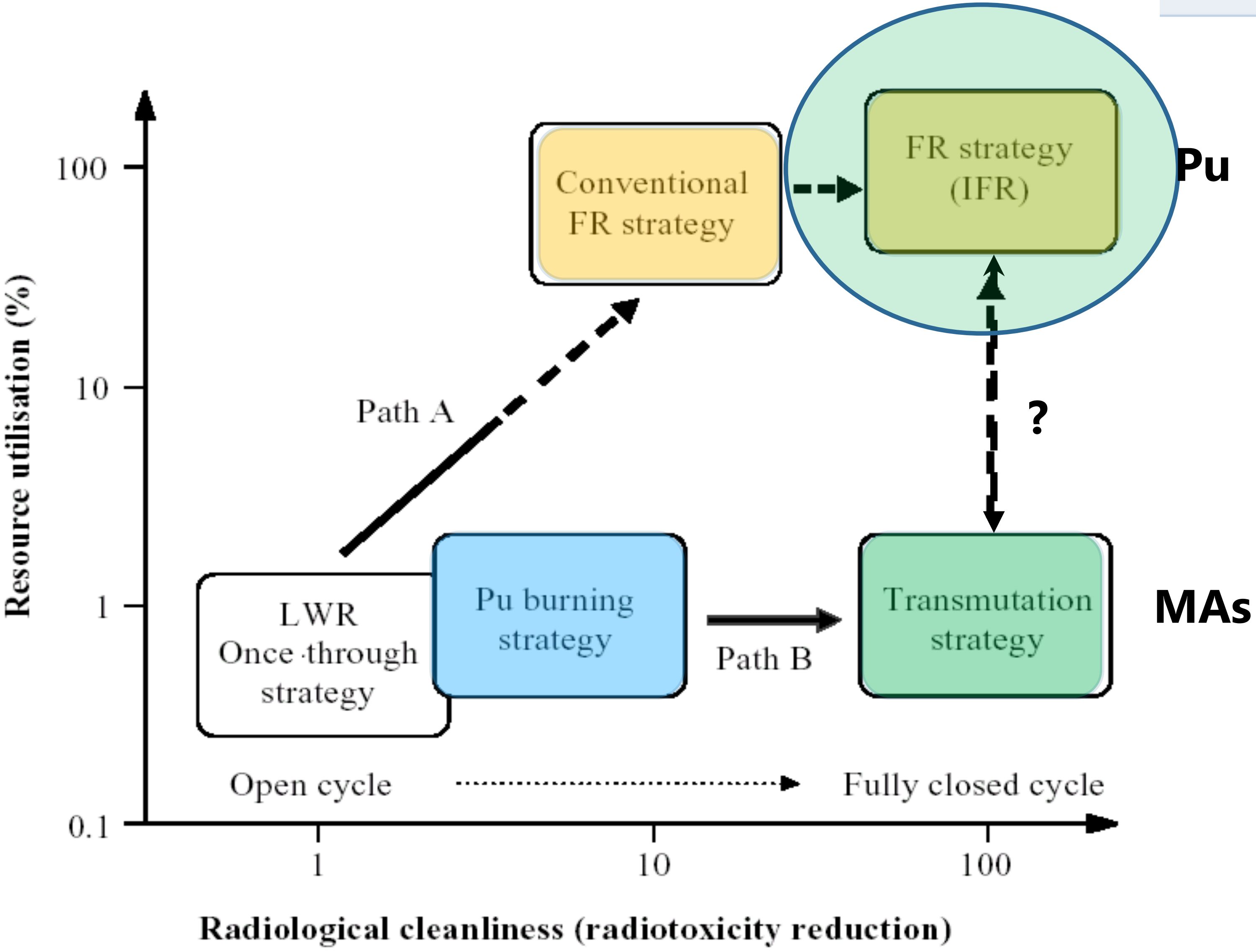
In theory we can retrieve then 145,82 more energy by using Fast Reactors than in Thermal ones (in practice we target 100)

Route towards sustainability

In a later stage why not Th (5X more abundant than U)

20,000 + 100,000 Years !

