Realization of a new research facility in Belgium
for nuclear innovation addressing societal challenges of Europe

MYRRHA

Present status and focus on latest developments of MYRRHA ADS Accelerator

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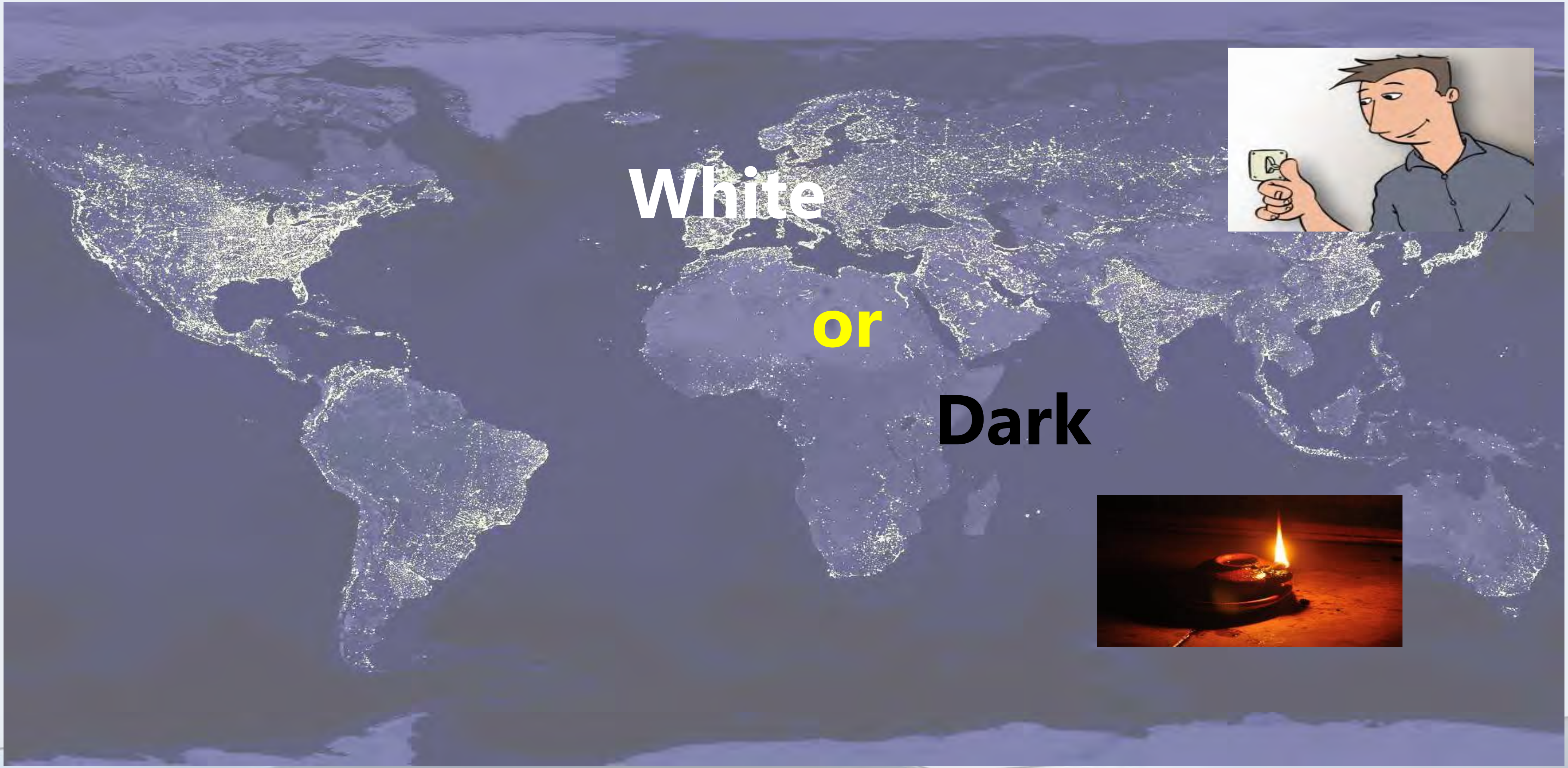
International Conference on Accelerators for Research and Sustainable Development 2022:
From Good Practices Towards Socioeconomic Impact
23–27 May 2022, Vienna, Austria

Energy facts & Global warming

Energy challenges :
What’s the colour of electricity? Green? Red? Blue?...



Energy challenges :
Will the energy savings, save the world ?

	2010
Pop. OECD (mio)	1.200
HDI / Energy Consumption (toe/cap.)	5.5
Total Energy Consumption OECD (mio oet)	6.600
Pop. Non-OECD (mio)	5.400
HDI / Energy Consumption (oet/cap.)	1
Total Energy Consumption Non-OECD (mio oet)	5.400
TOTAL CONSUMPTION (mio oet)	**12.000**

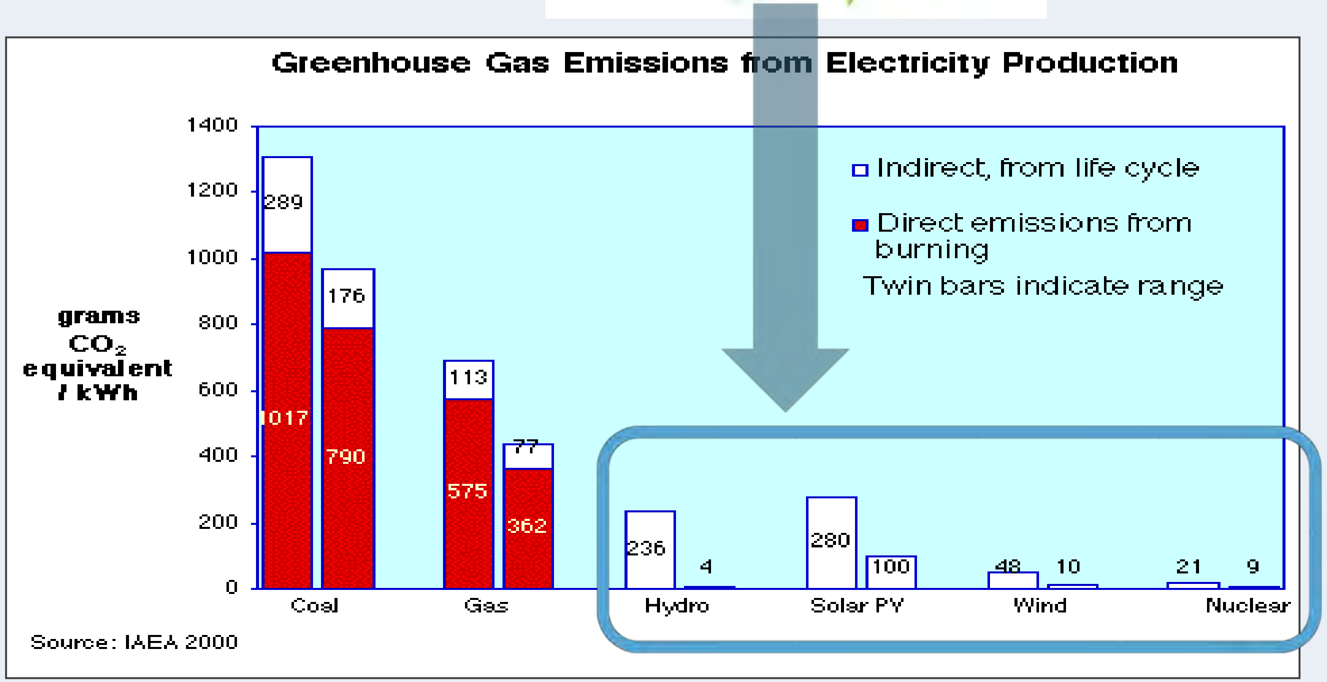
Energy challenges :
Will the energy savings, save the world ?

	2010	2030
Pop. OECD (mio)	1.200	1.400
HDI / Energy Consumption (toe/cap.)	5.5	3[e]
Total Energy Consumption OECD (mio oet)	6.600	4.200
Pop. Non-OECD (mio)	5.400	6.700
HDI / Energy Consumption (oet/cap.)	1	2
Total Energy Consumption Non-OECD (mio oet)	5.400	13.400
TOTAL CONSUMPTION (mio oet)	**12.000**	**17.600**

Energy challenges :
Will the energy savings, save the world ?

