4th International Workshop on ADS & Thorium

August 31 – September 2, 2016, Huddersfield, UK

SCK•CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE

MYRRHA project status (06.2016)

Contribution for HLW management and SMR development based on lead technology

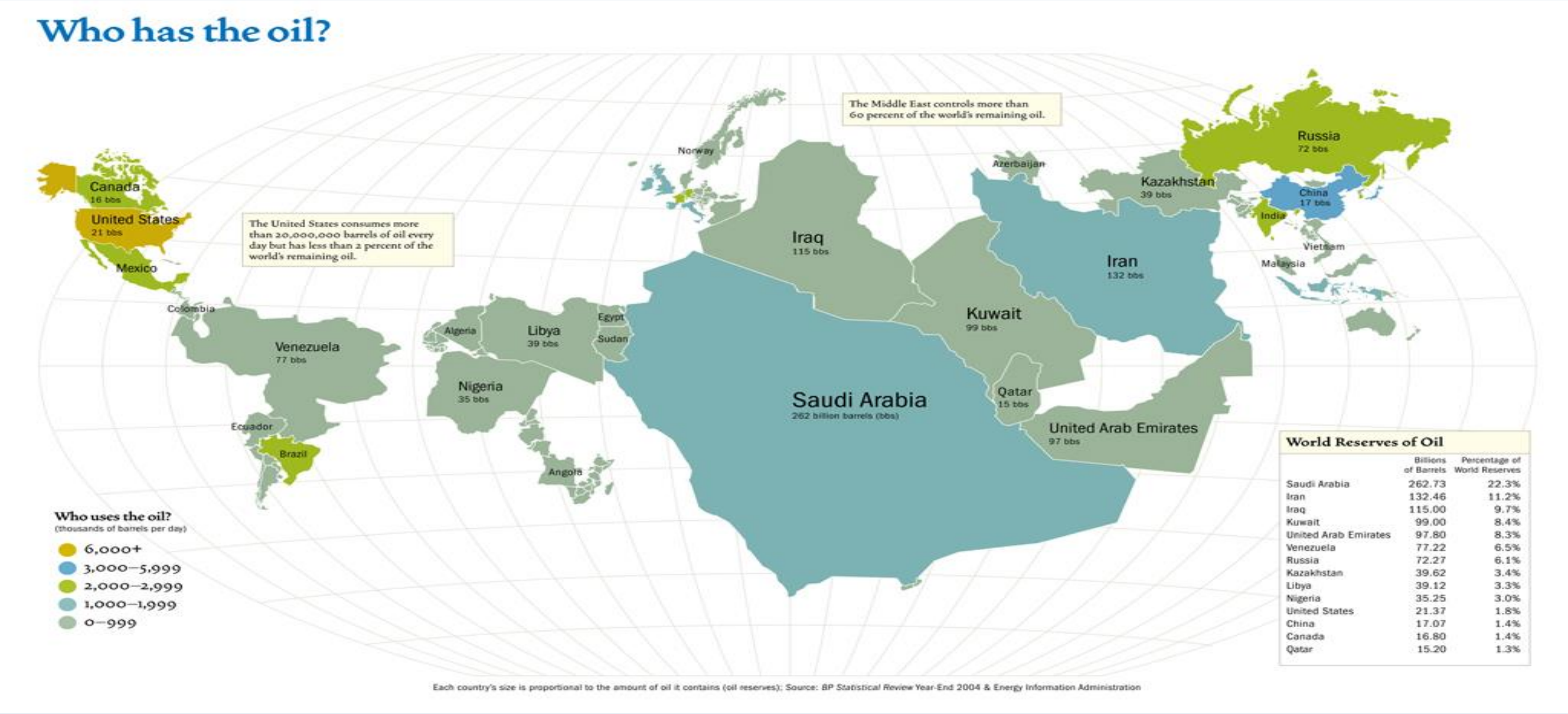
Hamid Aït Abderrahim

haitabde@sckcen.be
myrrha@sckcen.be

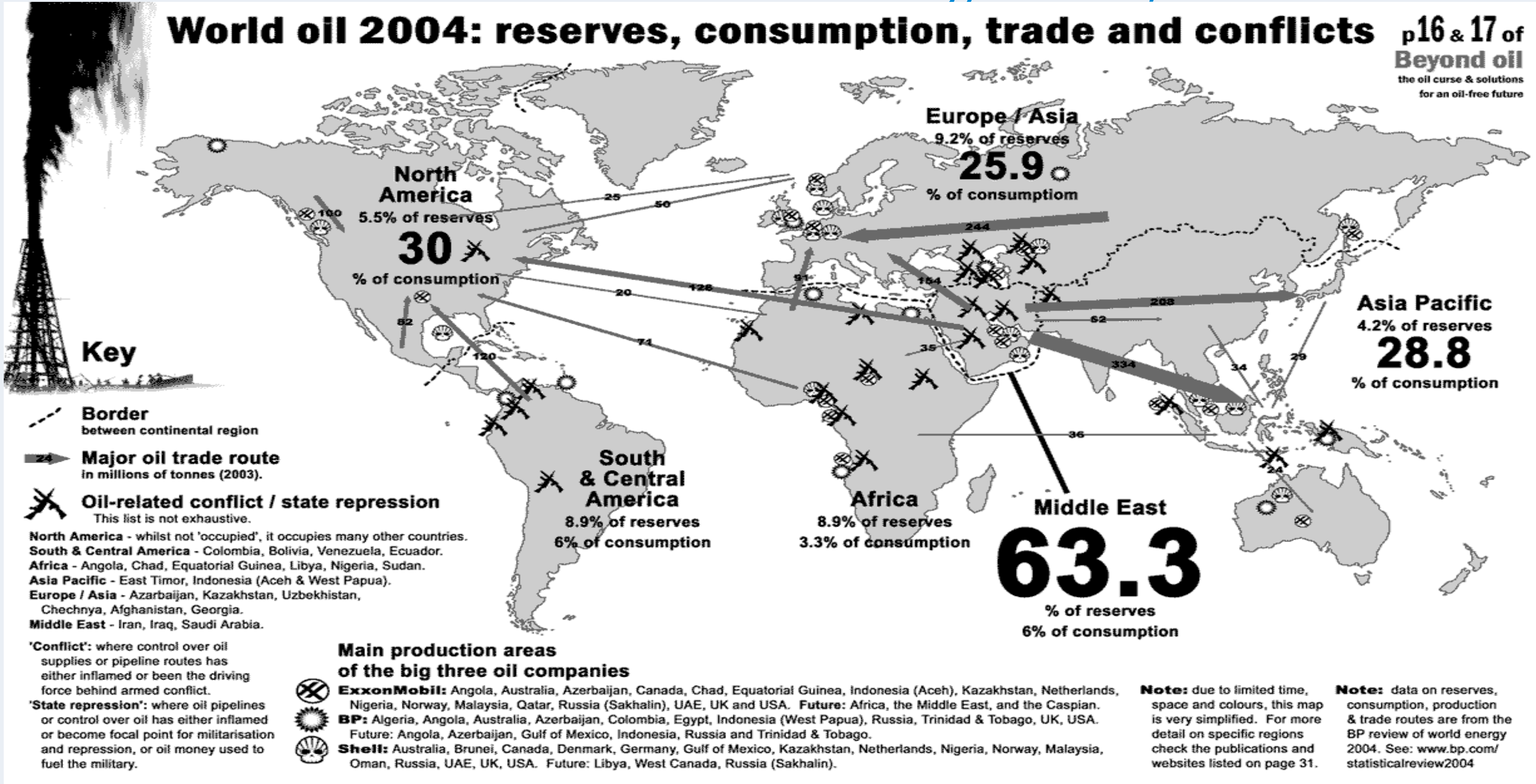
Outline

- Some energy related facts
- Role of Nuclear Energy in the Future Energy Mix (SMR?)
- The EC Partitioning & Transmutation strategy for HLW management
- MYRRHA Project at a Glance (Status 06.2016)
- Conclusion

Energy challenges :
geopolitical considerations – Who has the oil?