We need to get here



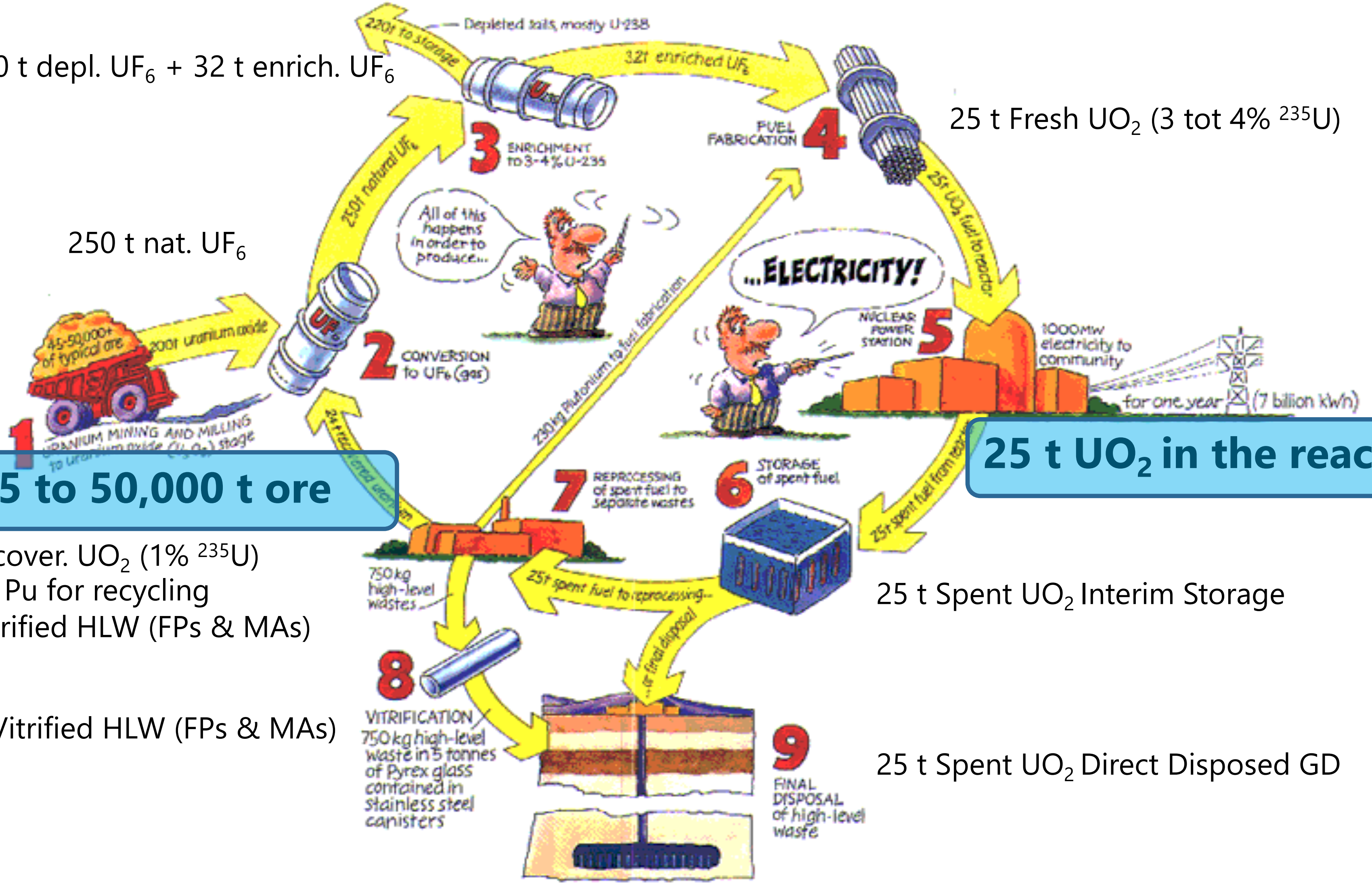
MYRRHA

Quantities at different stages for 1GWe PWR

220 t depl. UF_6 + 32 t enrich. UF_6

250 t nat. UF_6

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



45 to 50,000 t ore

25 t UO_2 in the reactor

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

25 t Spent UO_2 Interim Storage

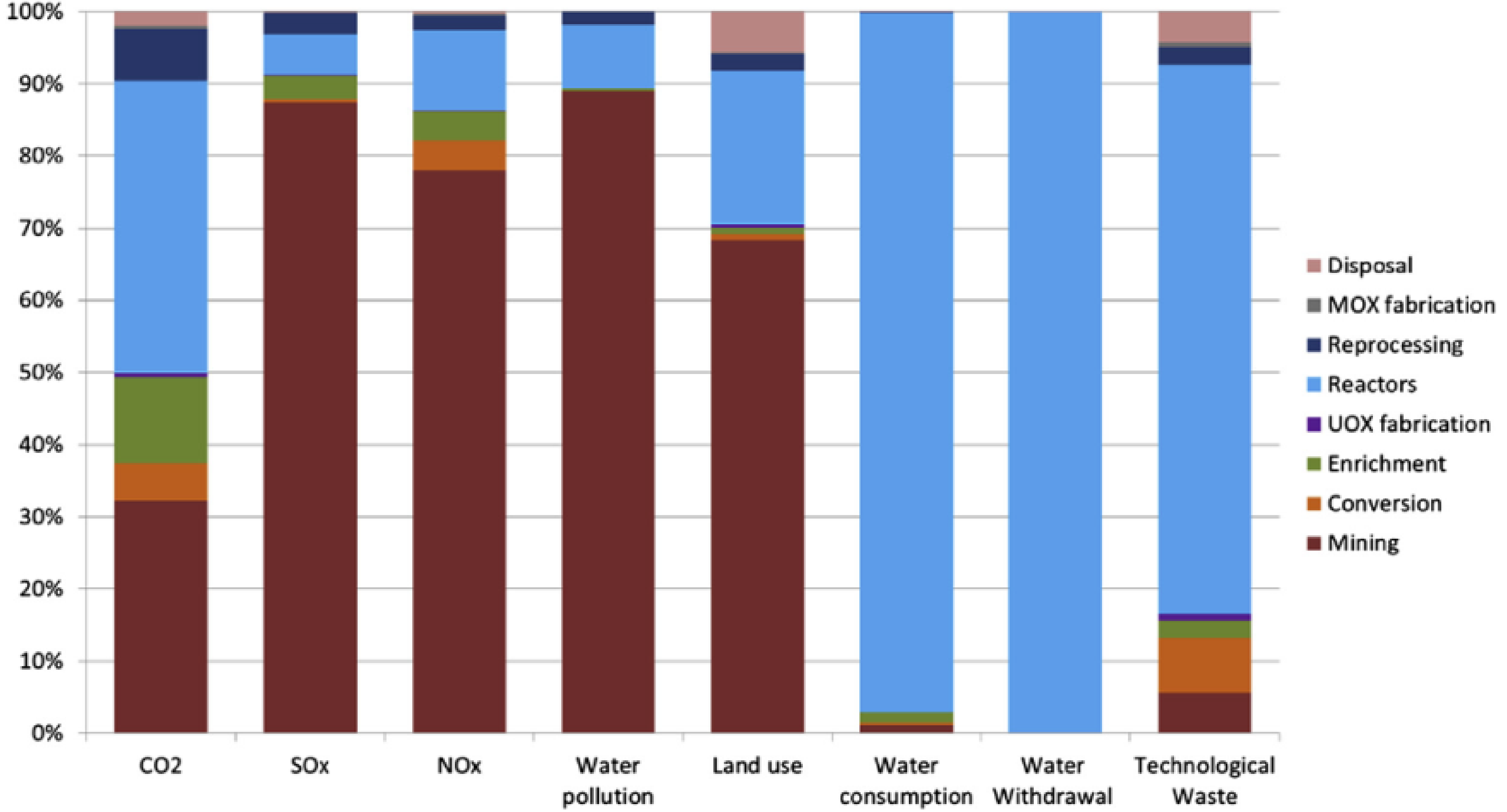
750 Vitrified HLW (FPs & MAs)

25 t Spent UO_2 Direct Disposed GD

Source:

Chap.II – results of the current French cycle

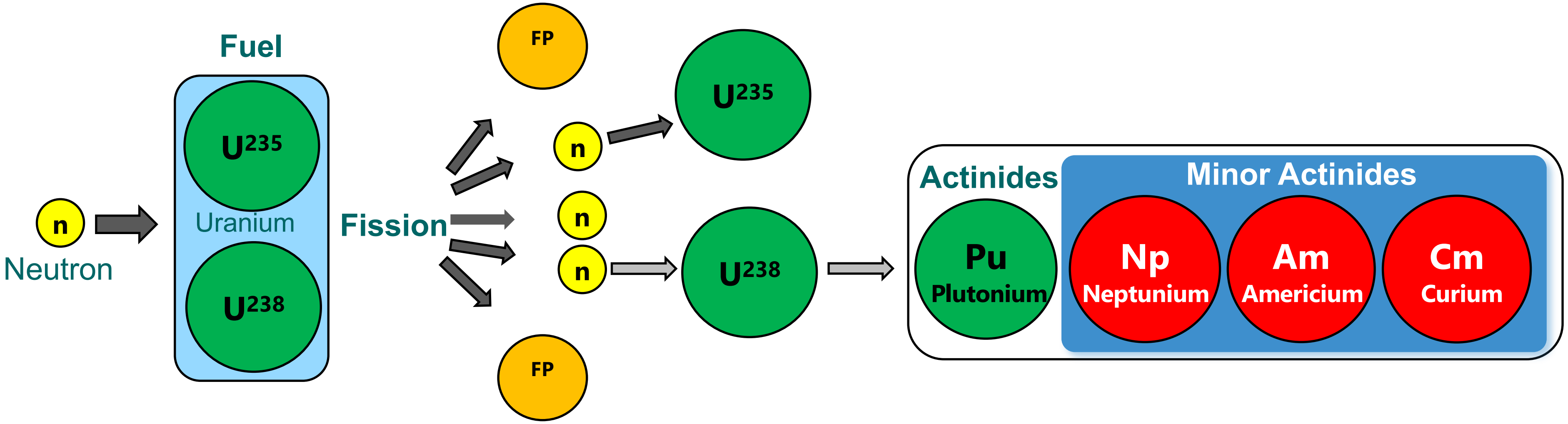
The general environmental indicators of the TTC



(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)

Fission generates high level radioactive waste



1 ton of nuclear fuel used 4,5 year in commercial PWR reactor **produces electricity for 100,000 Belgian families per year** (3500 kWh/y per family)

➔

After 4,5 years the spent nuclear fuel contains:

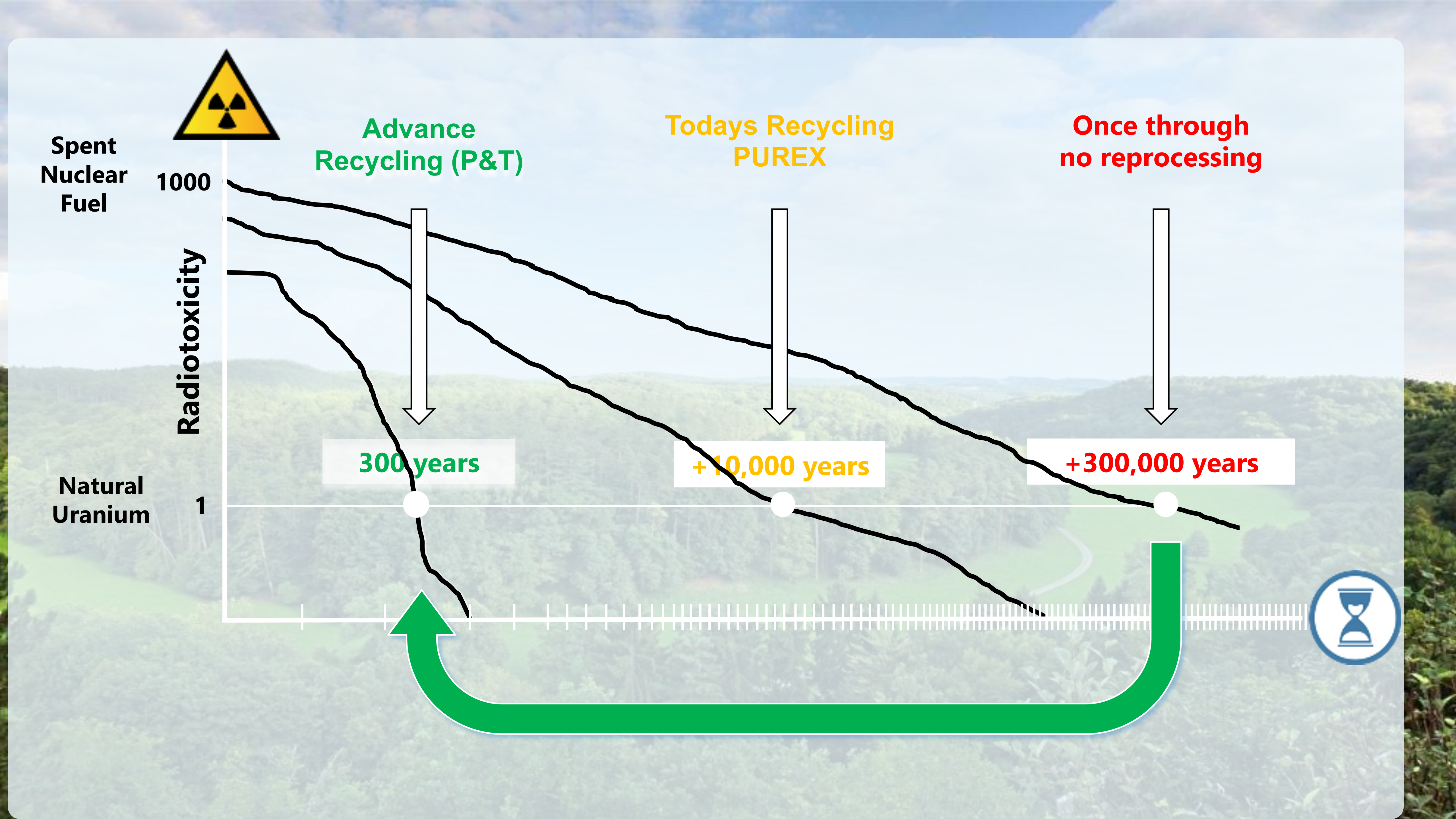
- **94,7% of resources we can recycle (U+Pu)**
- **5,1% of nuclear waste with low radiotoxicity (FP's)**
- **0,2% of high radiotoxicity nuclear waste**

Source: SCK•CEN MYRRHA Project Team

Partitioning & Transmutation

vs

- Just like for classical household waste we need sorting and then valorizing through recycling
- **Partitioning**
  - Separate the ingredients of the spent fuel in “similar” categories we can treat in a similar way
- **Transmutation**
  - Use intense neutron field to transmute isotopes into others, less “nasty” and producing energy (circular economy)

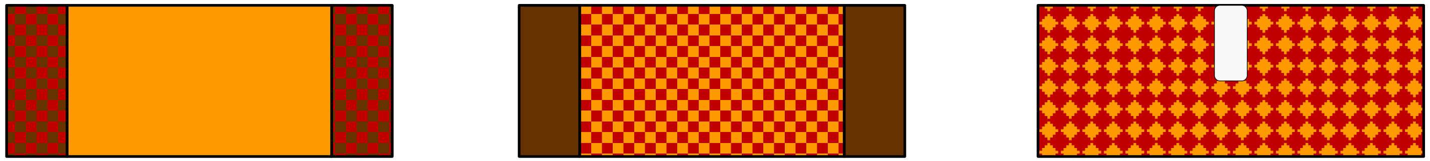

Spent
Nuclear
Fuel
1000
Radiotoxicity
Advance
Recycling (P&T)
Todays Recycling
PUREX
Once through
no reprocessing
300 years
+10,000 years
+300,000 years
Natural
Uranium
1

Belgian geological repository: impact on footprint (km^2)

	No further reprocessing	Full reprocessing	MA+FP P&T case
	footprint (km^2)	footprint (km^2)	footprint (km^2)
fuel cycle dependent			
UOX spent fuel	1.85	-	-
MOX spent fuel	0.10	-	-
V-HLW future	-	0.32	0.06
Total C waste	1.95	0.32	0.06
CSD-C future	-	0.07	0.10
Total B&C waste	1.95	0.39	0.17
relative	**1.00**	**0.20**	**0.08**

Three options for Minor Actinide (MA) transmutation

FR heterogeneous	FR homogeneous	ADS



Driver fuel Blanket with MA	Fuel with MA Blanket	Fuel with MA

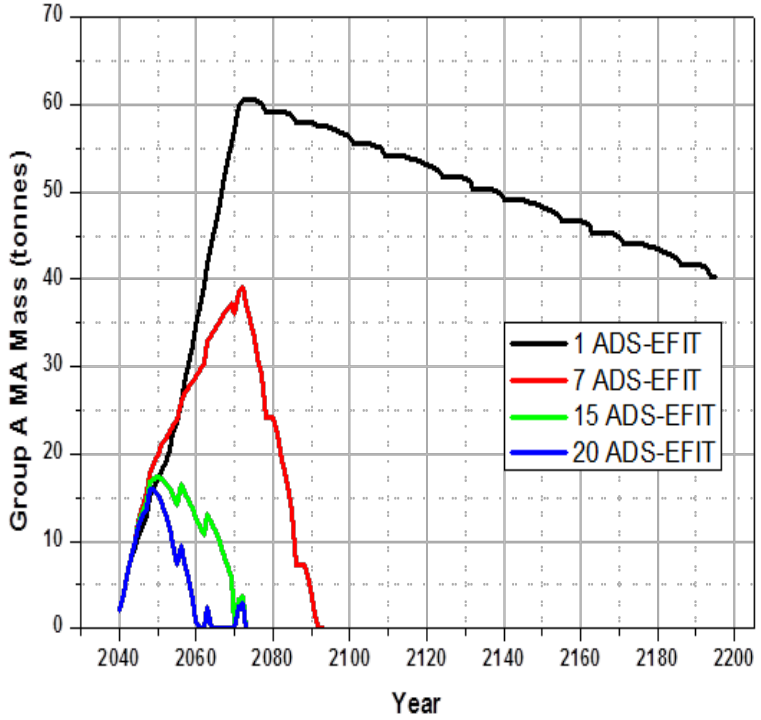
Core safety parameters limit the amount of MA that can be loaded in the critical core for transmutation, leading to transmutation rates of:

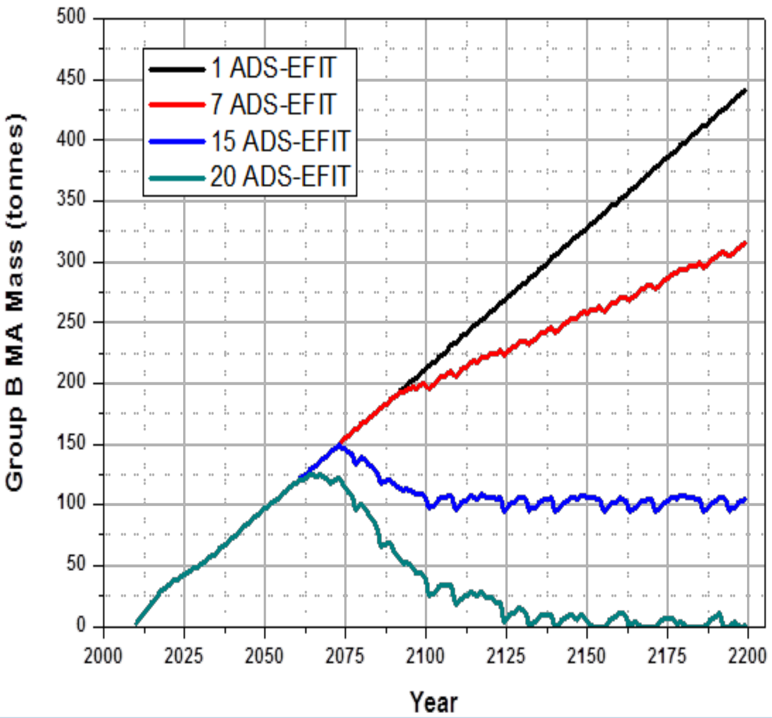
- FR = 2 to 4 kg/TWh
- ADS = **35 kg/TWh** (based on a 400 MW_{th} EFIT design)