	2010	2030	2050
Pop. OECD (mio)	1.200	1.400	1.500
HDI / Energy Consumption (toe/cap.)	5.5	3e	2.8
Total Energy Consumption OECD (mio oet)	6.600	4.200	4.200
Pop. Non-OECD (mio)	5.400	6.700	7.500
HDI / Energy Consumption (oet/cap.)	1	2	2.8
Total Energy Consumption Non-OECD (mio oet)	5.400	13.400	21.000
TOTAL CONSUMPTION (mio oet)	**12.000**	**17.600**	**25.200**

Energy challenges :
invest in all CO_2 non-emitting energy sources including nuclear energy



World Energy hunger is real and we preferably try also to combat climate change

Pathways to Net Zero Emissions

- Pathways based on the world's carbon budget, emissions reductions targets and timelines have been modelled and published by various organisations
- None of the published pathways project aspirational scenarios for nuclear innovation
- All published pathways include levels of nuclear energy deployment based on currently available commercial technologies
- Nuclear innovation does not feature prominently because of a lack of specialised expertise in nuclear technologies among modelling teams

Samples of ambitious and aspirational pathways to net zero

Organisation	Scenario	Parameter	2020	2050	Growth rate (2020-50)
IIASA (2021)	Divergent Net Zero Scenario (1.5°C)	Cost of carbon (USD per tCO_2)	0	1 647	-
		Wind (in GWe)	600	9 371	1461%
		Solar (in GWe)	620	11 428	1743%
IEA (2021c)	Net Zero Scenario (1.5°C)	Hydrogen (MtH_2)	90	530	490%
		CCUS ($GtCO_2$)	<0.1	7.6	-
		Energy intensity (MJ per USD)	4.6	1.7	-63%
Bloomberg NEF (2021)	New Energy Outlook Green Scenario (1.5°C)	Wind (in GWe)	603	25 000	4045%
		Solar (in GWe)	623	20 000	3110%

Curtesy of Diane Cameron, OECD/NEA

Source:

World Energy hunger is real and we preferably try to combat climate change & contribution of nuclear fission energy

Nuclear in Emissions Reduction Pathways

Organisation	Scenario	Climate target	Nuclear innovation	Description	Role of nuclear energy by 2050	
					Capacity (GW)	Nuclear growth (2020-50)
IAEA (2021b)	High Scenario	2°C	Not included	Conservative projections based on current plans and industry announcements.	792	98%
IEA (2021c)	Net Zero Scenario (NZE)	1.5°C	Not included but HTGR and nuclear heat potential are acknowledged.	Conservative nuclear capacity estimates. NZE projects 100 gigawatts more nuclear energy than the IEA sustainable development scenario.	812	103%
Shell (2021)	Sky 1.5 Scenario	1.5°C	Not specified	Ambitious estimates based on massive investments to boost economic recovery and build resilient energy systems.	1 043	160%
IIASA (2021)	Divergent Net Zero Scenario	1.5°C	Not specified	Ambitious projections required to compensate for delayed actions and divergent climate policies.	1 232	208%
Bloomberg NEF (2021)	New Energy Outlook Red Scenario	1.5°C	Explicit focus on SMRs and nuclear hydrogen	Highly ambitious nuclear pathway with large scale deployment of nuclear innovation.	7 080	1670%

All pathways require global installed nuclear capacity to grow significantly, often more than doubling by 2050.

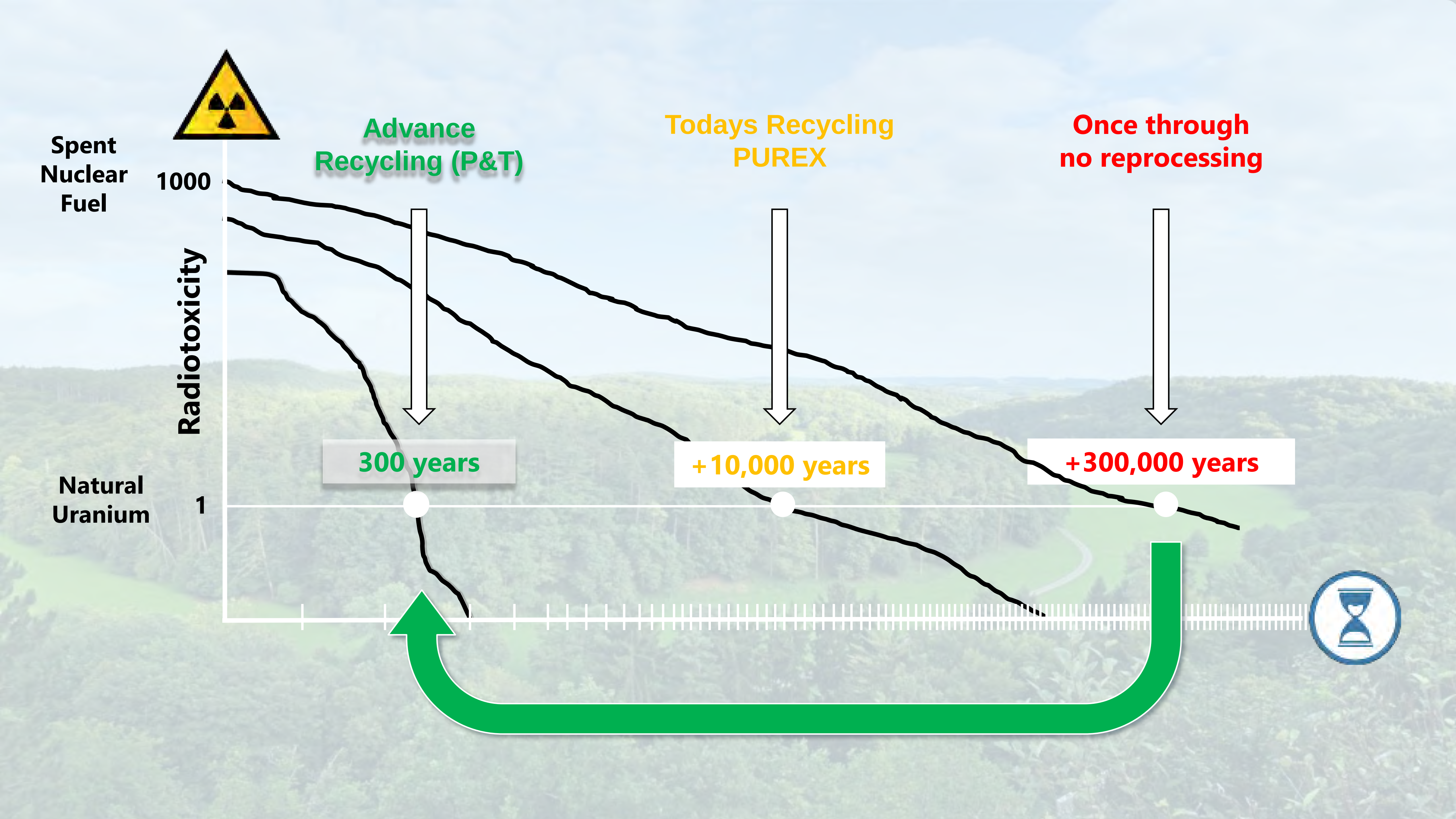
Curtesy of Diane Cameron, OECD/NEA

Source:

What are then the reasons for opposing or ignoring nuclear energy?

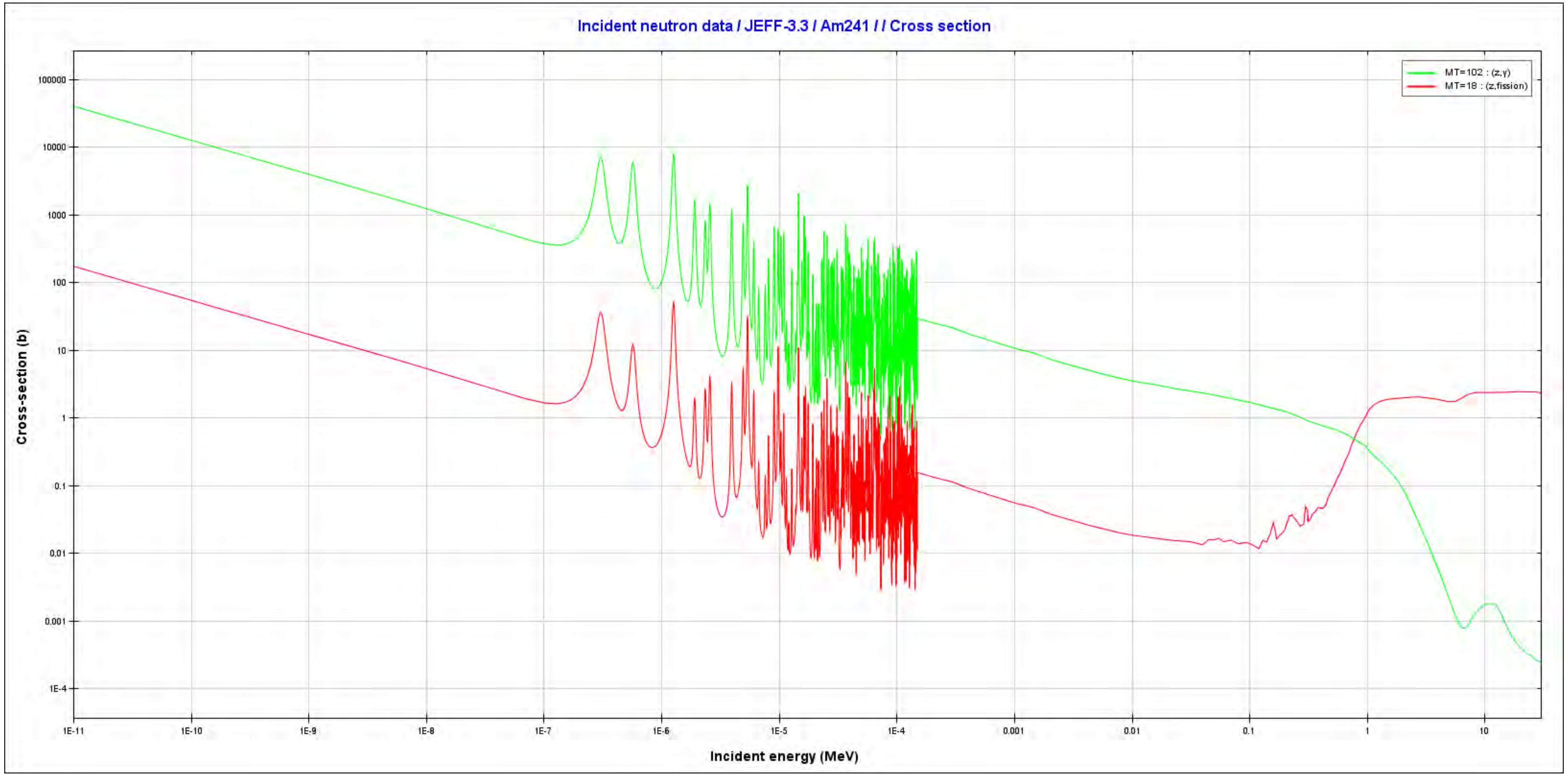
- Outdated and not anymore fashion → we need to innovate and be faster in deployment
- To expensive and capital intensive → we need to go SMR
- Not sustainable → we need to move rapidly towards Fast Reactors (SMR) and closed fuel cycle
- Electricity represent only a little fraction of energy needs → we need to enlarge the portfolio by going higher temperature
- There is no solution for nuclear waste or not acceptable one by society (too long time burden) → we need to reduce the ecological footprint of GD and the time duration of the radiotoxicity of the waste it has o contain **(here comes ADS role)**