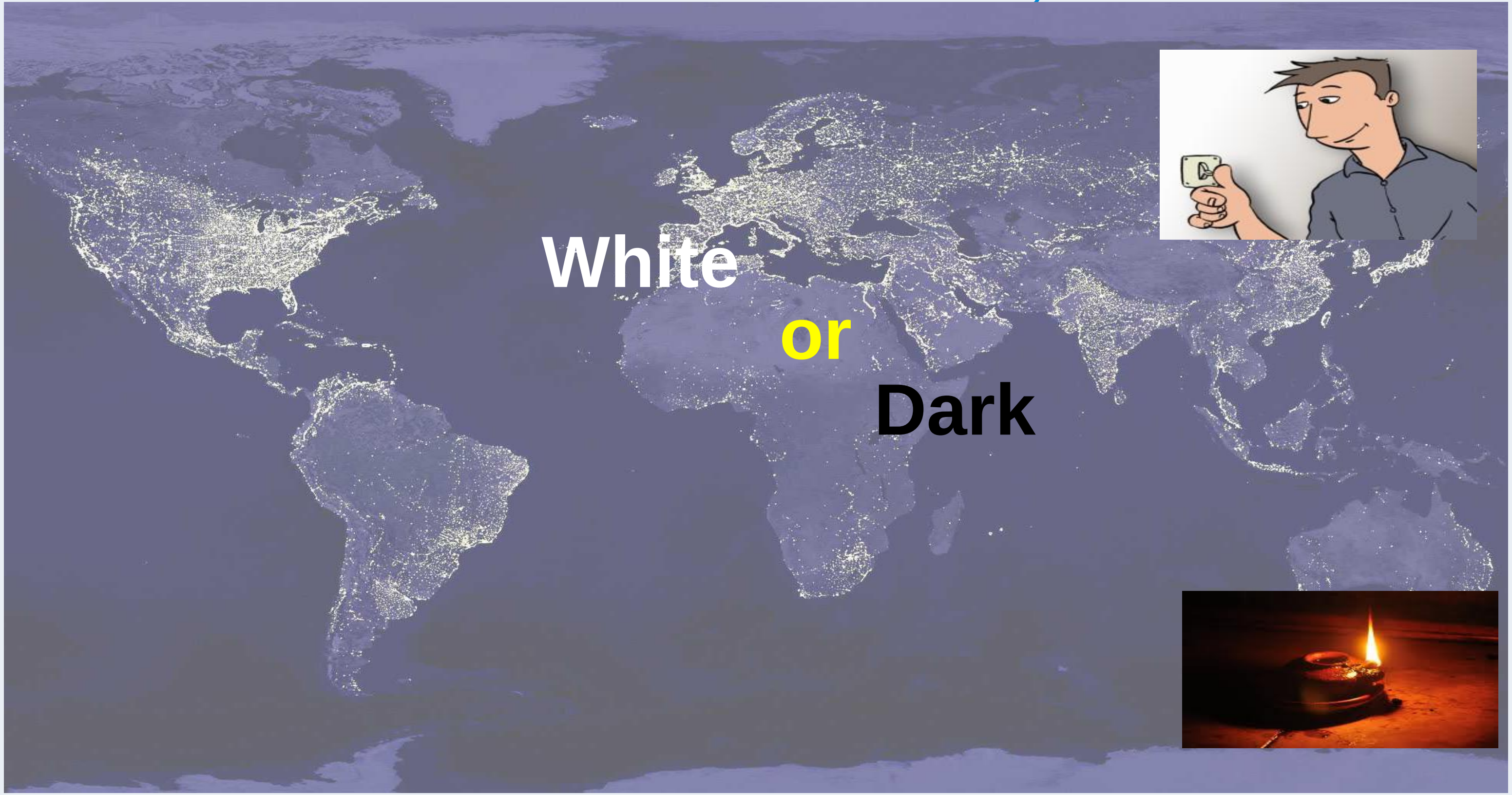


Energy challenges :
correlation energy routes / armed conflicts



Energy challenges :

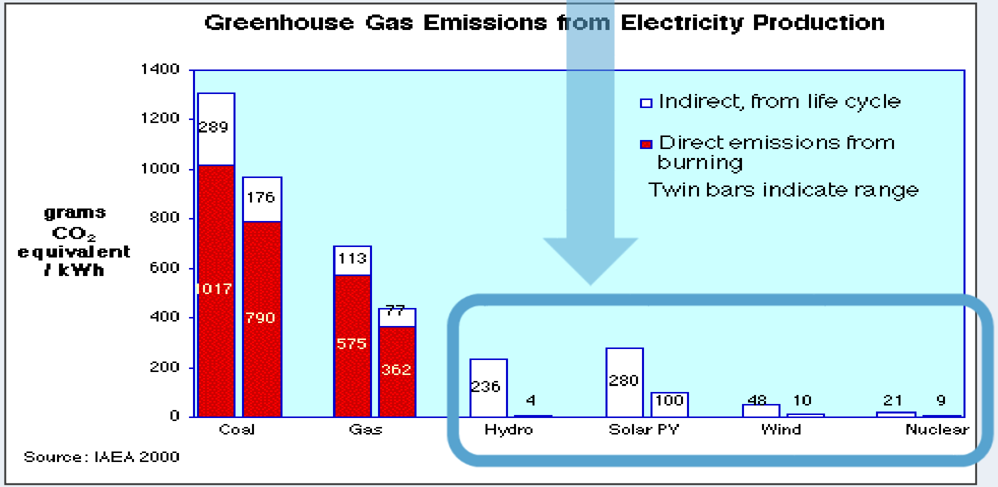
What’s the colour of electricity? Green? Red? Blue?...



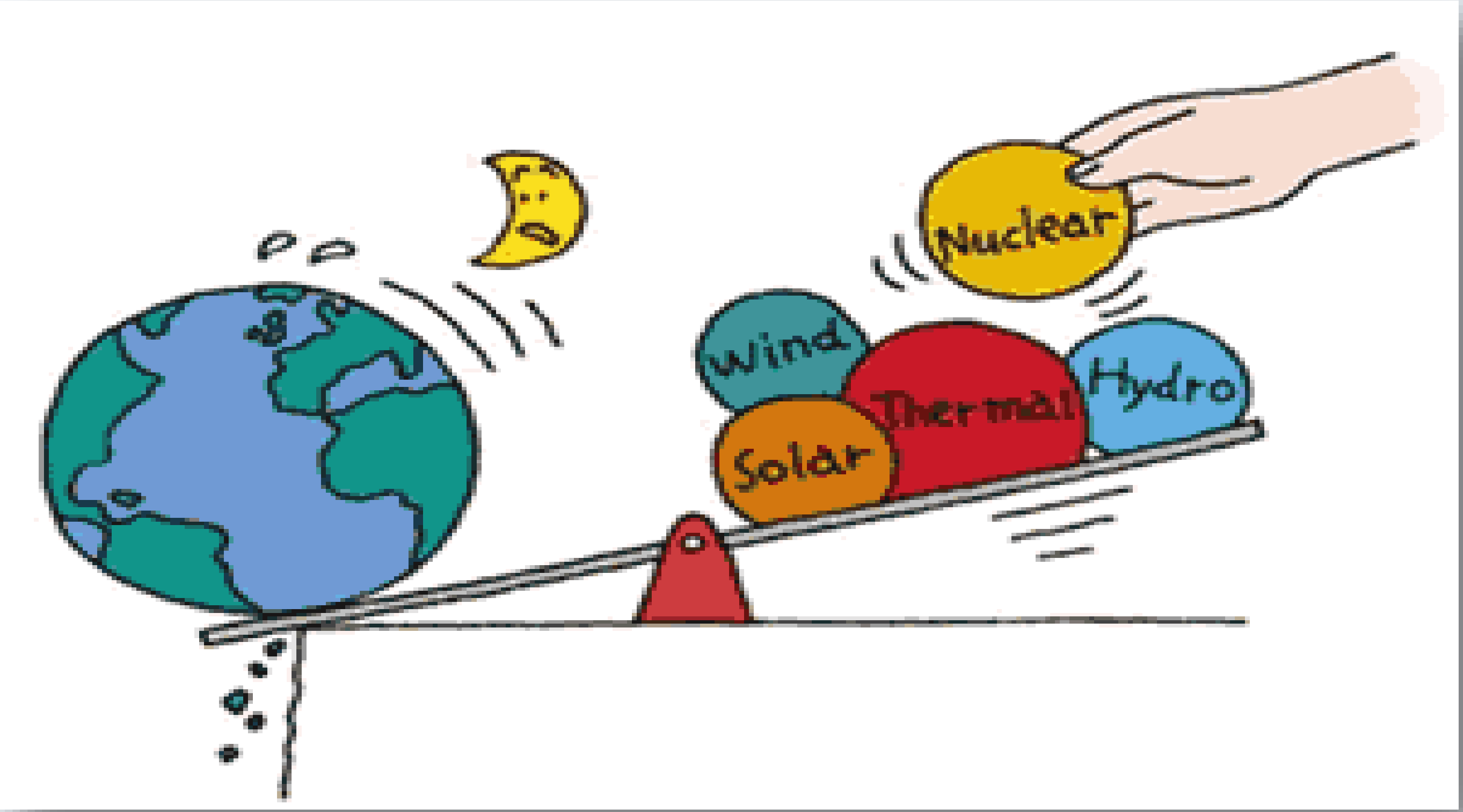
Energy challenges :
Will the energy saving, save the world ?