→ ADS performs the best

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)





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

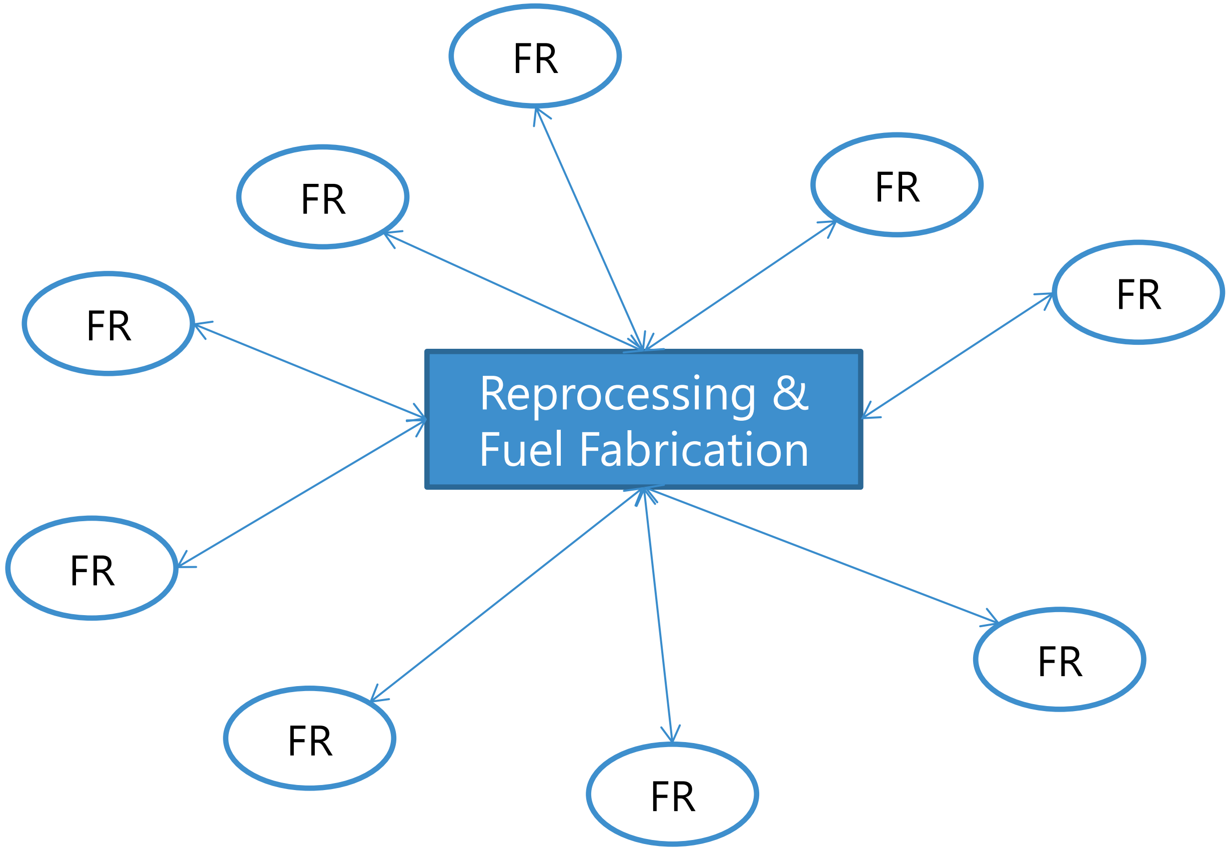
Kashiwazaki-Kariwa = 23895 MWth

Source: [TBD]

Transport issues of MA-Fuels FR vs ADS

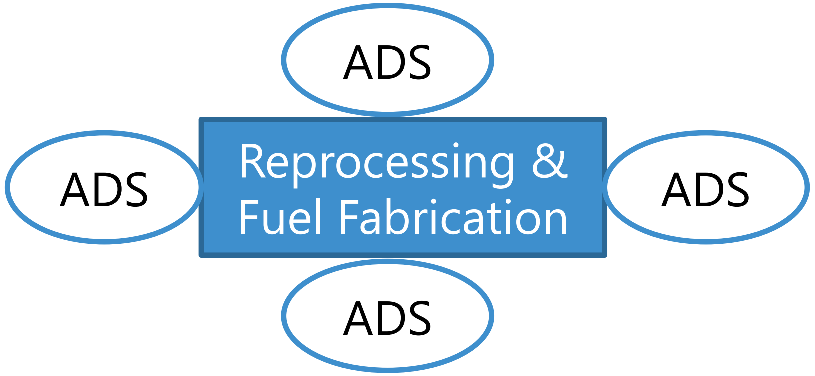
Transmutation in Fast Reactors

- Large number of FRs needed
- Many transport of MA-Fuels on the roads



Transmutation in ADS

- Small units in small number ➔ Single site
- Few or no transport of MA Fuel on the roads



no or limited "on-the-road" transport

Source:

MYRRHA: Accelerator Driven System

PHASE 1 *LINEAR ACCELERATOR* *PHASE 2*

100 MeV **600 MeV**

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

PHASE 3

REACTOR
LBE
SUB-CRITICAL
~100 MWTH

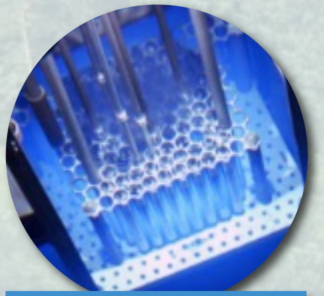
MYRRHA's Application Portfolio

SNF*/ Waste

Radio-isotopes

Fusion

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



Mat.& Fuel GEN IV

Support to SMR LFR

Fundamental research

*SNF = Spent Nuclear Fuel

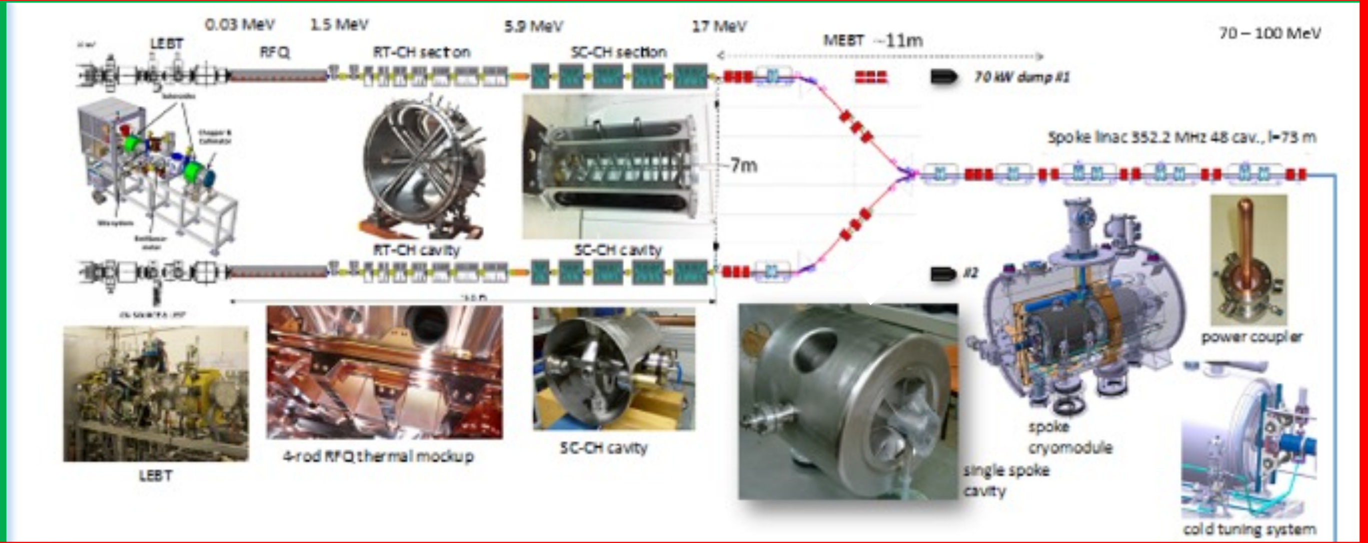
MYRRHA's PHASED IMPLEMENTATION STRATEGY

Benefits of the phased approach:

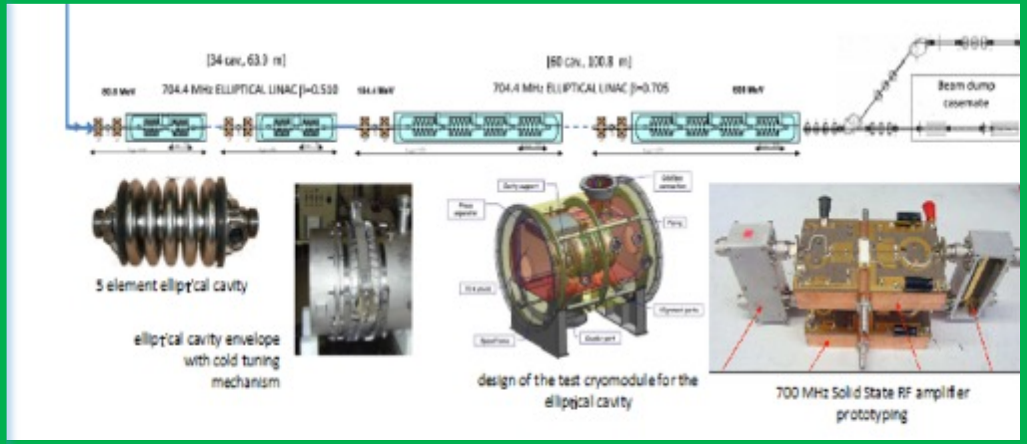
- already a first operational facility available in Mol at **<u>end of 2026</u>**
- spreading the investment costs
- successful milestone then next step >> reducing technical & financial risks

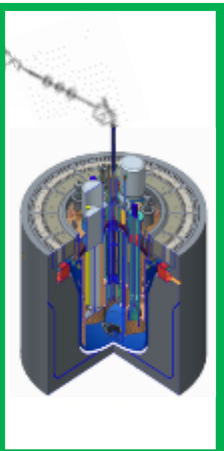
UNDER CONSTRUCTION

Phase 1 – 100 MeV + Proton Target Facility



Phase 2 – 600 MeV



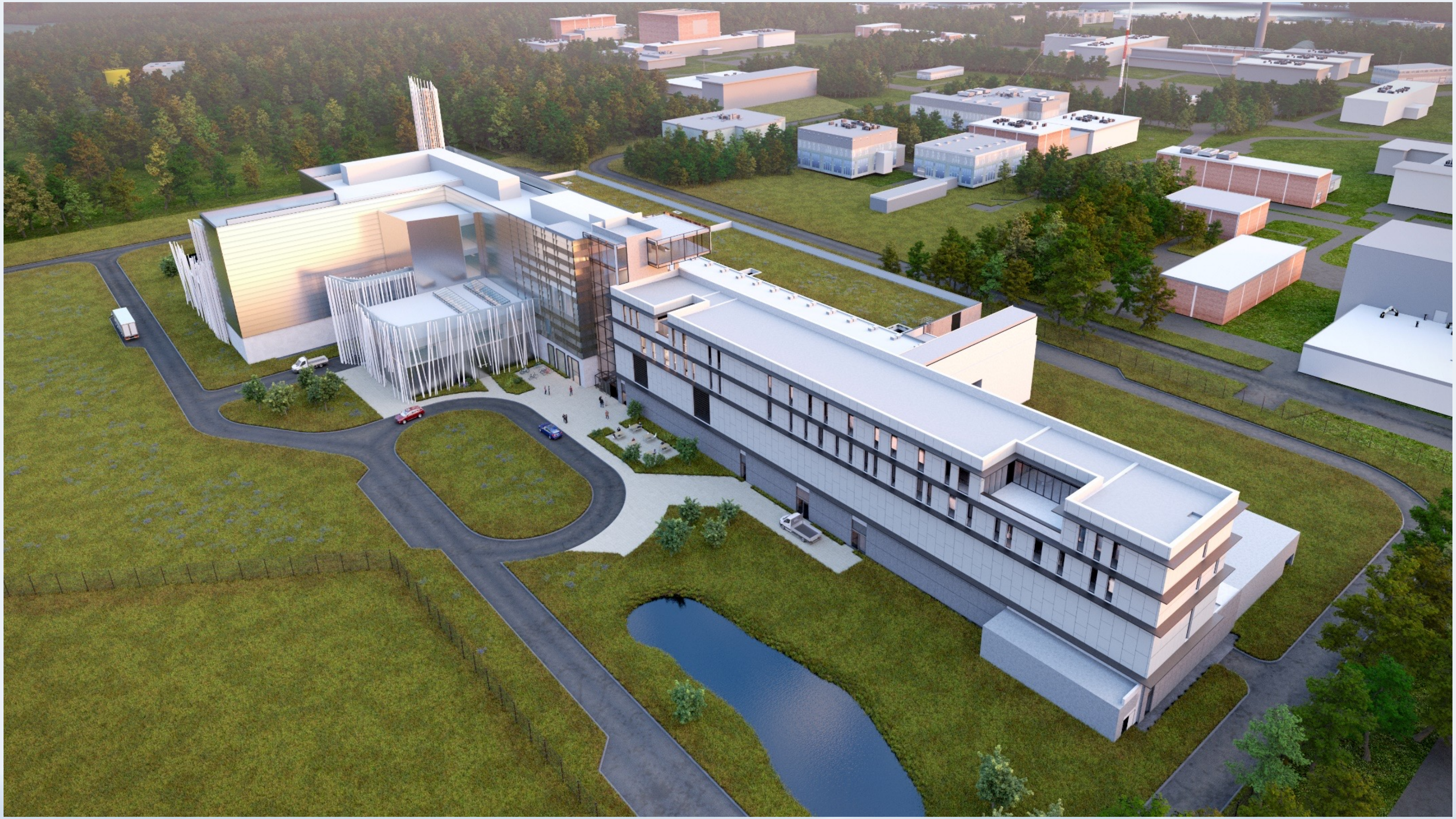


Phase 3 – Reactor

Source: SCK CEN MYRRHA Project Team

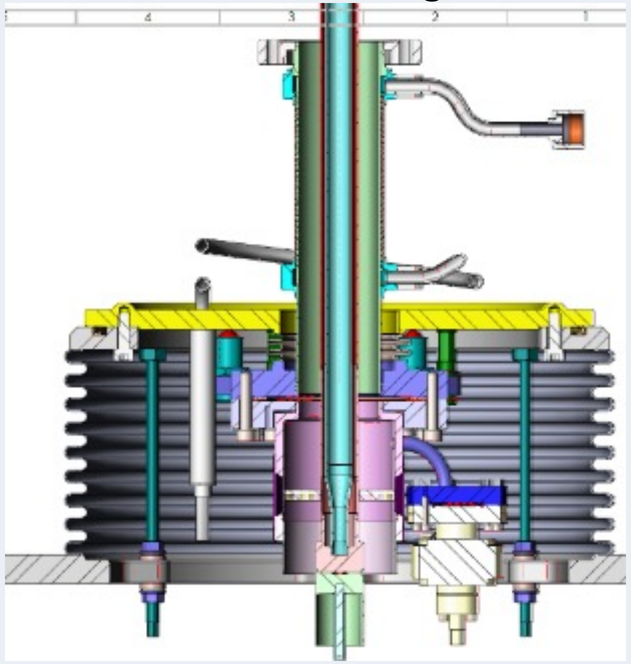
MYRRHA Phase 1 | MINERVA Facility Layout