Source:



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

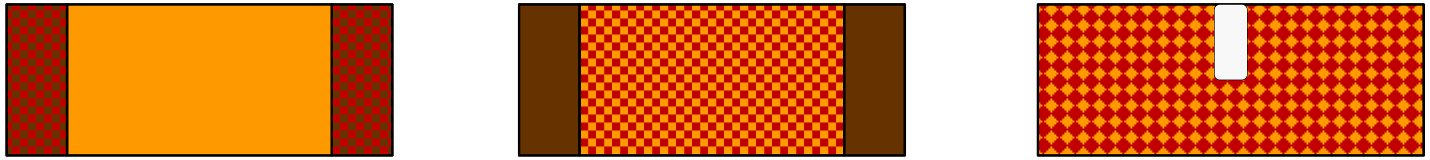
Transmutation = fast neutrons



Source:

Minor Actinide (MA) transmutation
Critical Fast Reactor vs ADS

FR heterogeneous	FR homogeneous	ADS



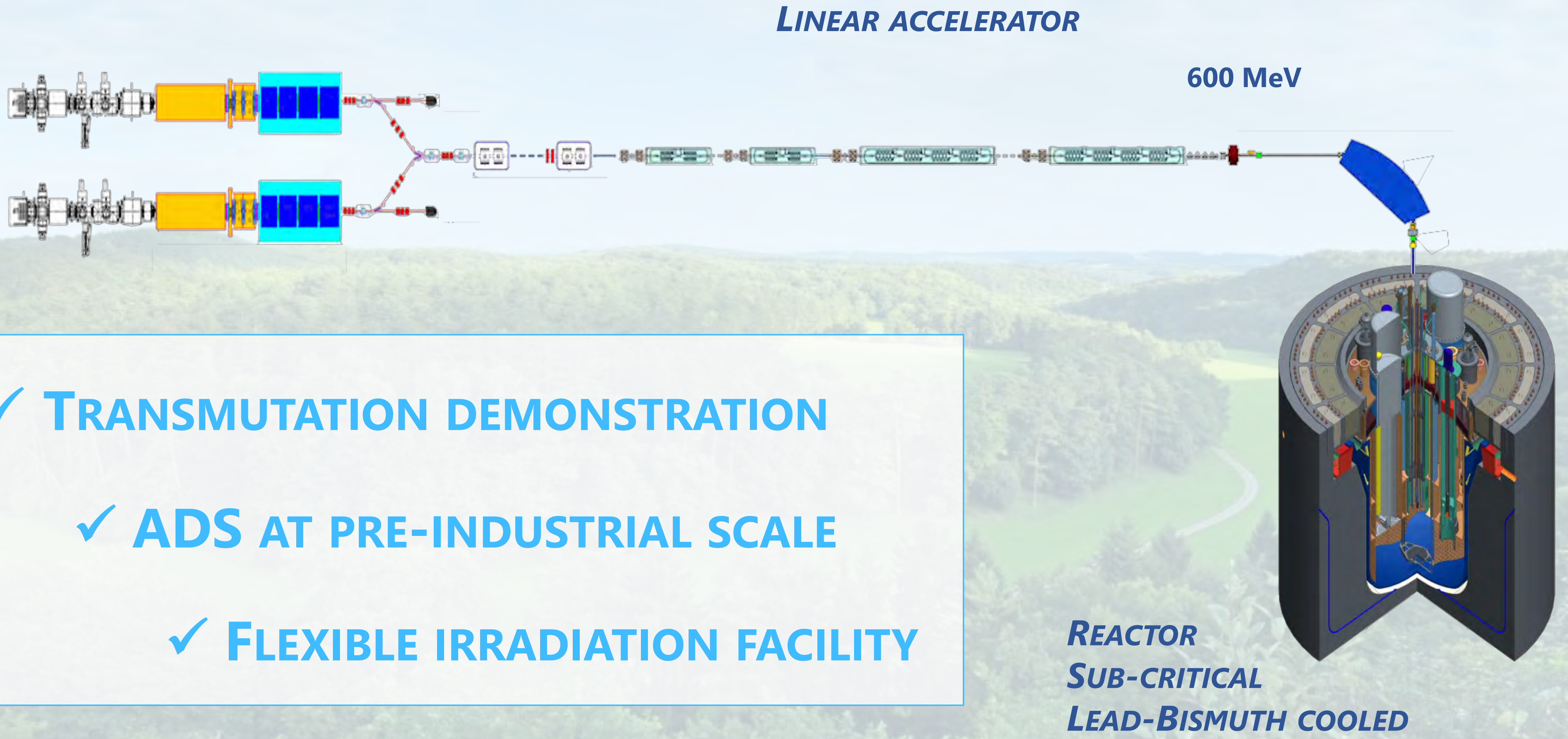
Driver fuel Blanket with MA	Fuel with MA Blanket	Fuel with MA

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)