	2010	2030	2050
Pop. OECD (mio)	1.200	1.400	1.500
Energy Demand (oet/cap.)	5.5	3[e]	2.8
Total Energy Consumption OECD (mio oet)	6.600	↓ 4.200	4.200
Pop. Non-OECD (mio)	5.400	6.700	7.500
Energy Demand (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**

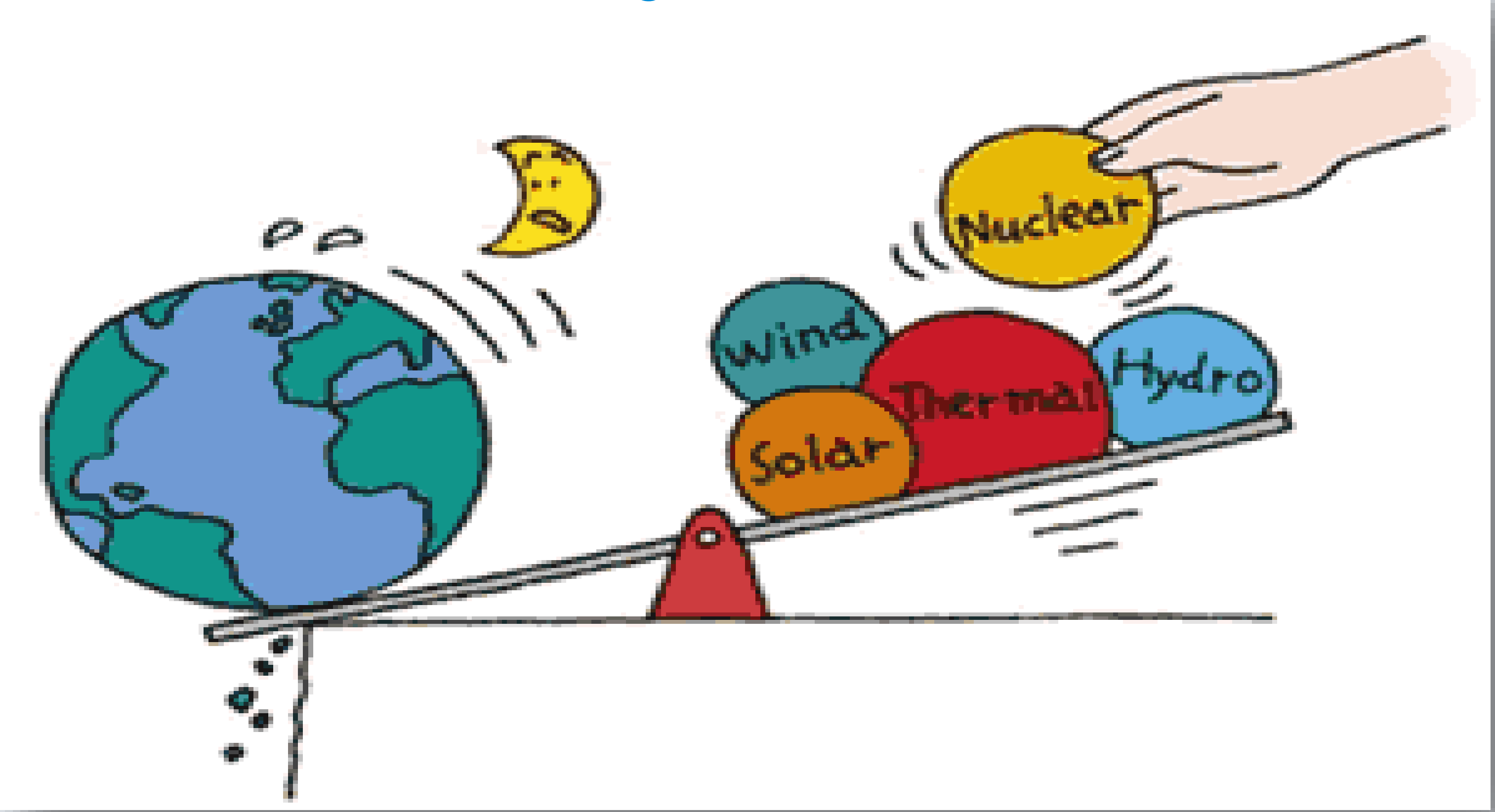
Energy challenges :
invest in all CO_2 non-emitting energy sources including nuclear energy



So, future is bright for nuclear



So, future was bright for nuclear
(we were talking about nuclear renaissance in 2005)



We knew what to do
Global challenges for nuclear energy today

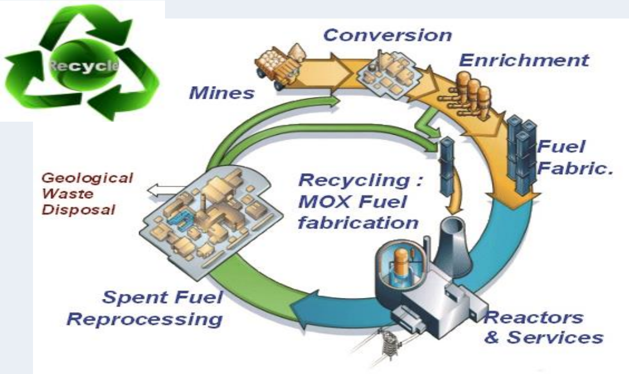
Common needs

Burning legacy of the past

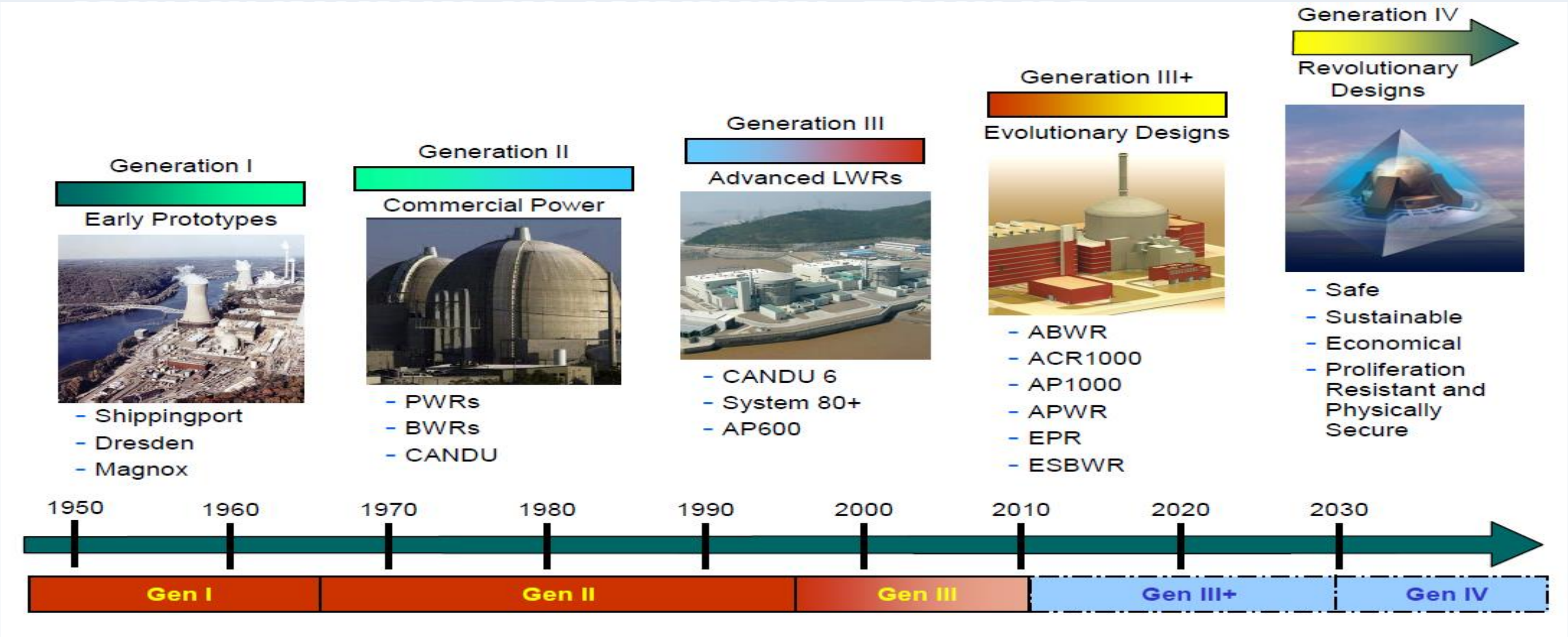
Reducing cost of ultimate waste

Better use of resources

Enhance Safety



We got a worldwide guideline for the nuclear technology
By Gen.IV International Forum



Then what's wrong with this nice story?