Permit for to start construction expected in spring 2024



Cryo module progress

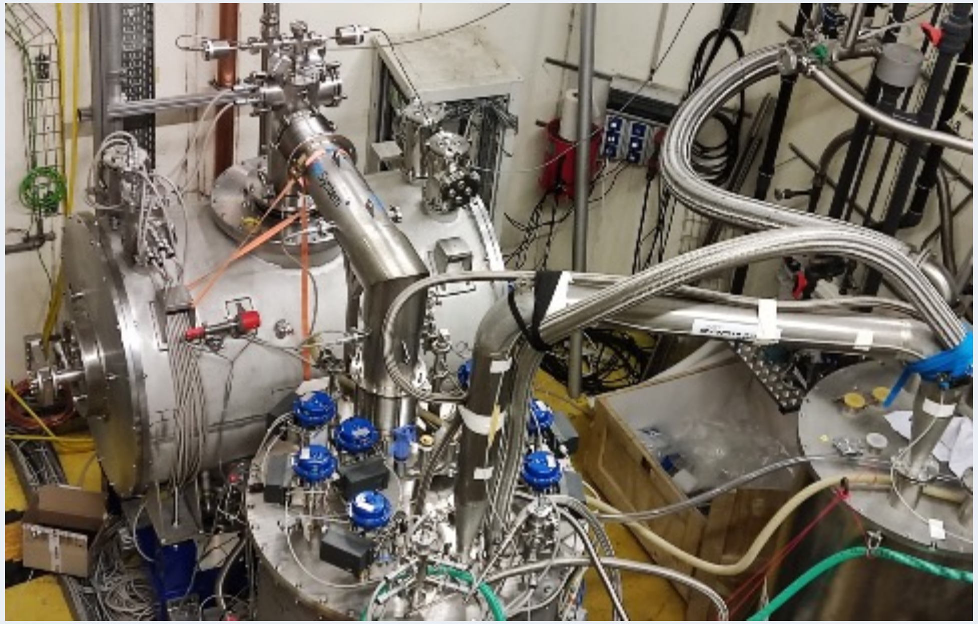
1st Preseries Cavities produced at RI and about to be sent to IJCLab for testing



First conceptual design of warm motor solution (CTS issues not resolved) together with external design company

New RF-coupler design converging

Assembled prototype cryomodule in test pit attached to testQVB -> sufficient LHe now available for low power RF-test.



➔ Consolidations progressing and starting to converge, but still many things to do …

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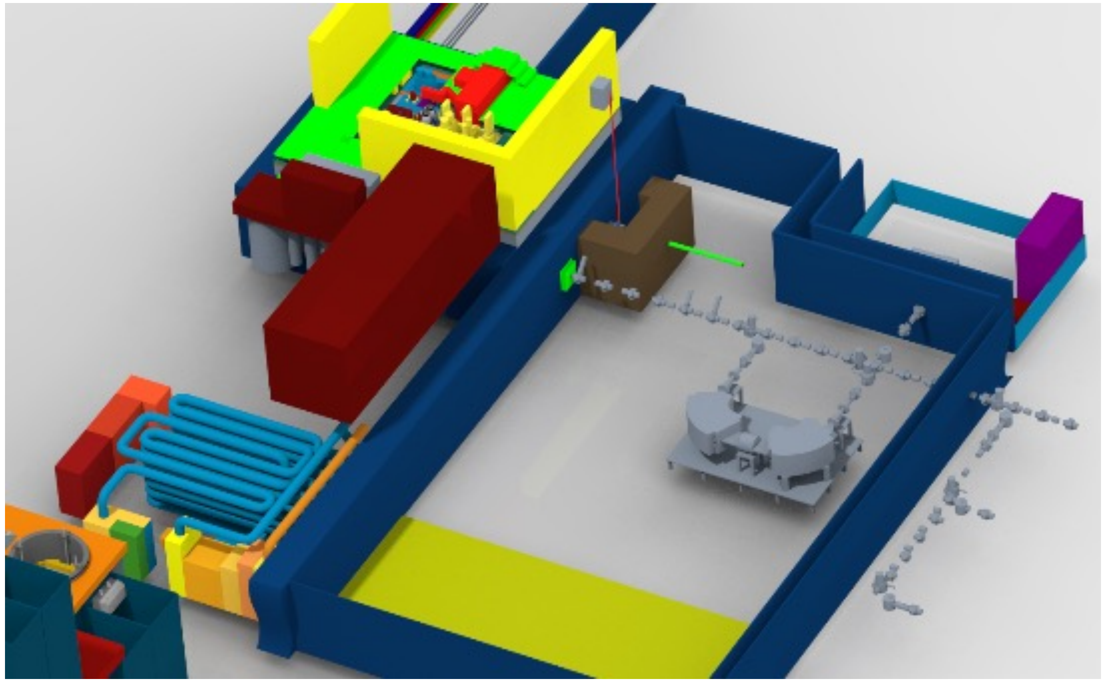
ISOL@MYRRHA status update

- Proton Beam Diagnostics OBA Conceptual Design completed – TRC approved
- Layout Update of RIB Distribution System (RDS) finalized
- Target Ion Source Assembly (TISA) Conceptual Design completed – TRC approved
- ISOL@MYRRHA Resonant Ionization Laser Source (IMRILS) Conceptual Design completed (both Laser Lab and Laser Beam Transport) – TRC approved
- Actinide Target Material Laboratory (ATML) Conceptual Design completed – under TRC approval

3D model of updated RDS layout

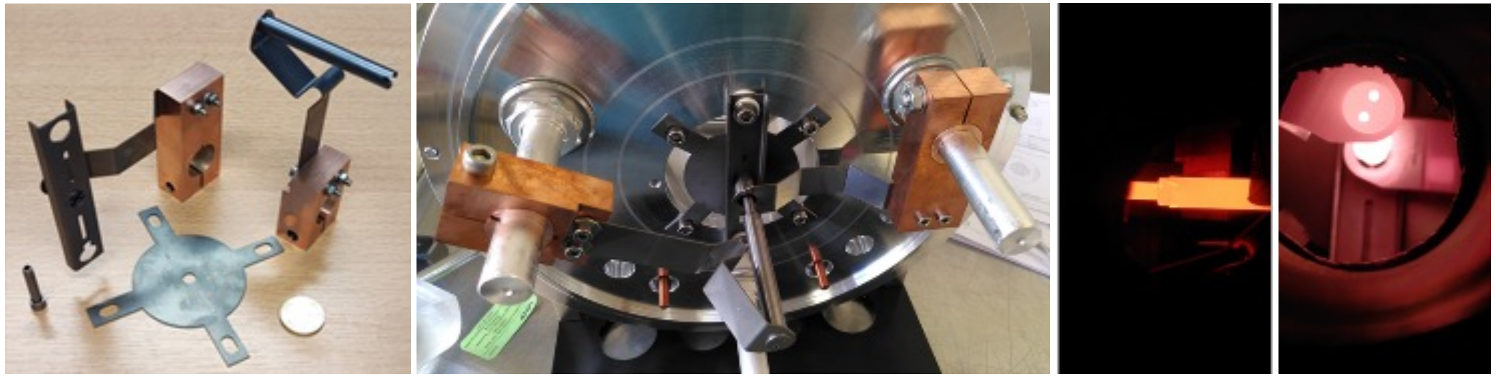


- User Laboratories concepts under development together with the user community – requested input provided to building designer and safety

ISOL@MYRRHA status update

- First prototype ISOL@MYRRHA high throughput ion source (designed and manufactured at SCK CEN) successfully passed first tests at CERN ISOLDE

1st Ion Source: in-house designed & built **tests at ISOLDE/CERN**



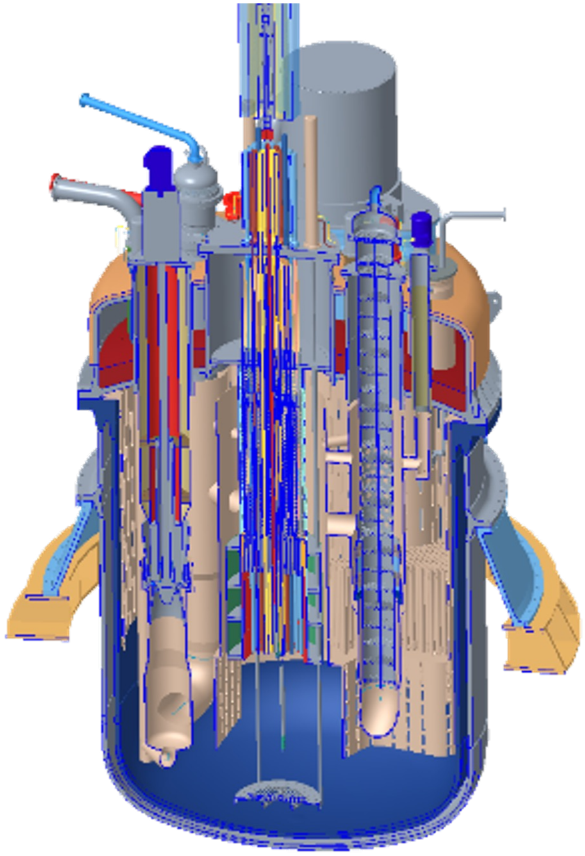
ISOFF: Off-Line System in Labo2

- Progress with the ISOL off-line system (Labo2)
  - Vacuum components installed; first vacuum test
  - Advancing the electrical cabinets; installing PLCs; advancing work on wiring;
  - Installing cooling lines (almost complete)