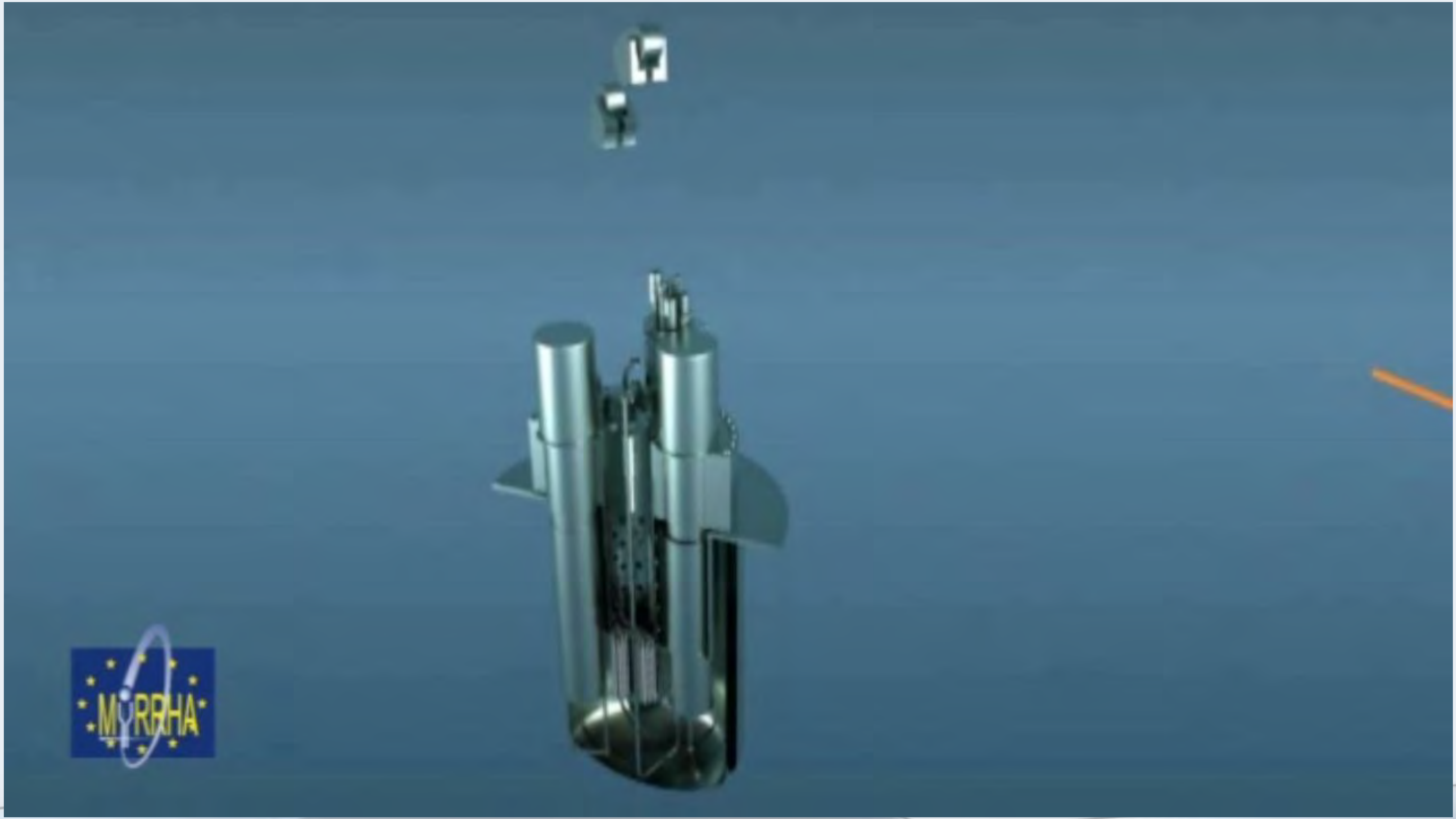
→ ADS performs the best

MYRRHA: Accelerator Driven System

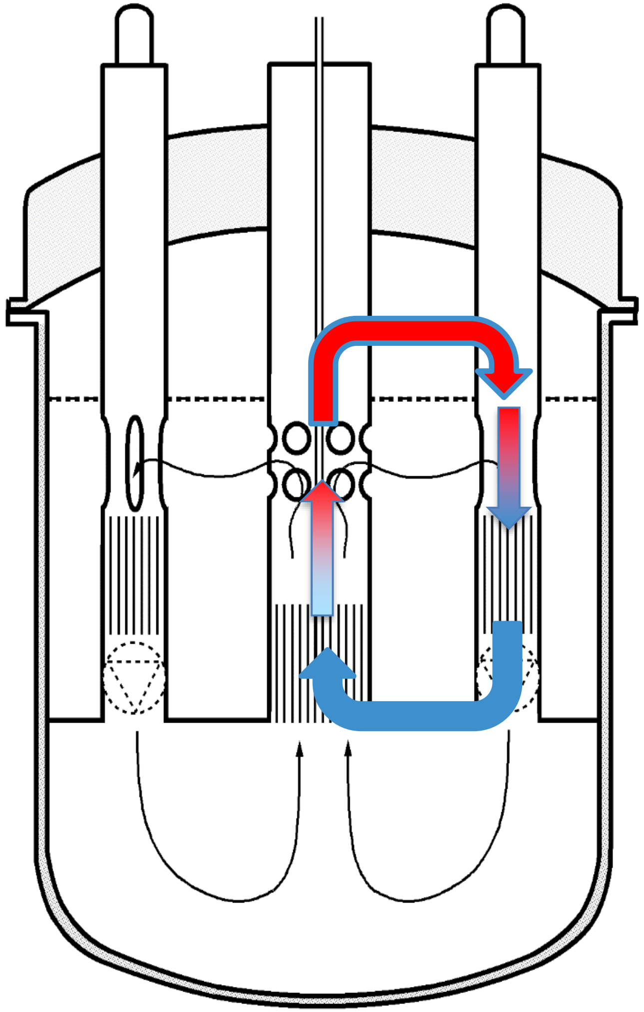


- ✓ Transmutation demonstration
- ✓ ADS at pre-industrial scale
- ✓ Flexible irradiation facility

MYRRHA ADS : intrinsic safety for criticality



MYRRHA ADS : passive safety for decay heat removal



- No need for any active system (no electricity)
- Based on natural circulation of the coolant by gravity between the cold Heat Exchanger (HX) and the hot core
- Implemented in the MYRRHA experimental reactor
- Proven experimentally at appropriate scale at SCK CEN

→ MYRRHA is inherently safe!

MYRRHA accelerator – challenges & answers

1. **Reliable**: extremely high Mean Time Between Failures, MTBF > 250 h

   Beam trips impose severe thermal stress on the reactor components → must be solved within few seconds
2. **Continuous**: Continuous Wave beam delivery
3. **Powerful**: beam current up to 4 mA, high power up to 2.4 MW

Answer

Superconductivity

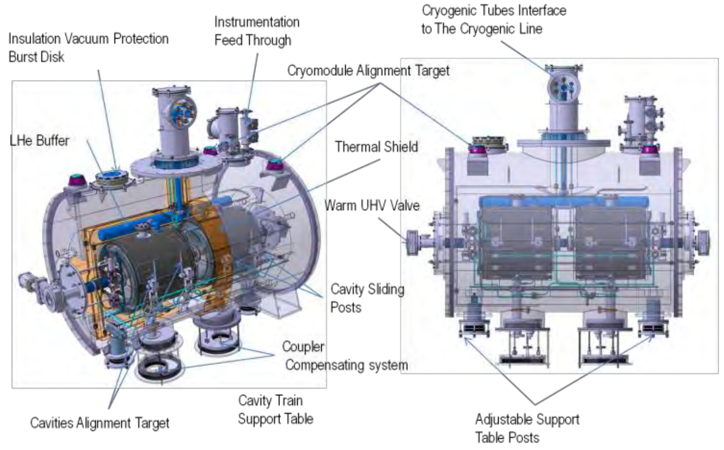
- Access to large accelerating gradients (operation margins)
- Large beam apertures with small losses
- Lower power consumption in CW
- High beam current handling
- Compact machine

Fault tolerance

- Solid design: robust optics, use components far from their technological limits, modularity
  - Solid State (SS) RF amplifiers
  - Modular DC power supplies
  - Digital Low Level RF (LLRF) control
- Redundancy, with
  - Parallel scheme in the injector: frozen optics
  - Serial scheme: modular structures
- Reparability (short Mean Time to Recovery) to guarantee high availability

MYRRHA accelerator – some technological choices

- Single spoke cavity cryomodules
  - Design and prototyping by IPNO, France



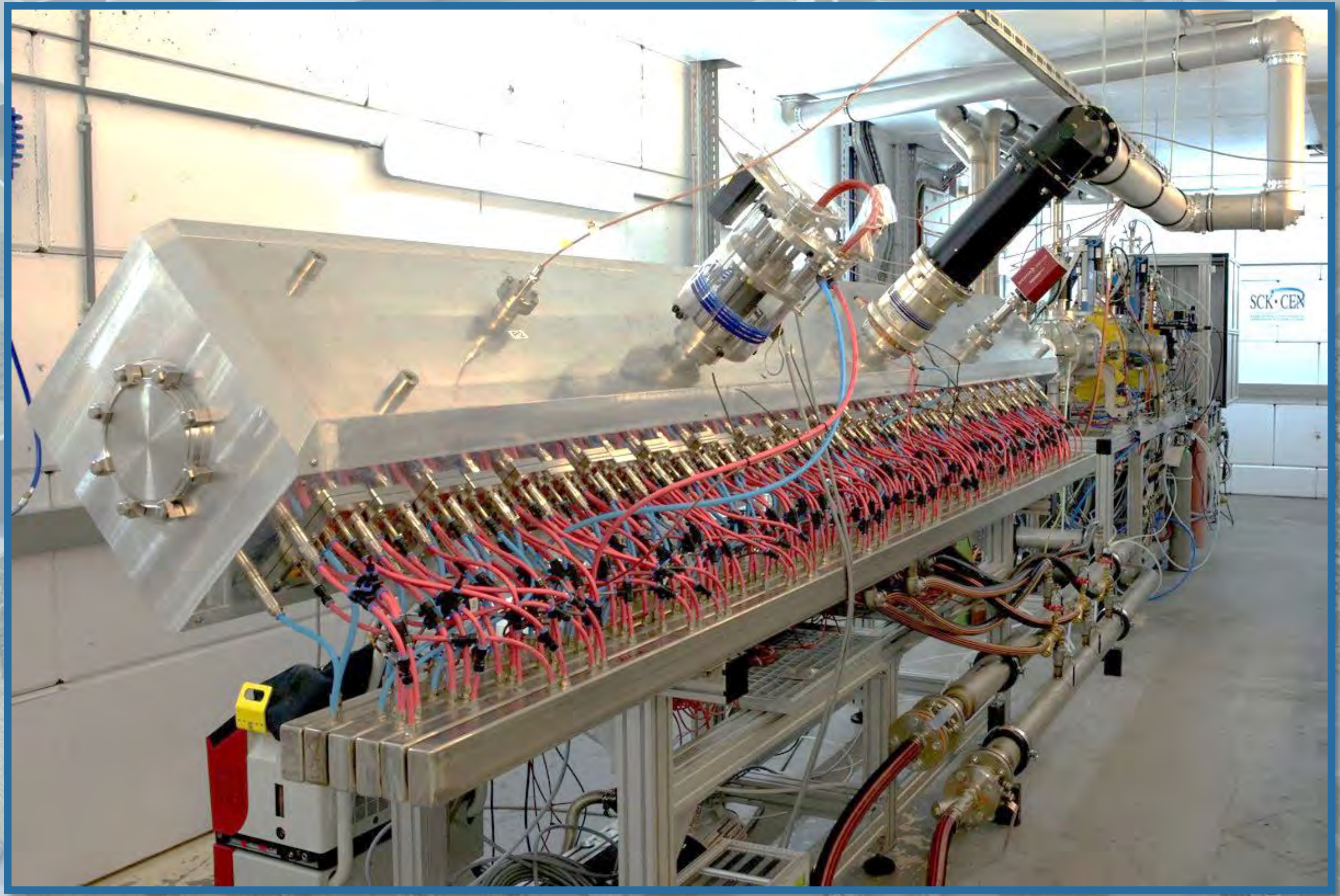
- Solid state amplifiers
  - First compact 176 MHz systems
  - Industrial development by IBA, Belgium

- 176 MHz CH cavities in the accelerator injector
  - Developed by IAP, Frankfurt university