- May be the **European nuclear actors are not anymore the leading players**
- May be we are overemphasising the R&D towards **more and more safety** bringing in our systems more and **more complexity and forgetting innovation**
- May be **innovation is not stimulated enough** in this sector driven by industries willing progress by **small steps rather than by breakthroughs**
- May be this **sector wants that the environment (political, social, industrial) should adapt itself to nuclear energy** technology characteristics of the past and **not the opposite**

To make nuclear energy sustainable and part of the energy-mix of tomorrow

SNETP
Sustainable Nuclear Energy Technology Platform

nuclear waste

resource utilisation

Enhanced safety

proliferation risk

We got a worldwide guideline for the nuclear technology

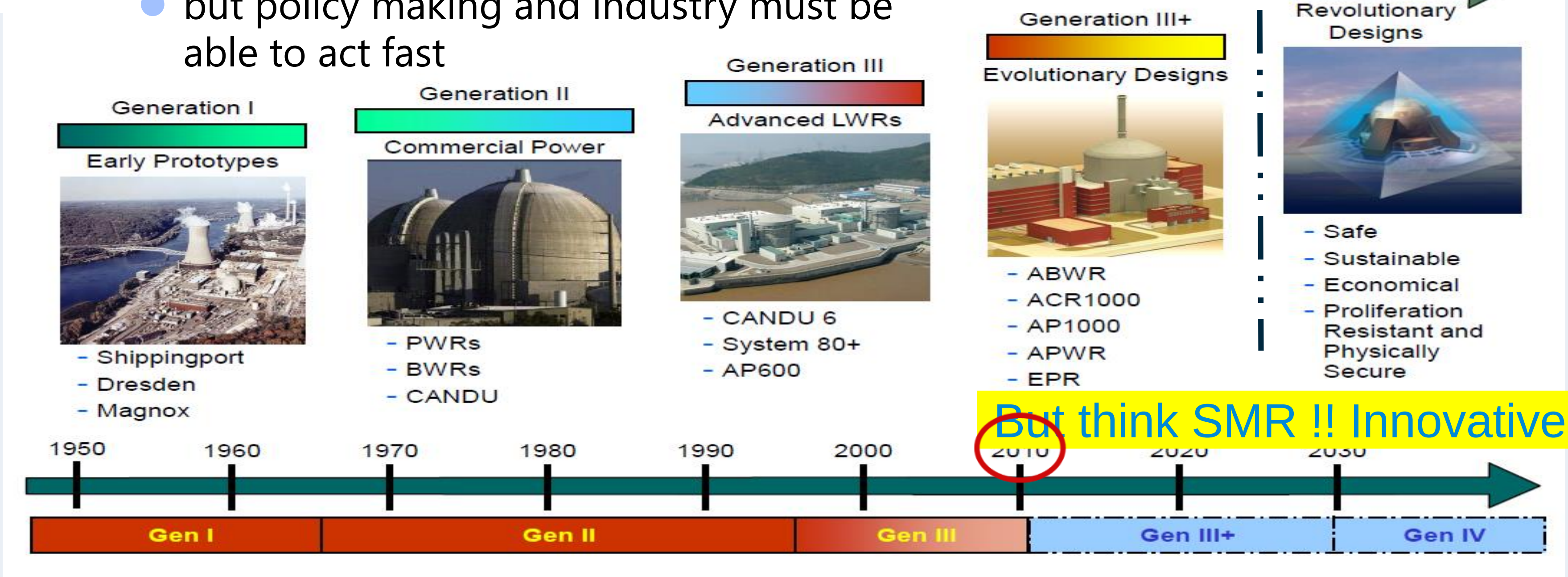
By Gen.IV Internal Forum but this can be updated

GEN II, III, III+ can do the CO_2 job by 2050

- nuclear x3?: technology exists: need for ~20 plants to be on-line/year til 2050
- but policy making and industry must be able to act fast

Fast neutrons

- reduce waste legacy
- maximise resources



But think SMR !! Innovative ones

Turn R&D into :
Economic valorisation may be with actors not coming from the sector

Développement de petits réacteurs modulaires
(50 – 300 MW)

Mini nuclear reactors
The Economist Dec 9 2010

A new paradigm for power generation (1)

Bill Gates, one of the richest men in the world, suggests that we use nuclear power plants to reach a goal of zero carbon output.

Toshiba and TerraPower aim to create a reactor that doesn't need to be refueled for 100 years.

It's possible Microsoft Chairman Bill Gates and Toshiba have opened dialogue to create a next-generation nuclear reactor able to run up to 100 years before it needs to be refueled, according to Japanese media reports.

Gates' TerraPower and Toshiba's Westinghouse reactor design company plan to develop the uranium-based Traveling-Wave Reactor (TWR) with 100,000 Kilowatts up to 1 million KW support.

Until something is official between the two sides, and Toshiba will continue development on a reactor that needs to be refueled once every 30 years. The Super-Safe, Small and Simple (4S) reactor is an ultra compact reactor that will likely have U.S. approval before the end of the year.

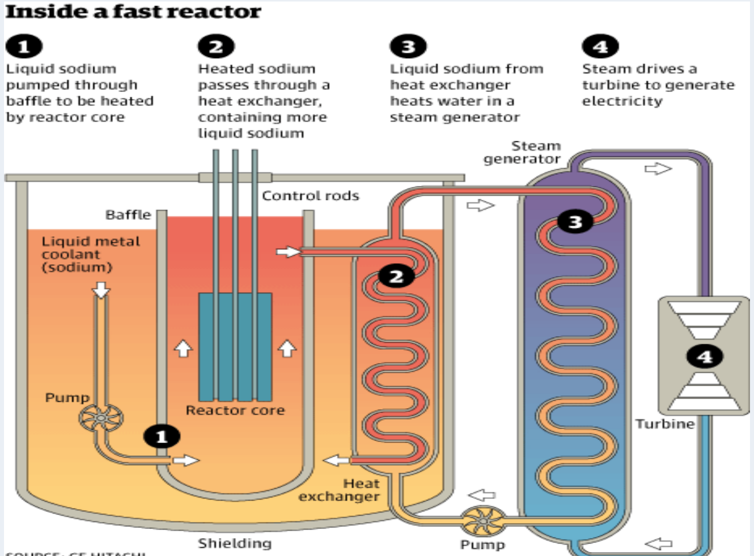
If there are no major hiccups, the reactor will be available before 2014.

Today's units need to be refueled every few years – using fuel based from depleted uranium can last significantly longer. There is special need for these mini-reactors in developing nations, analysts say, with the price tag expected to lower in the future.

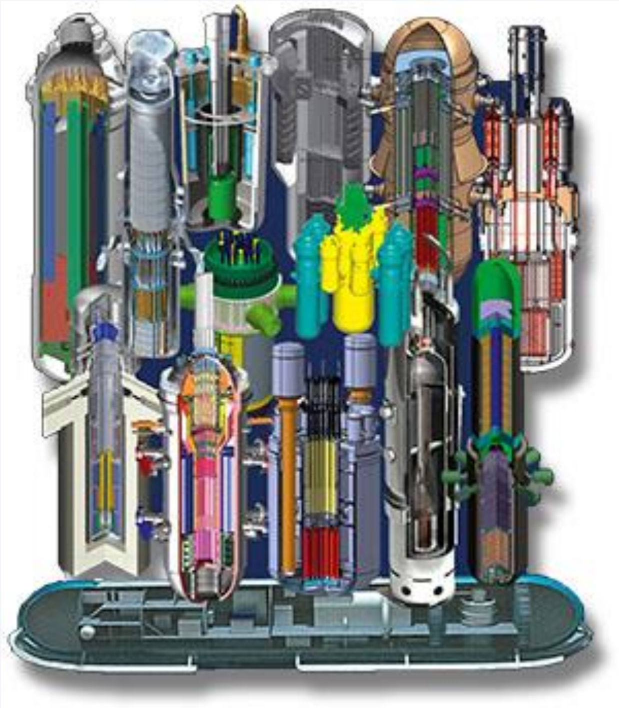
A new paradigm for power generation (2)

Richard Branson urges Obama to back next-generation nuclear technology
Billionaire pushes for the technology in a letter to White House that says integral fast reactors are clean, inexpensive and safe

Richard Branson: "Obviously we urgently need to come up with a clean effective way of supplying our energy since not only are the dirty ways like oil running out but we need to do so to help avoid the world heating up". In The Guardian of July 20, 2012



SMRs are being developed all over the world



10 countries
45 concepts of SMR
4 technologies: Water, gas, Liquid metal

Design requirements
    Vessel size (4x6m)
    Higher Operating temperature
Passive decay heat removal systems