MYRRHA reactor primary design Rev. 1.8, frozen end 2020

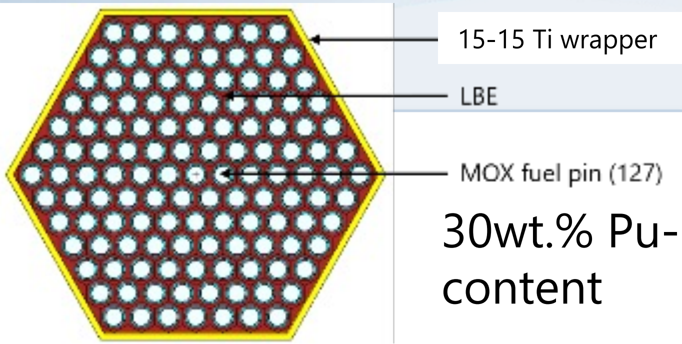
- Integrated Pool-type concept with LBE coolant
- Fuel assemblies: hexagonal bundles of cylindrical wire-spaced fuel pins (MOX fuel 30wt.% Pu)
- 4x heat exchangers: double-walled with leak detection; water/steam on secondary side
- 2x primary pumps: vertical shaft mixed-flow design
- Bottom core loading: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



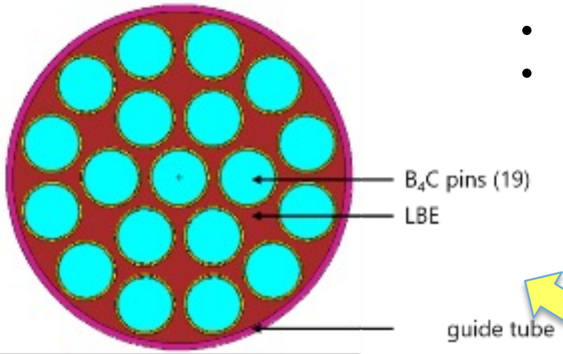
Subcritical (BOC) core layout

fuel assembly (78)



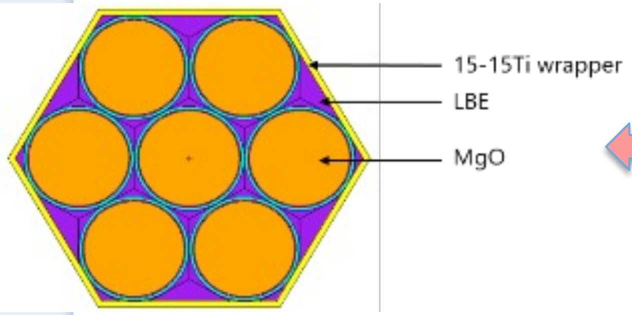
30wt.% Pu-content

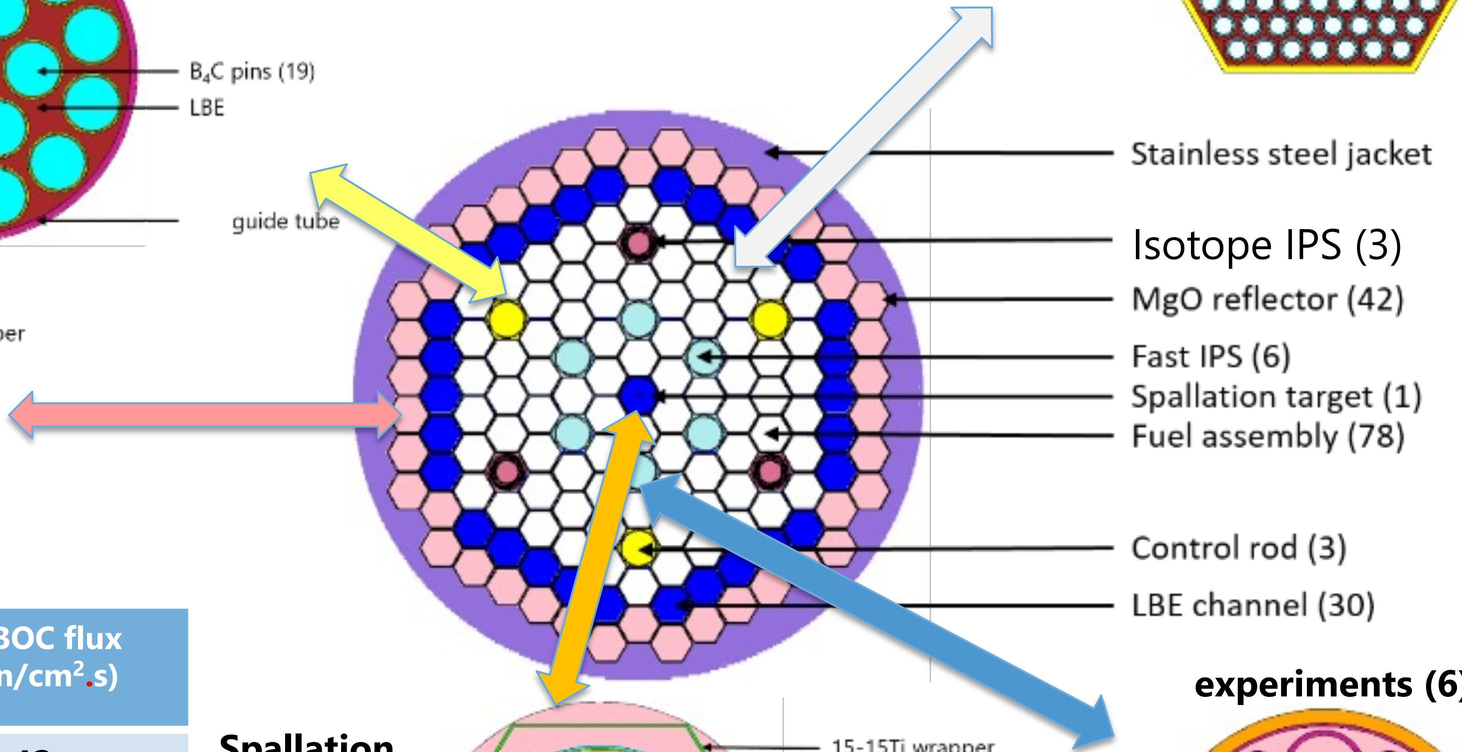
control rods (3)



- **LBE dummy channels (30)**
- **beam tube + spallation target**

MgO reflector (42)

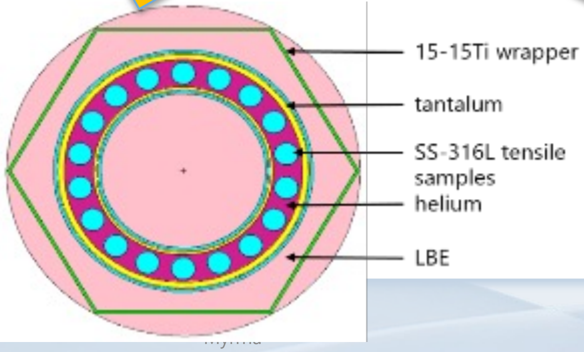




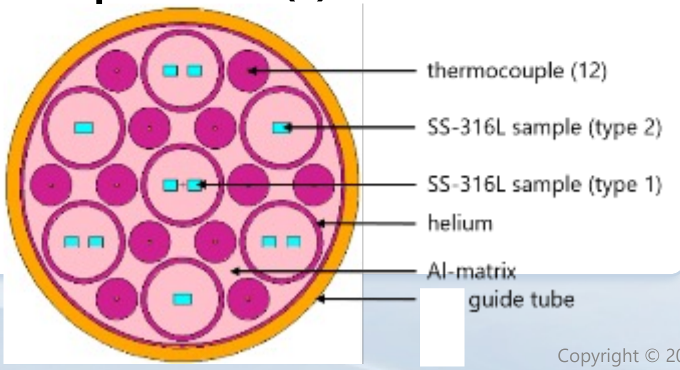
Parameter	Value
k_{eff}	0.93
Core power (MW)	60
Beam current (mA)	3.63