The MYRRHA accelerator takes shape in LLN

MYRRHA protons accelerated successfully

☆ ***30 June 2020***



The cryomodule prototype of MYRRHA ready for testing

Superconductivity and French prototype: a crucial milestone coming up for MYRRHA

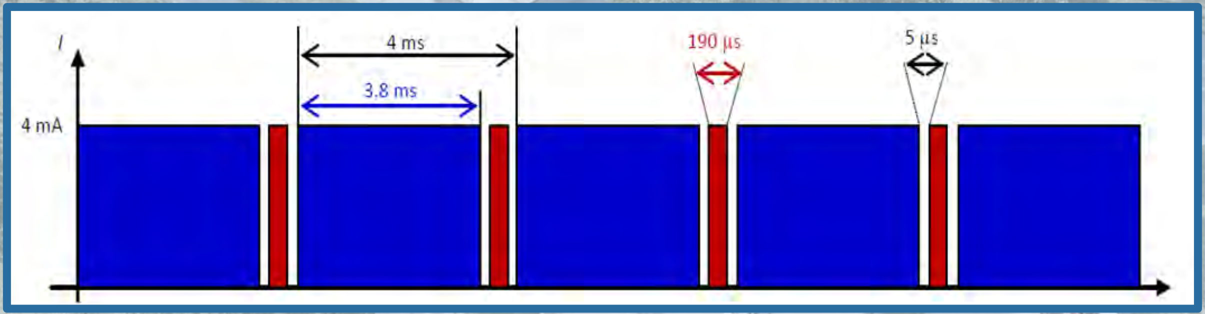
☆ ***27 November 2020***

The 4-rod RFQ shines in LLN

The MYRRHA 4-rod RFQ reach its first success: nominal proton beam delivered intensity of 4 mA and energy of 1,5 MeV

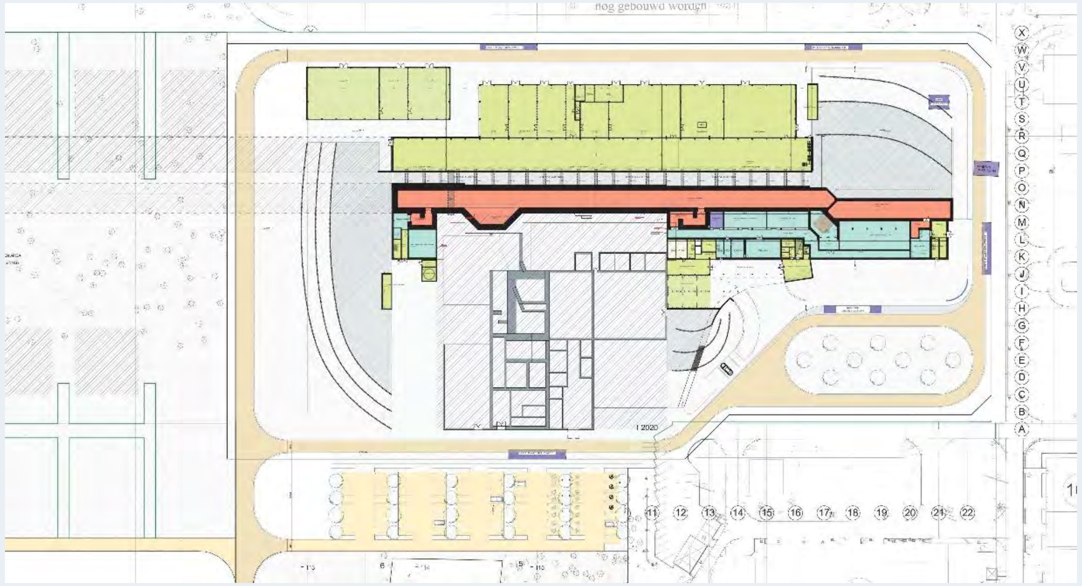
- **Transmission through RFQ 98%**
- **Beam holes ✓, Duty cycle (99,75%: 95% MYRRHA Reactor + 4,75% PTF**