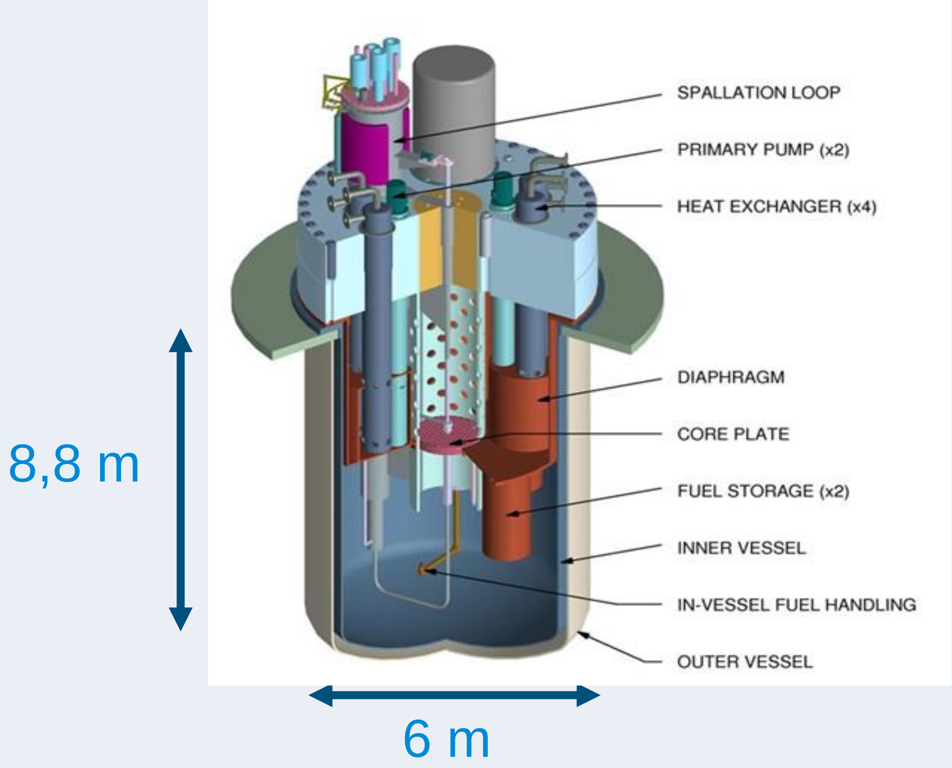
Fuel cycle of 10-15 years (for innov.)

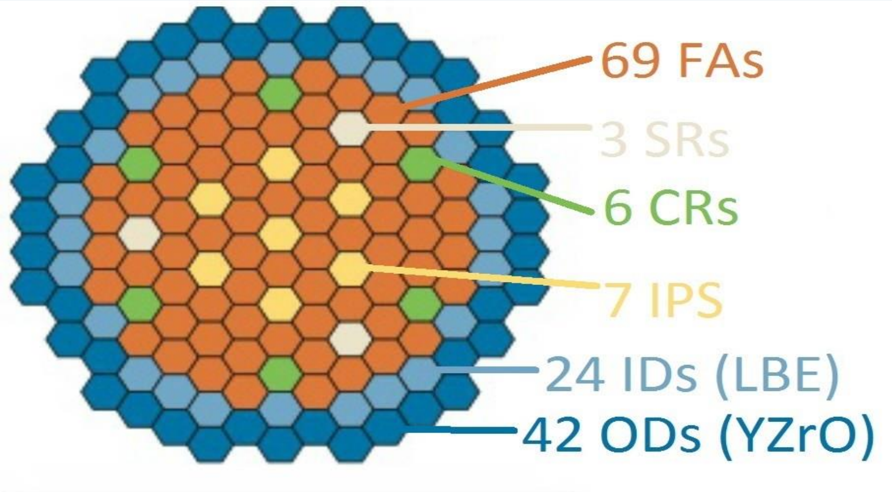
SMR-CD is a MYRRHA-based power reactor

- 60 – 100 MWe unit with fuel cycle of ~10 years ➔ less refuelling
- Transportable ➔ mass production
- Passive safety systems ➔ unlikely major accidents

- Competitive against Large Reactor (LR)
- Short construction time (3 years)
- Limited Capital Investment (400 ~ 500 M€) FOAK

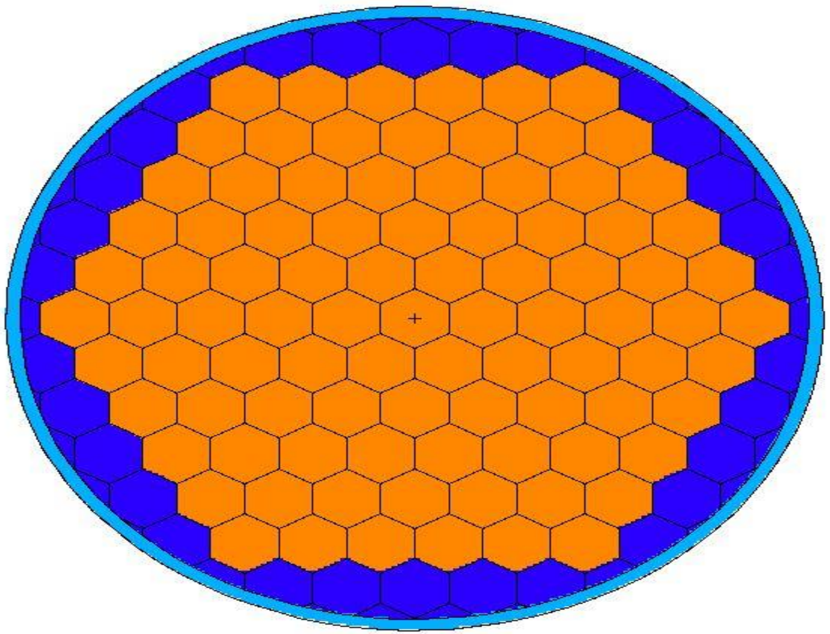
MYRRHA is research reactor with ADS using MOX and LBE