Position	Peak BOC flux (10^{15} n/cm^2.s)
Fusion targets	3.42
Hottest FA	3.14
Experiments	2.34

Spallation target assembly (1) – view of irr. targets



experiments (6)



MYRRHA HLM Facilities – R&D support to design

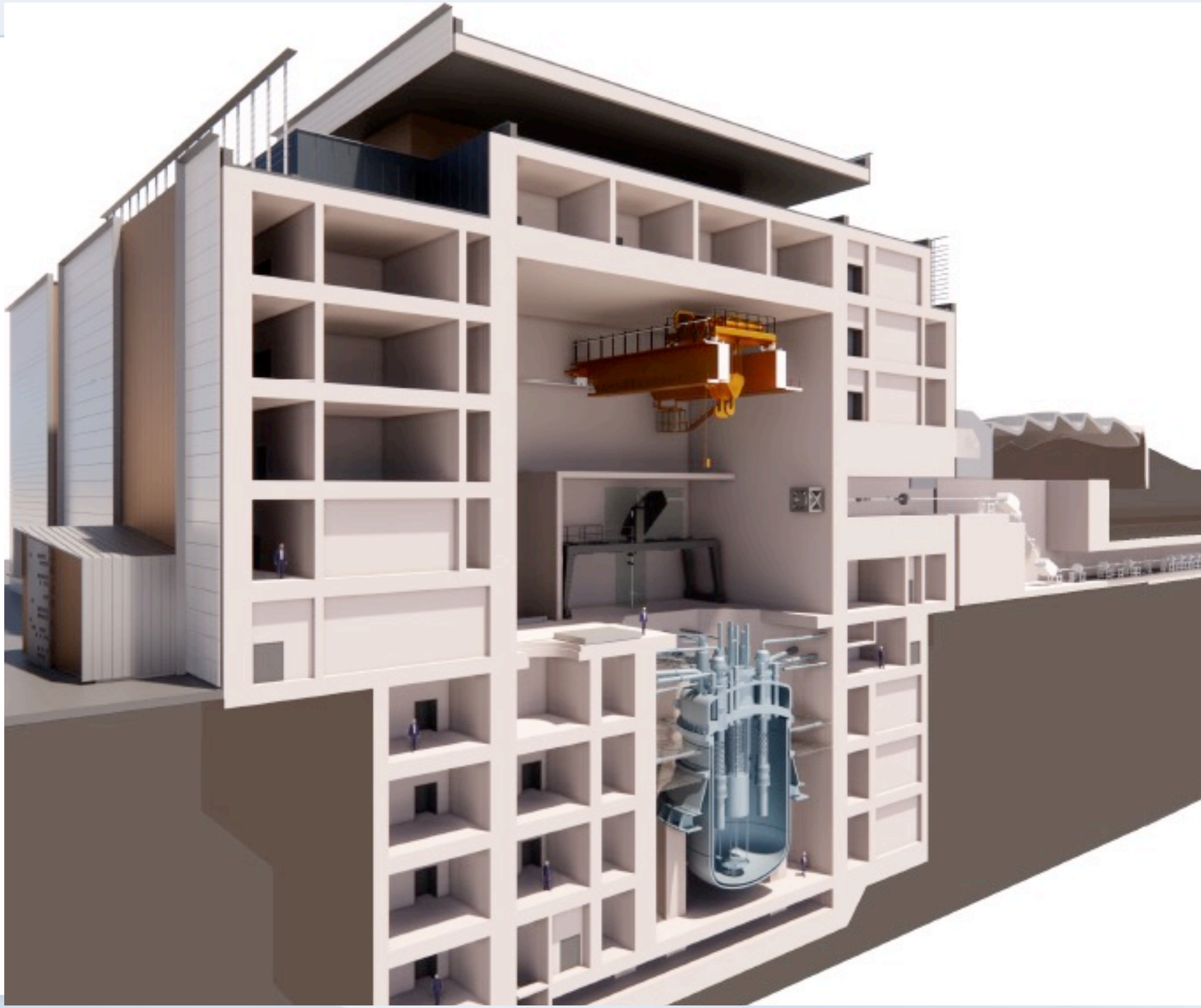






Balance of Plant

- Multi-disciplinary integration
  - Reactor Building
    - Nuclear material handling
    - Ex-vessel remote handling
    - Hot Cells
    - Building Equipment
    - HVAC
    - Utilities
      - Process
      - I&C
      - Electrical
      - Fire protection
  - Accelerator (beam line and bending magnet)
  - Spent Fuel Building
  - Waste Building



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Belgian Government decision of 7 September 201

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 sck cen

INS MDB

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)

Predicting future is very easy for smooth variations whereas we are living civilization changes that induces drastic changes in very short periods

Easter morning 1900: 5th Ave, New York City. Spot the automobile.

Source: US National Archives.

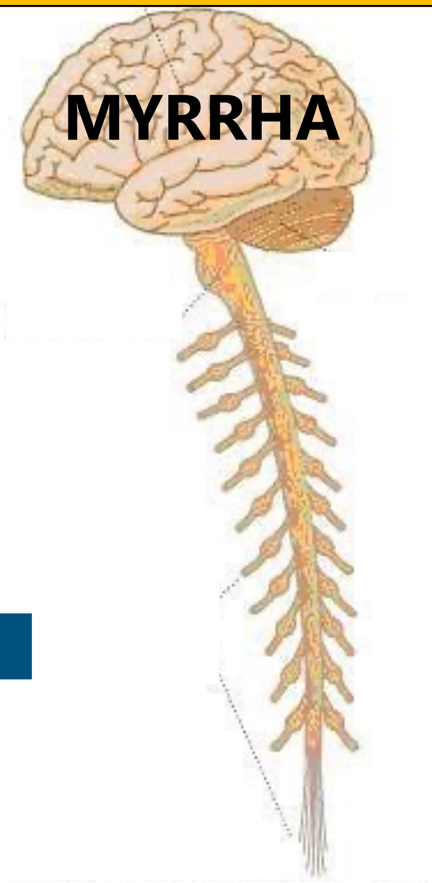
Easter morning 1913: 5th Ave, New York City. Spot the horse.

Source: George Grantham Bain Collection.

Conclusions
The potential of MYRRHA in terms of research and innovation is very large

MYRRHA is a Wonderful project full of mysteries

MYRRHA: a backbone of innovation inspired by Belgium



1 Radio-chemistry

- Separation for Partitioning of HLW[1]
- Alpha – therapy radio-isotopes
- Separation of radio-isotopes for Space Power

2 Material development

- New fission reactors
- Fusion materials
- But can serve beyond Nuc.En (JPNM)

3 Fundamental Physics

- RIB[2] physics
- Rare decays
- Extreme precisions experiments

4 Accelerator technology (reliability ADS)

- Improve availability of accelerator facilities
- Brilliance
- Performance
- Economy

5 HLM[3] technology

- Fusion technology
- New reactor technology (LFR/SMR)
- Heat storage for solar power

6 Beyond U fuel cycle & Electricity

- Thorium => ADTR[4], Molten Salt ADS/Reac.
- SMR & Cogen : Elec+Heat, Elec+H_2

[1] HLW = High-Level Radio-active Waste
[2] RIB = Radio-active Ion Beam facility
[3] HLM = Heavy Liquid Metal technology (as coolant for reactors)
[4] ADTR = Accelerator Driven Thorium Reactor

Source: SCK CEN MYRRHA Project Team

Thank you for your attention and we welcome Italy & Italians to joining us in MYRRHA

We don’t make projects because they are easy but because they are desired & needed by and for the society