☆ ***4 December 2020***



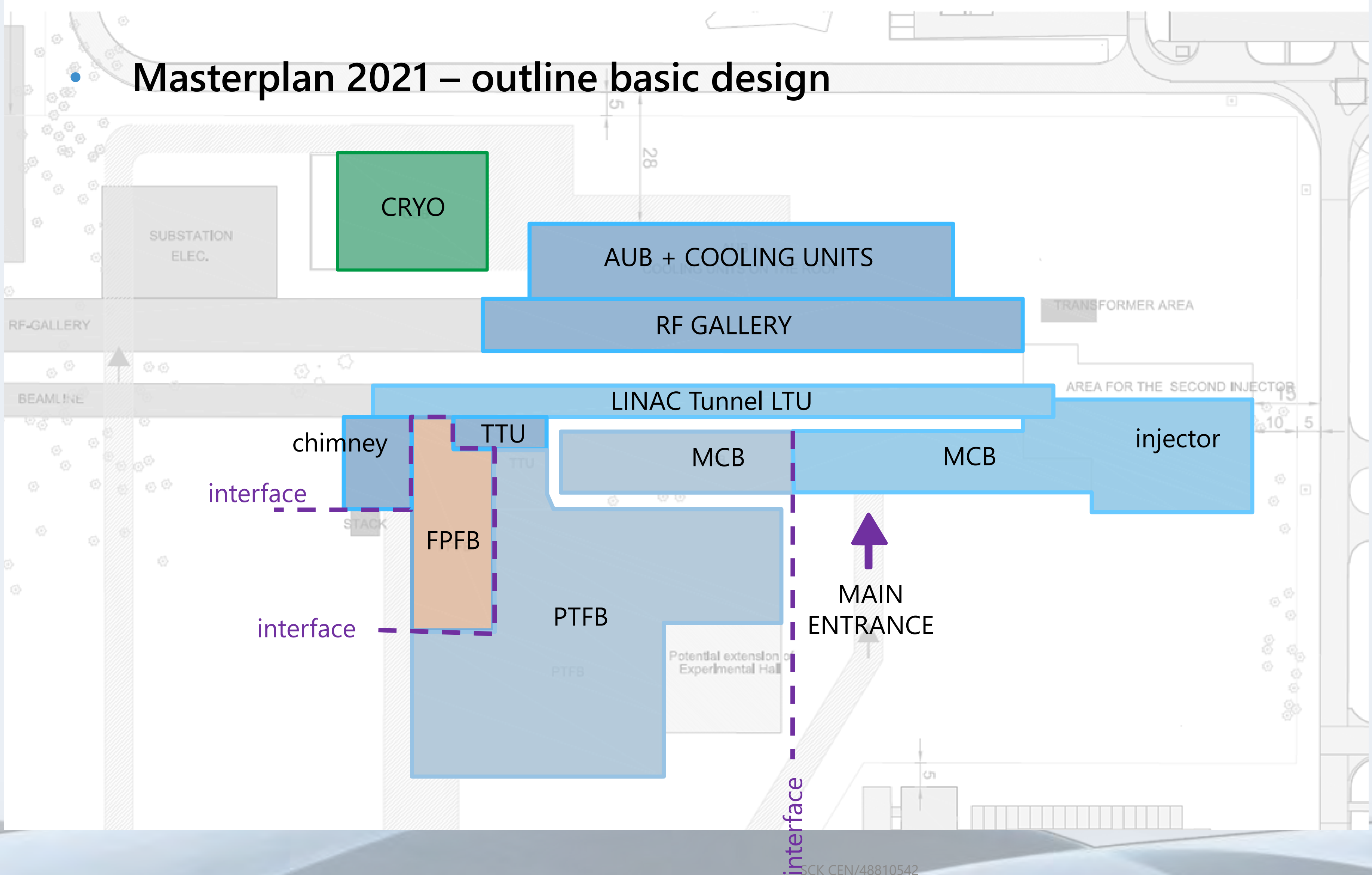
MINERVA implementation by 2026

- Overall architecture frozen, main internal floor plan decisions taken



Design status

- Masterplan 2021 – outline basic design

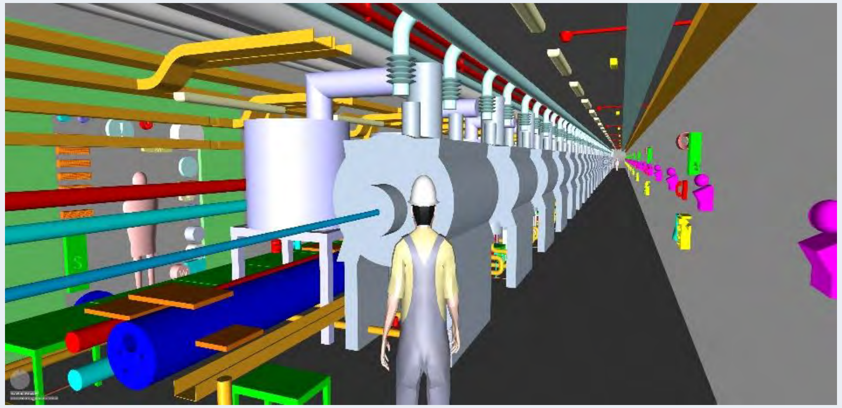


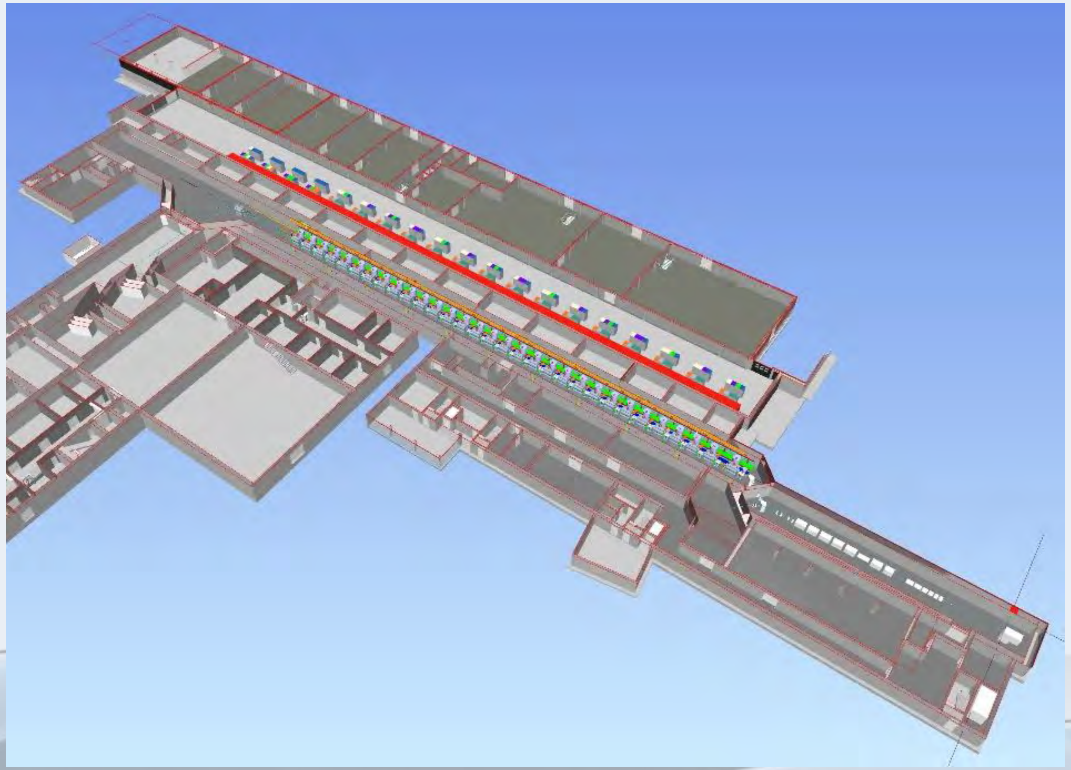
= ACC
= PTF
= FPF
= AUXILIARY

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

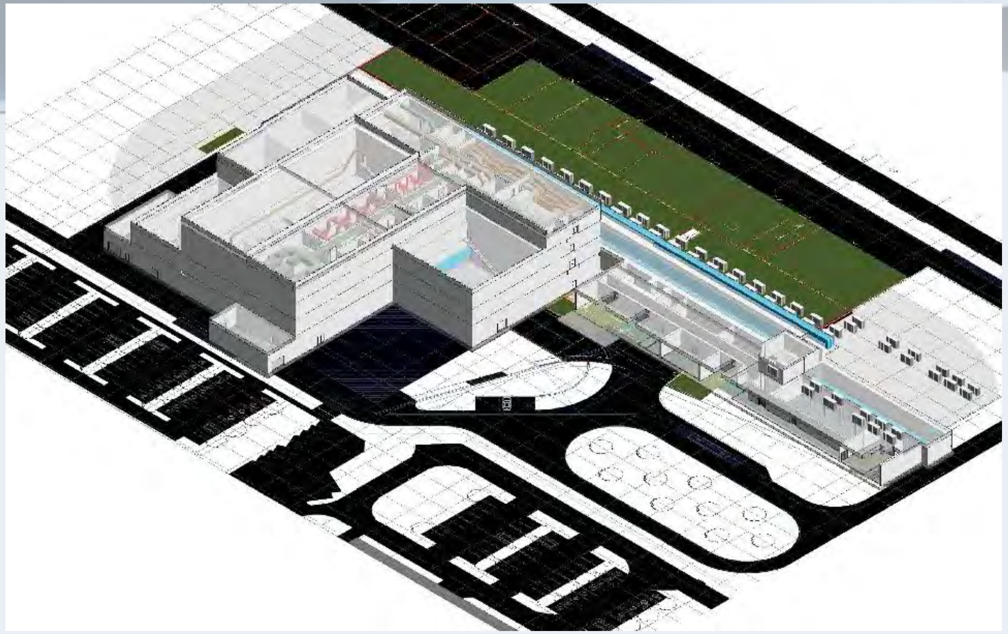
- **Outline Basic Design phase**
  - 3D data model
    - determines <u>minimum</u> level of detail (LOD 100) of all SSC
    - links ‘all’ information
    - tool for integration of SSC