Core configuration of MYRRHA

Core of SMR-CD: Thermal hydraulics



SMR-CD’s FA: #85, D:133 mm, L:1,3 m
4 CRs + 2 SRs

Pressure drop (<2,5 bar) : MYRRHA

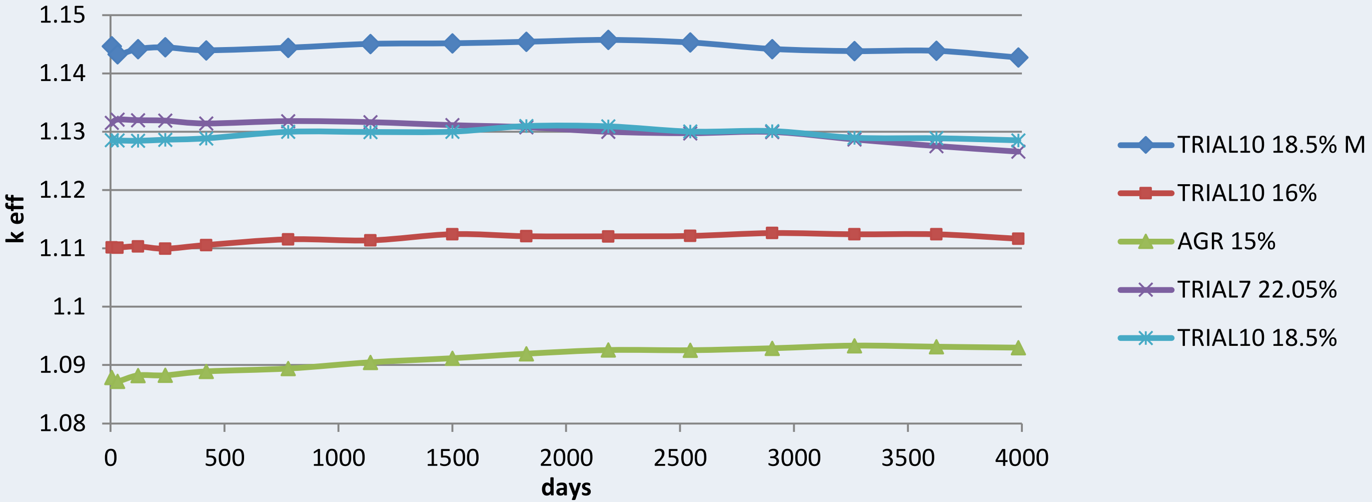
Coolant velocity (< 2 m/s) : erosion

Operating Temperature

T > 270°C : embrittlement

T < 440°C : corrosion

Long Fuel Cycle achivable

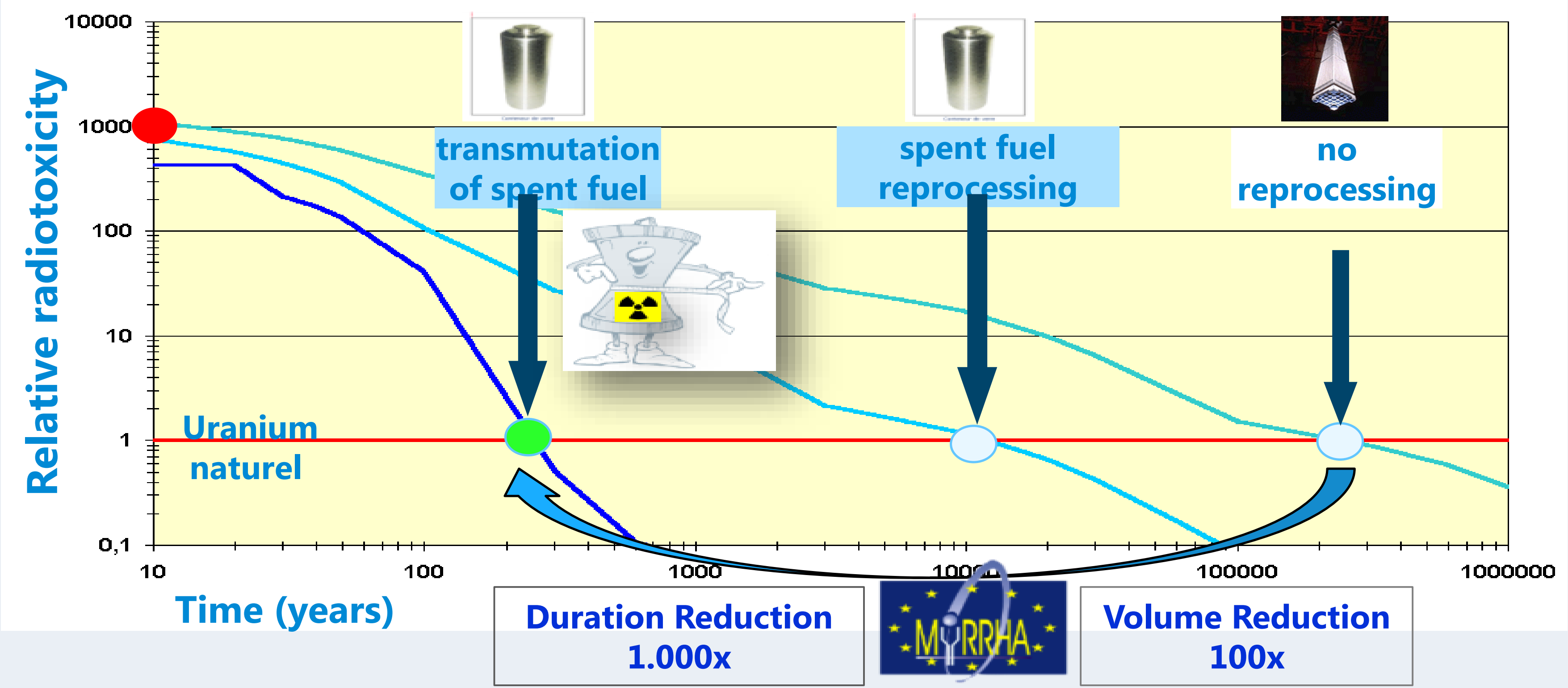


All these fuels are optimized and make the test core slightly super-critical. Compositions are in atomic fractions.

Name	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	*a*
TRIAL7 22.05%	58.20	3.02	33.79	0.06	4.93	0.1067
TRIAL10 18.5% M	2.35	49.74	42.91	0.06	4.94	0.1058
TRIAL10 18.5%	29.62	31.56	33.826	0.060	6.069	0.1058
TRIAL10 16%	7.04	54.11	33.84	0.06	4.95	0.1028
AGR 15%	10.80	54.31	29.94	0.00	4.95	0.1075

The EC Partitioning & Transmutation strategy for HLW management

Come with acceptable solutions for HLW
Motivation for transmutation



Demonstration of P&T at **engineering level** at the center of the European Commission Strategy

- The EC and EU Membre States R&D activities consists of four "building blocks" (BB):
  1. Demonstration of the capability to process a sizable amount of spent fuel from commercial LWRs in order to separate plutonium (Pu), uranium (U) and minor actinides (MA),
  2. Demonstration of the capability to fabricate at a semi-industrial level the dedicated fuel needed to load in a dedicated transmuter, (JRC-ITU)
  3. Design and construction of one or more dedicated transmuters, → **MYRRHA**
  4. Provision of a specific installation for processing of the dedicated fuel unloaded from the transmuter, which can be of a different type than the one used to process the original spent fuel unloaded from the commercial power plants, together with the fabrication of new dedicated fuel.

EC contributes to the 4 BB and fosters the national programmes towards this strategy for **demonstration at engineering level**.

Belgium contributes to the EC P&T strategy by focusing on BB3 through the realisation of MYRRHA as a pre-industrial ADS demonstrator and R&D facility

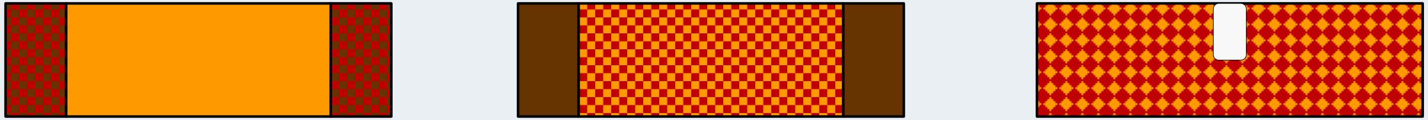
Three options for Minor Actinide transmutation

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

FR heterogeneous

FR homogeneous

ADS



Driver fuel
Blanket with MA

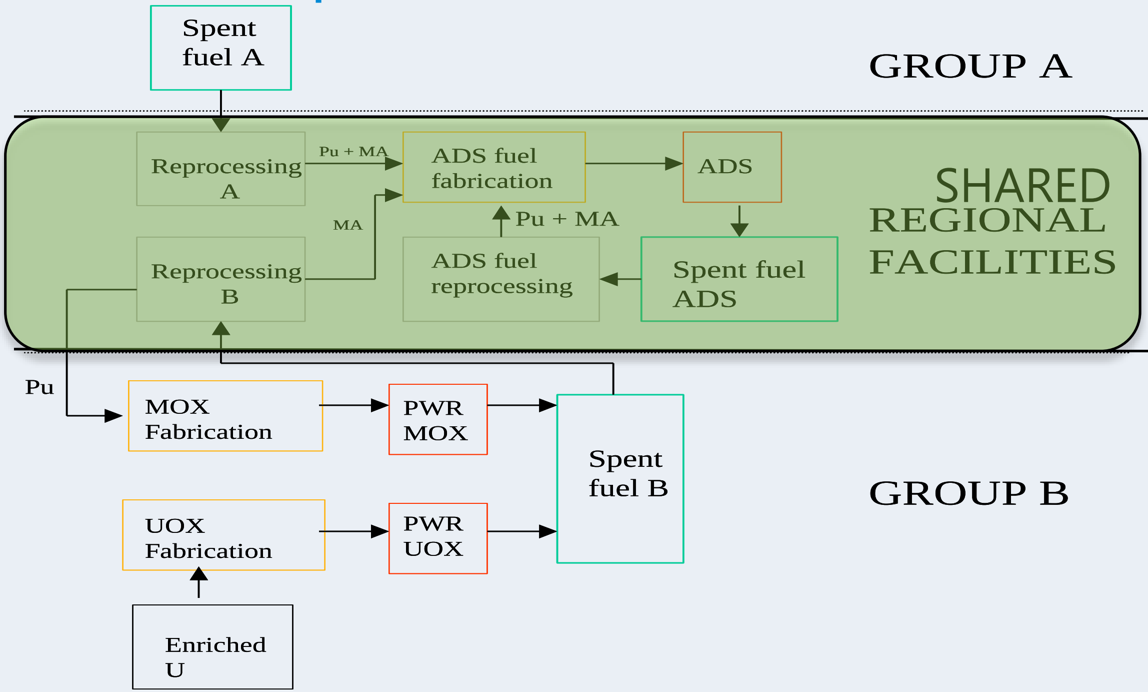
Fuel with MA
Blanket

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)

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



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

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

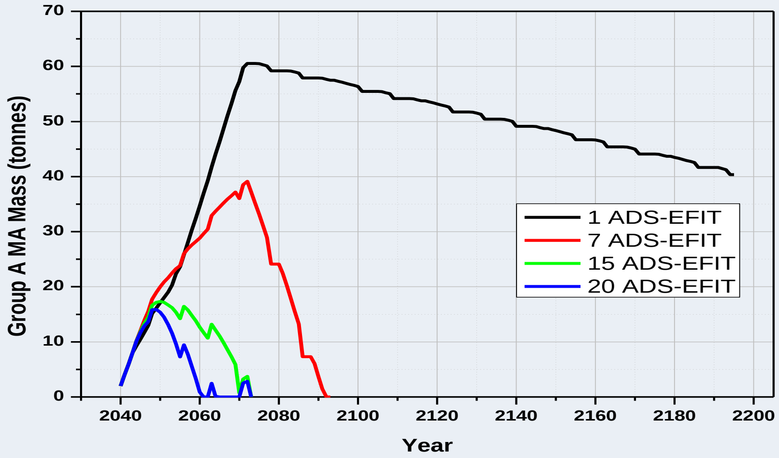
Scenario 1 objective: elimination of A's spent fuel by 2100