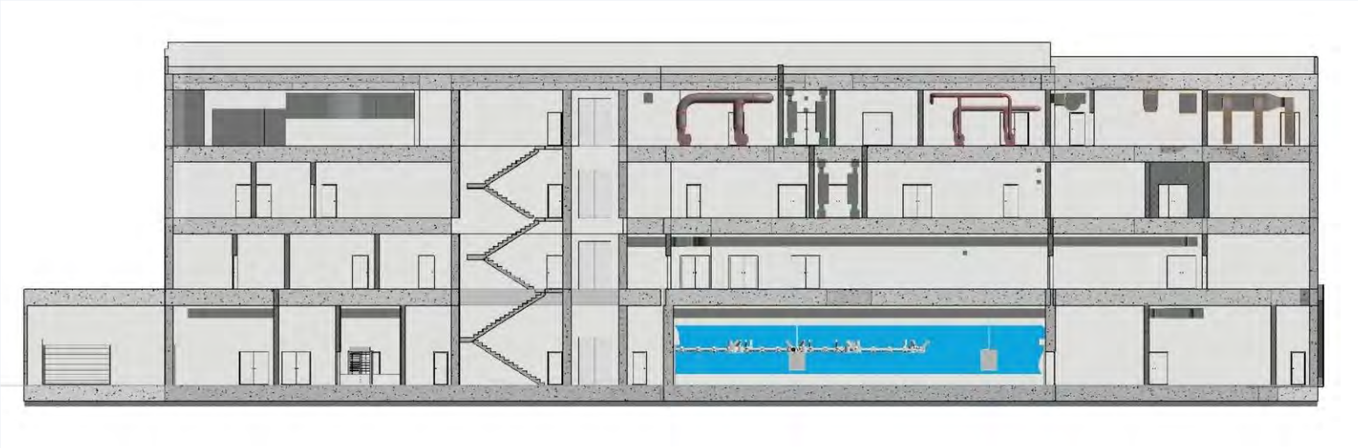


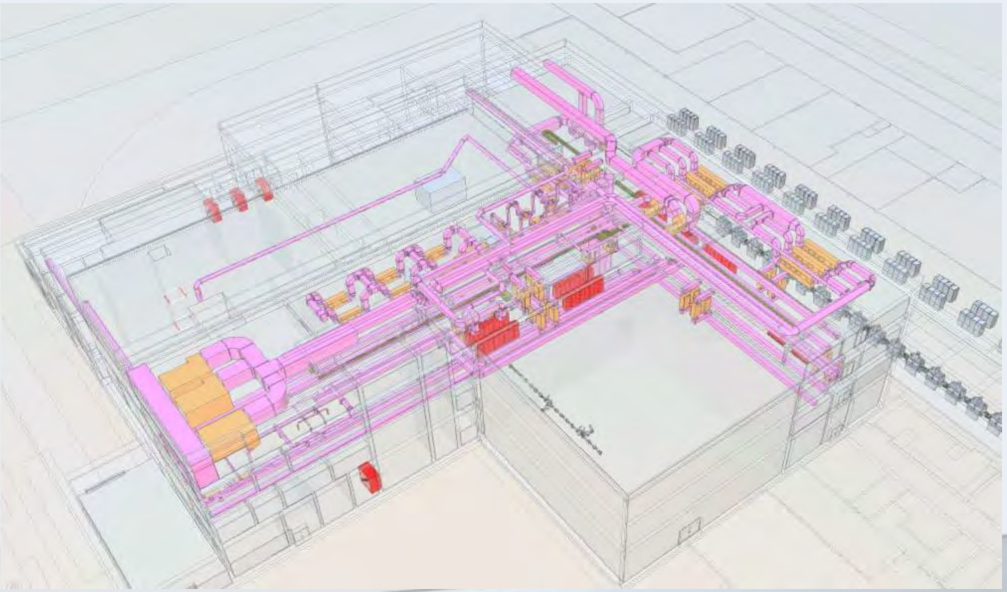


NF PTF

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

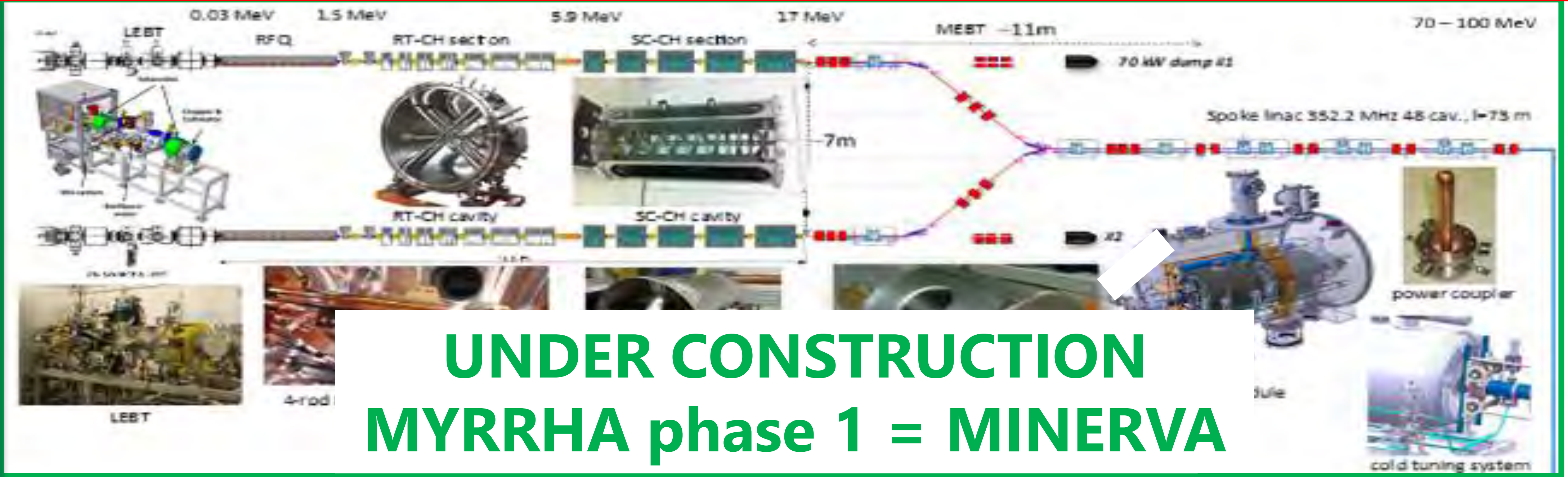






MYRRHA's PHASED IMPLEMENTATION STRATEGY

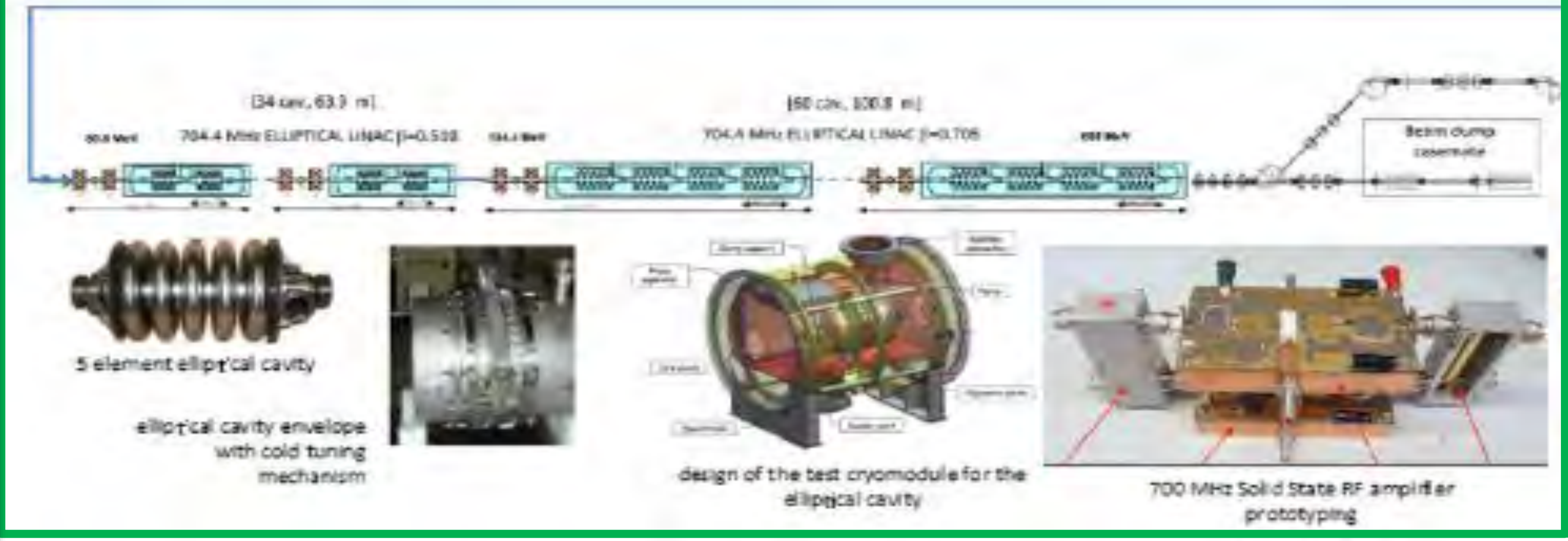
Phase 1 – 100 MeV + Proton Target Facility



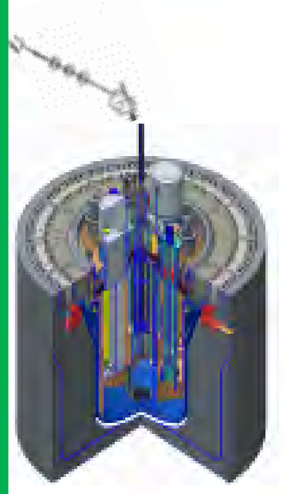
UNDER CONSTRUCTION

MYRRHA phase 1 = MINERVA

Phase 2 – 600 MeV



Phase 3 – Reactor



Source: SCK·CEN / MYRRHA Project Team

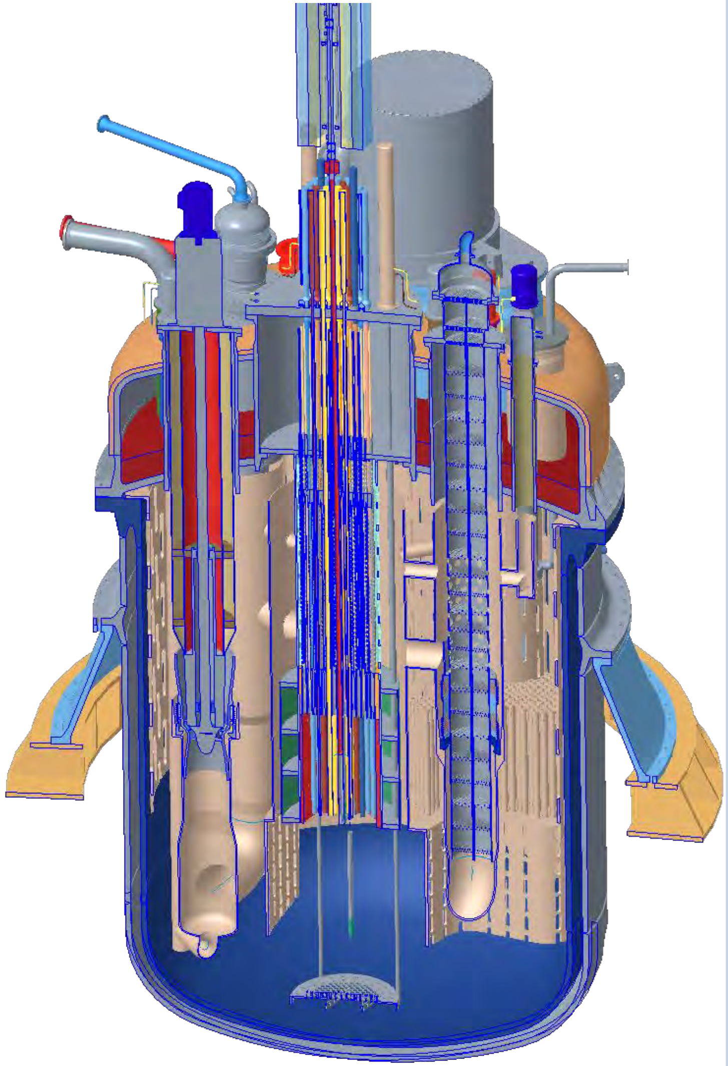
MYRRHA Reactor: implementation in 2036

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

Source:

MYRRHA reactor primary design Rev. 1.8, frozen end 2020

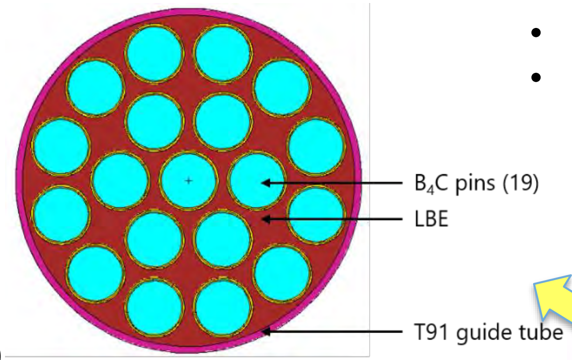
- Integrated Pool-type concept with Lead-Bismuth coolant
- Fuel assemblies: MOX fuel ~30wt.% Pu
- 4x heat exchangers
- 2x primary pumps
- Bottom core loading
- Safety vessel integrated into the primary vessel
- Decay heat removal by natural circulation
- Large sub-criticality
- Maximum power 70 MWth
- In-vessel temporary fuel storage



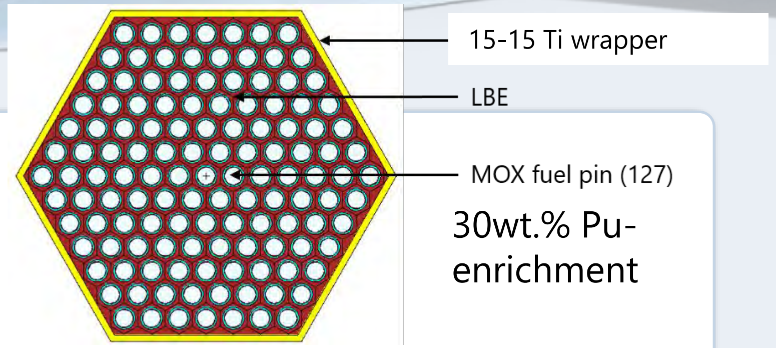
Subcritical (BOC) core layout

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

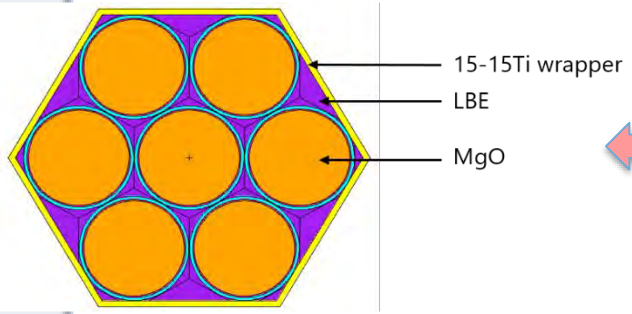
control rods (3)