A = Countries Phasing Out, B = Countries Continuing

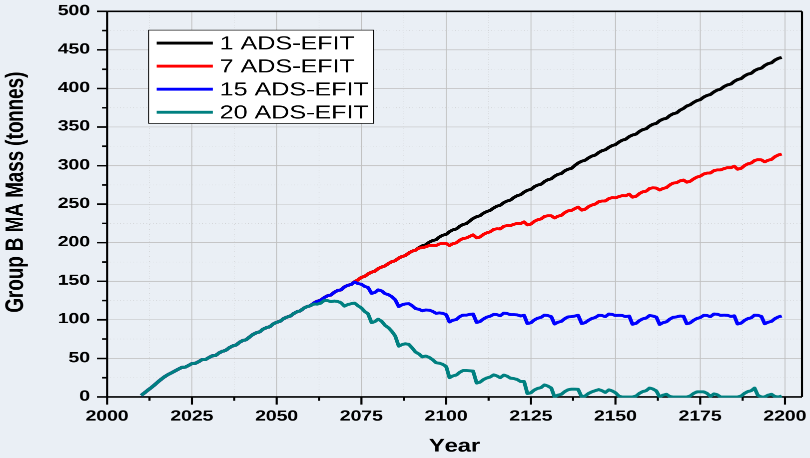
Industrial implementation of ADS in a regional approach

From PATEROS FP6 project

EU countries phasing out NE



EU countries continuing NE



- ADS technology enables present generation to avoid transferring the burden of HLW to future generations

* PATEROS partners: SCK•CEN (BE), Ansaldo Nucleare (IT), CEA (FR), CIEMAT (SP), CNRS (FR), ENEA (IT), AREVA NP (FR), FZK (DE), ITU (EU), KTH (SE), NRG (NL), NRI (CZ), PSI (CH), UPM (SP), ITN (PT), Nexia Solutions (UK), Manchester University (UK)

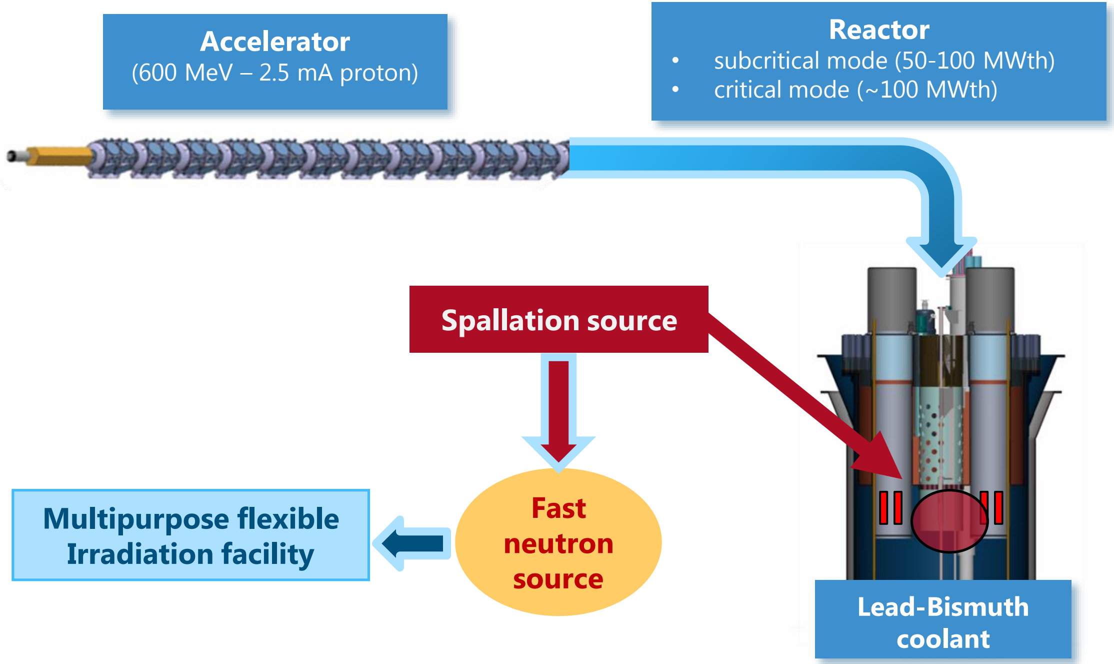
Economics evaluation need validations

- Investment – capacity needed
- Operational costs
- Fuel cycle costs
- Transportation costs
  - Spent LWR fuel
  - Homogeneous MA fuel for Fast Reactors
  - Heterogeneous MA fuel for Fast Reactors
  - ADS fuel
- Technological Readiness Levels are low → very hard to estimate costs
- **We need pre-industrial level demo facilities for the various stages of P&T at international level, Belgium contributes to BB3 through MYRRHA**

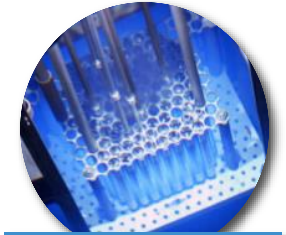
Key objective of the MYRRHA-programme

Construction of an Accelerator-Driven System (ADS) as a Large Research Facility consisting of

- A 600 MeV – 2,5 mA proton linear accelerator
- A spallation target/source
- A lead-Bismuth Eutectic (LBE) cooled reactor able to operate in subcritical & critical mode



MYRRHA is a multipurpose research facility

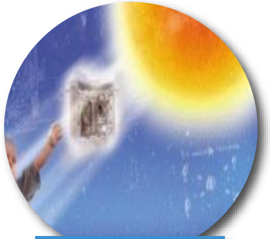


Fission GEN IV

SNF & HL Waste

Radio-isotopes

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



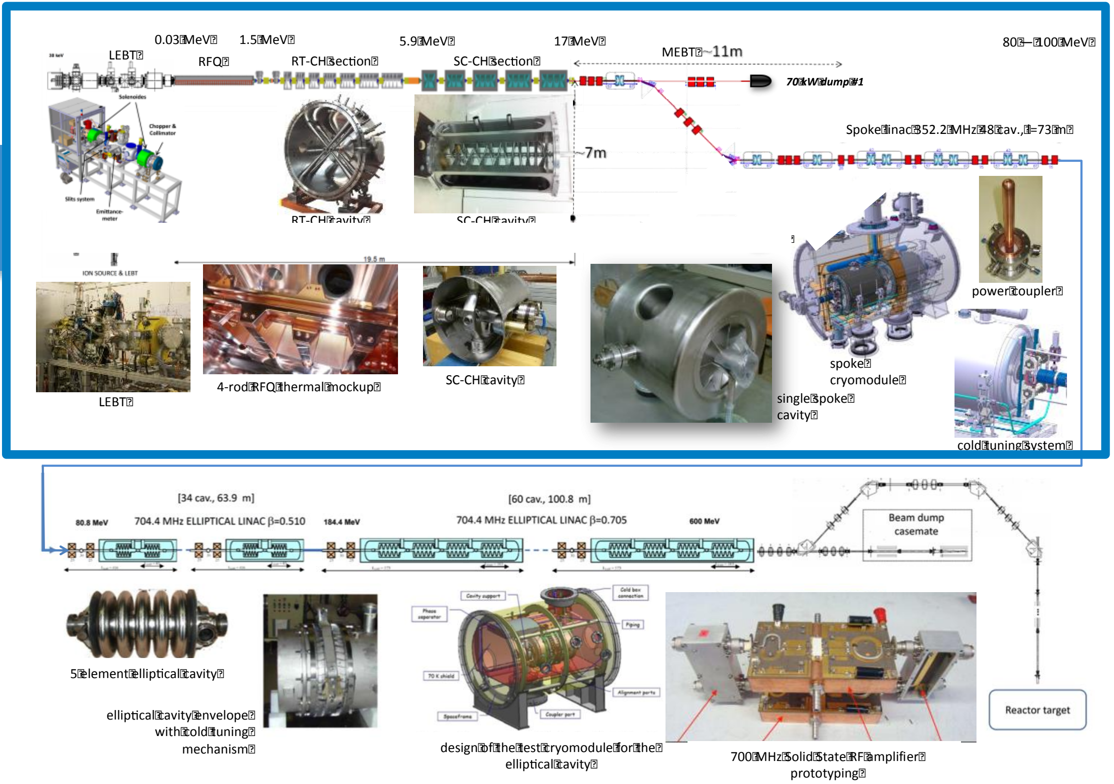
Fusion

Fundamental research

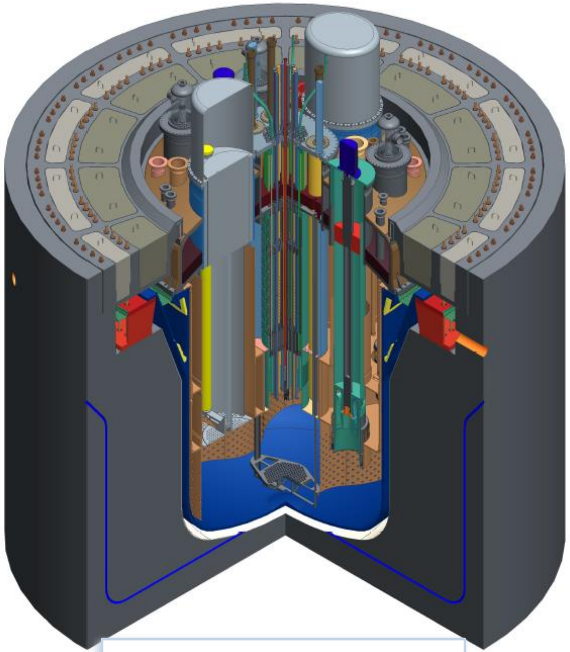
Silicon doping

MYRRHA accelerator design

MYRRHA accelerator 0 – 100 MeV section



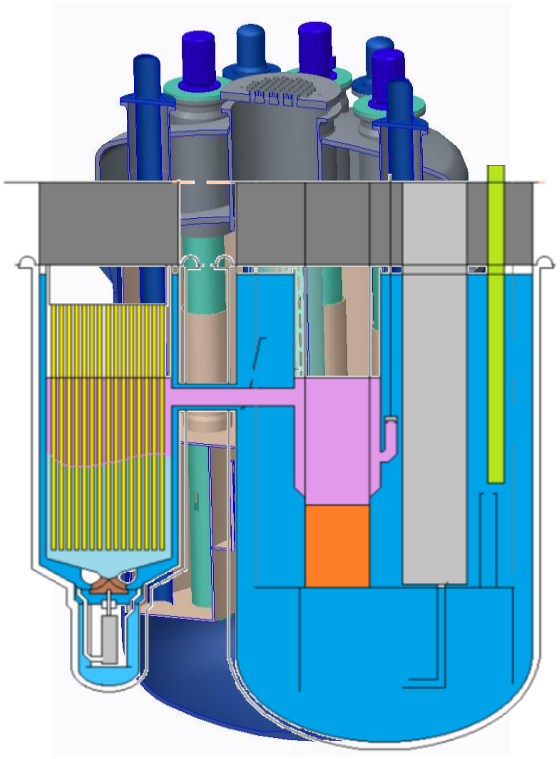
MYRRHA reactor design



MYRRHA design rev. 1.6
Ø reactor vessel : 10,4 m
Ø reactor skirt: 14,6m

- **MYRRHA primary system rev. 1.6 consolidated**
  - Operation in critical mode limited to 100 MW_{th}
  - Four lines of defence for major safety functions
- **End 2014 total cost 1,6 G€**
- **Po-issue**
- **O2-concentration control**

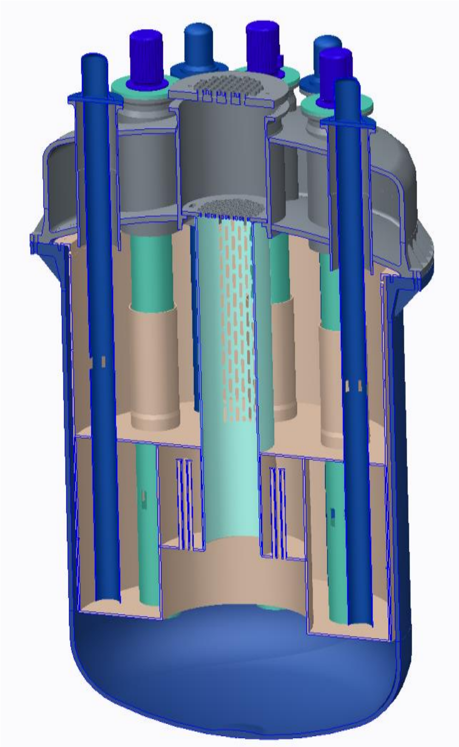
MYRRHA reactor design



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 Innovative IVFHM & double-walled PHX
1	Pool	Reduced size Innovative IVFHM & double-walled PHX
2	Loop	Bottom loading Existing IVFHM concept & external double-walled PHX
3	Loop	Top loading

MYRRHA reactor design



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
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3	Loop	Top loading

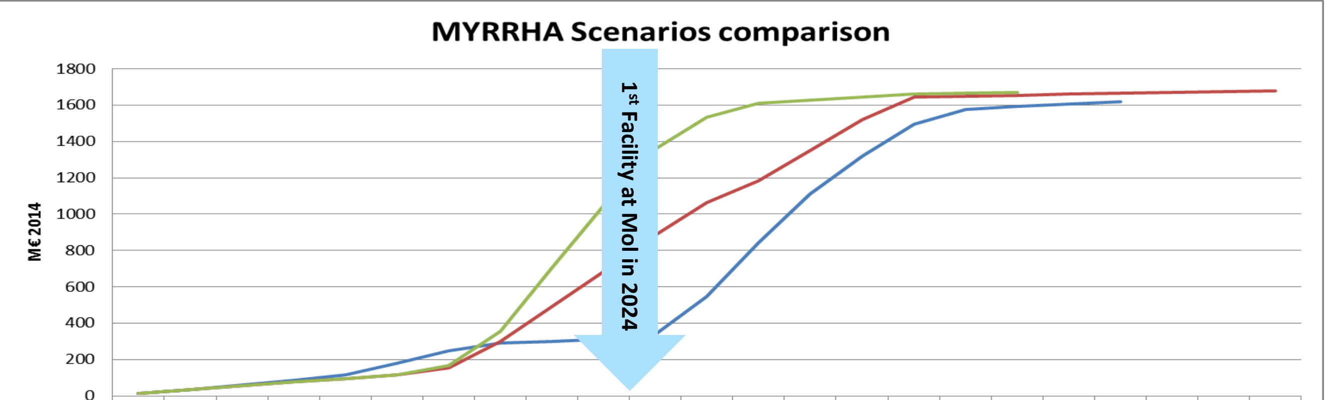
Implementation approach

- **SCK•CEN investigated three scenarios for the implementation of MYRRHA:**
  - SC1: Accelerator first + Reactor later
  - SC2: Reactor first + Accelerator later
  - SC3: Accelerator and Reactor all together
- **Scenario one (SC1) was selected as the most appropriate approach for the realisation of MYRRHA**
  - Reducing the technical risks
  - Spreading the investment cost
  - Allowing first R&D facility available by 2024

Financing scheme

> Scenario 1

- Spreads investment cost with smaller upfront investment value
- Mitigates risk related to accelerator reliability and allows more time for risk reduction on the reactor design
- Extends timeline
  - For solving innovative reactor design options
  - For building & extending consortium and users community
- **Allows new research facility by 2024 at SCK•CEN**



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037
SC1	11,3	34,5	59,3	83,8	115,3	177,7	249,3	288,8	298,3	311,8	339,3	547,5	841,3	1113	1320	1497	1577	1592	1607	1619			
SC2	11,3	33,3	56,3	79,3	96,3	116,8	153,9	300,9	493,5	683	882,7	1066	1182	1350	1519	1643	1650	1655	1661	1667	1672	1676	1679
SC3	11,3	33,3	56,3	79,3	96,3	116,8	166,9	355,4	703,5	1049	1359	1533	1611	1628	1645	1661	1666	1669					

Implementation approach

Phase 2 & 3: sequential or in parallel

2024: Stage-gate decision

Phase 1
LINAC injector & accelerator & exp. Stations up to 100 MeV

Preparations
Preparing the construction of SPs 2 & 3

Phase 2
Upgrade to 600 MeV

Phase 3
Reactor & spallation target module

Phase 1
LINAC injector & accelerator & exp. Stations up to 100 MeV

Preparations
Preparing the construction of SP 2 & 3

Phase 2
Upgrade to 600 MeV

Phase 3
Reactor & spallation target module

Global planning

Phase 1
LINAC Injector + Accelerator + experimental stations up to 100 MeV

2016	2017	2018	2019	2020	2021	2022	2023	2024

Phase 1: 100 MeV Accelerator built and commissioned in 2024

WP 1.1 - 100 MeV Accelerator R&D, design and construction

Phase 2: 600 MeV Accelerator preparatory phase - establish basis for decision on construction

WP 1.2 - 100 MeV Accelerator Balance of Plant

WP 2.1 - 600 MeV Accelerator R&D, design for taking decision in 2025

Phase 3: MYRRHA reactor preparatory phase - establish basis for decision on construction in 2025

WP 2.2 - 600 MeV Accelerator Balance of Plant

WP 3.1 – Primary System Design

WP 3.2 – Primary System R&D Supporting Programme

WP 3.3 – Balance Of Plant Primary System

High level deliverables for End 2017

Technical deliverables	
1	Technical Design Report (TDR) for full MYRRHA accelerator
2	Conceptual design of the 100 MeV accelerator building
3	Prototyping of all 100 MeV accelerator components
4	Confirmation of innovative reactor design components
5	Licensibility statement on MYRRHA from FANC
6	Total budget consolidation for Phase 1: Investment (±25%), OPEX & revenues
7	A fuel cycle scenario study including transmutation and impact on the geological disposal for the Belgian scenario [to be submitted before the end of 2016]
Non-technical deliverables	
8	Consolidation of the SC1 implementation plan & associated financing plan
9	Risk assessment & mitigation methodology
10	Commitment of the major stakeholders for the Phase 1 (investors, scientific & technological users)
11	Update of the 2010 socio-economic study of MYRRHA in Belgium and its regions (incl. the broader European dimension).

With a positive decision in 2017, **we will break ground in 2020**