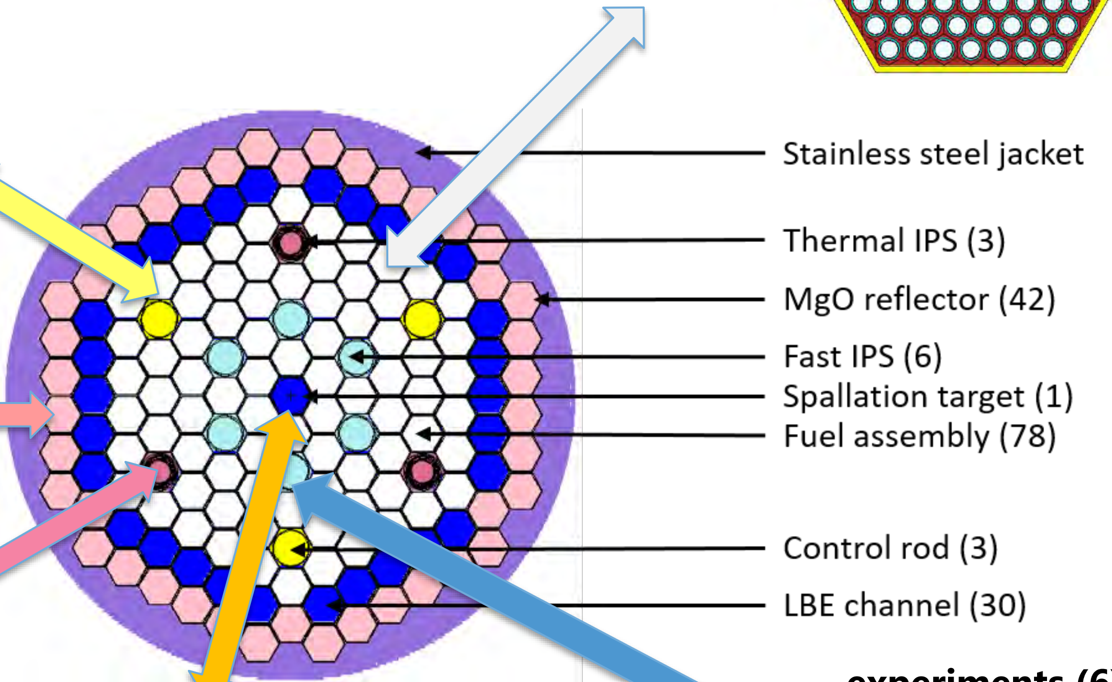


fuel assembly (78)



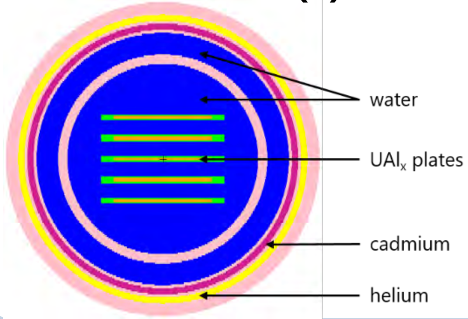
MgO reflector (42)



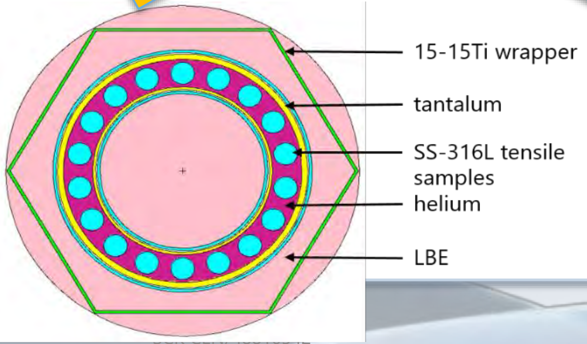


Parameter	Value
k_{eff}	0.92891
Core power (MW)	70
Beam current (mA)	3.6

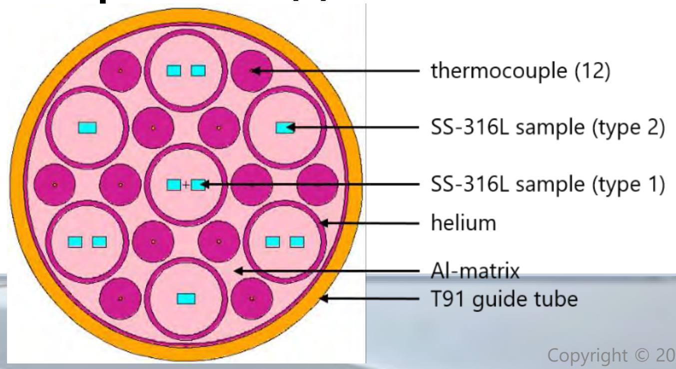
thermal islands (3)



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

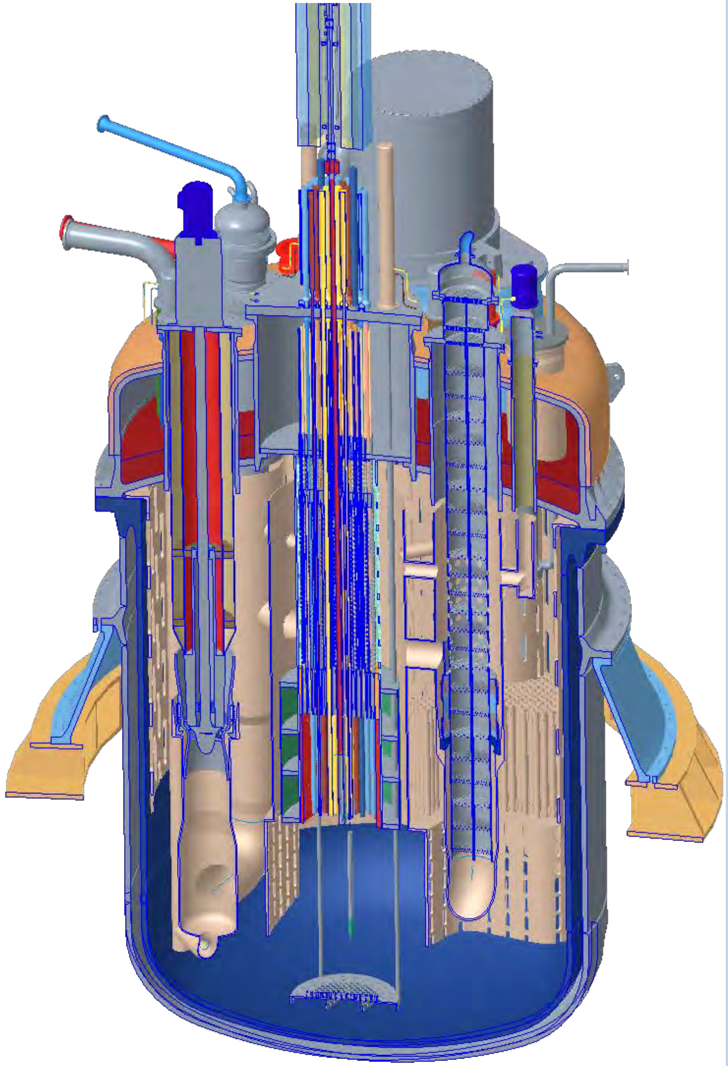


experiments (6)



MYRRHA reactor primary design Rev. 1.8, frozen end 2020
helping the faster development of LFR-SMR

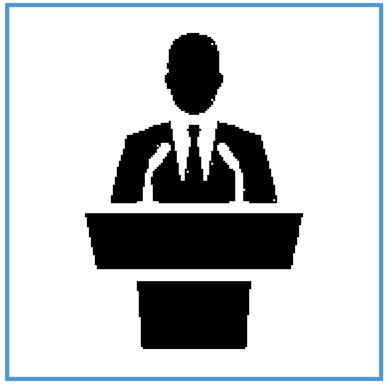
- Integrated Pool-type concept with Lead-Bismuth coolant
- Fuel assemblies: **MOX fuel ~30wt.% Pu**
- Decay heat removal by natural circulation
- Maximum power 70 MWth
- In-vessel temporary fuel storage



- ➢ Large HLM Technological complex for LFR support R&D
- ➢ Operating a Zero Power LFR Reactor since 2009
- ➢ Pre-Licensing experience of HLM Reactor with Belgian Regulator since 2011
- ➢ Large Data Base for MOX Fuel licensing

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 & FTS)
- 2019-2026: design, R&D and licensing for Phases 2 (extended linac 600 MeV) & 3 (reactor)
- 2027-2038: MINERVA operations (linac 100 MeV)

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

ANS MDB

MYRRHA International non-profit 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 AISBL
  - Establish the MYRRHA International Consortium
  - Guarding the overall scope of MYRRHA programme

MYRRHA AISBL/IVZW: Membership

- <u>Member categories :</u>
  a) **Founding members** : Belgian State and SCK CEN
  b) **Contributing members** open for :
    - Countries
    - **National Research Organisations, industries of a country**
    - International Institutions or Associations

- <u>Rights & Obligations</u>
  - 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 of nomination of a representative in the International Scientific and Technical Advisory Board (ISTAB)

Conclusion

Belgium sends a strong signal about its ambitions:

- Maintaining a high level of **know-how** in the nuclear field
- Continuing to be an **international pole of attraction** for young talents in nuclear applications
- Convert innovations into **solutions** for **societal challenges** (nuclear waste, nuclear medicine, sustainability)
- Encourage and welcome **international cooperation and partnership**

2018
Belgian Decision

→

Ground breaking
Q4 2022 – Q2 2023 !