Sistemi veloci verso la minimizzazione e la trasmutazione delle scorie

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ANSALDO NUCLEARE
Ansaldo Energia Group

Origin of Nuclear Waste

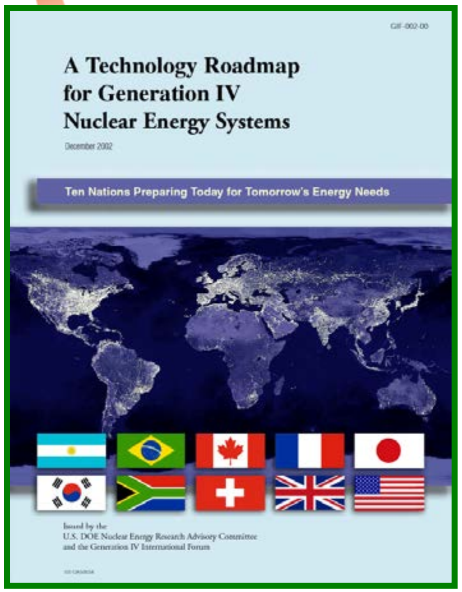
- **Most** of the reactors operative or in construction in the **world today** are **thermal spectrum reactors** (ANS Nuclear News, March 2013)
  - In operation: 271 PWRs, 83 BWRs, 48 HWRs, 15 GCRs, 15 LGR and only one LMFR
  - Forthcoming: 85 PWRs, 6 BWRs, 7 HWRs, 1 GCRs, 0 LGR and only 4 LMFR

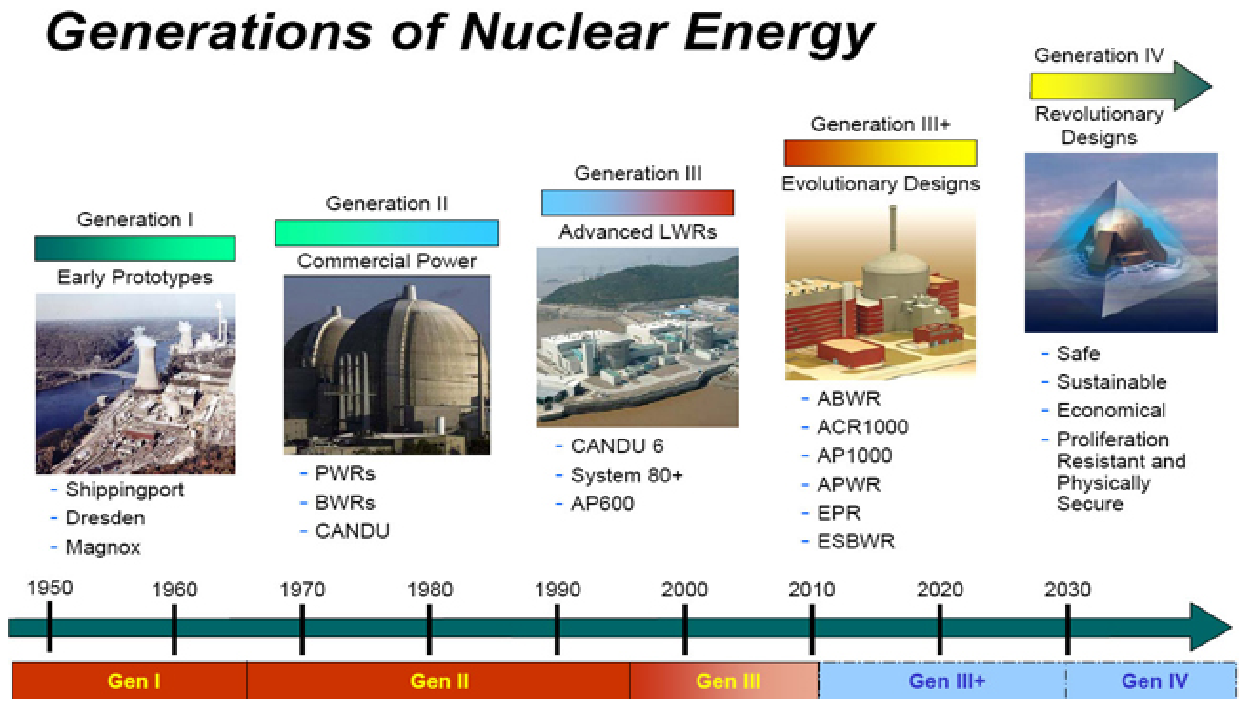
- Currently dominant **open fuel cycle,** in which uranium fuel is irradiated, discharged and replaced with new uranium fuel, has resulted in the gradual **accumulation of large quantities** of highly radioactive or fertile materials in the form of **Depleted Uranium**, **Plutonium**, **Minor Actinides** (MA) **and Long-Lived Fission Products** (LLFP)

- ~**2500 tons** of spent fuel are produced **annually in the EU** containing ~**25 tons of Pu,** ~**3.5 tons of MAs** (Np, Am, and Cm) and ~**3 tons of LLFPs** (Tc, Cs and I)
  - Typical annual discharge inventory from a 900 MWe PWR fuelled with about 72 tons of U (3.7% ^{235}U) is **~200kg of Pu**, ~**11kg of Np**, ~**10kg of Am**, ~**1kg of Cm,** ~**17kg of ^{99}Tc,** ~**10kg of ^{135}Cs,** and ~**4kg of ^{129}I**

- In **EU spent fuel is reprocessed** and some of the separated products have already been **utilized** in the form of **MOX** (Mixed Pu/U Oxide) fuels, but not yet in sufficient quantities to significantly slow down the steady accumulation of these materials in storage

Generation IV Goals & Concepts





GENERATION IV GOALS

Sustainability

Safety & Reliability

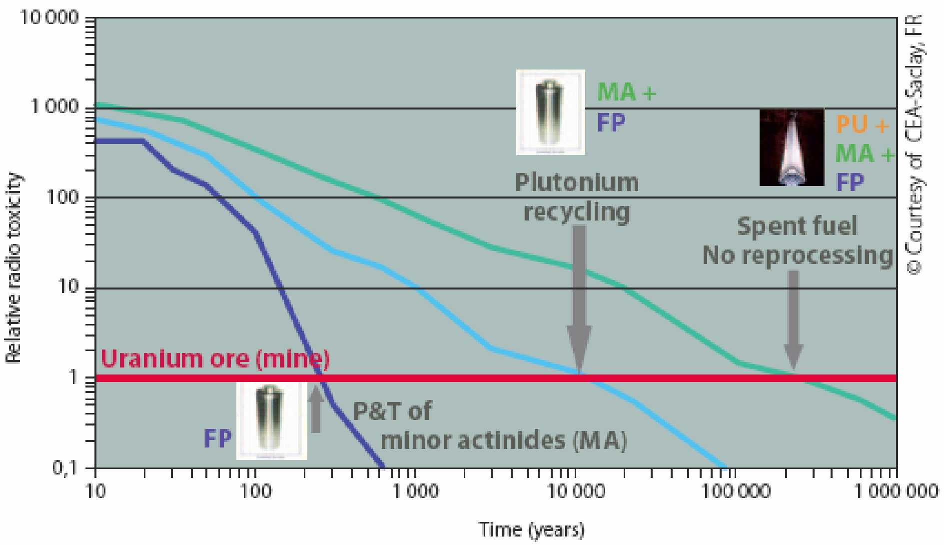
Economics

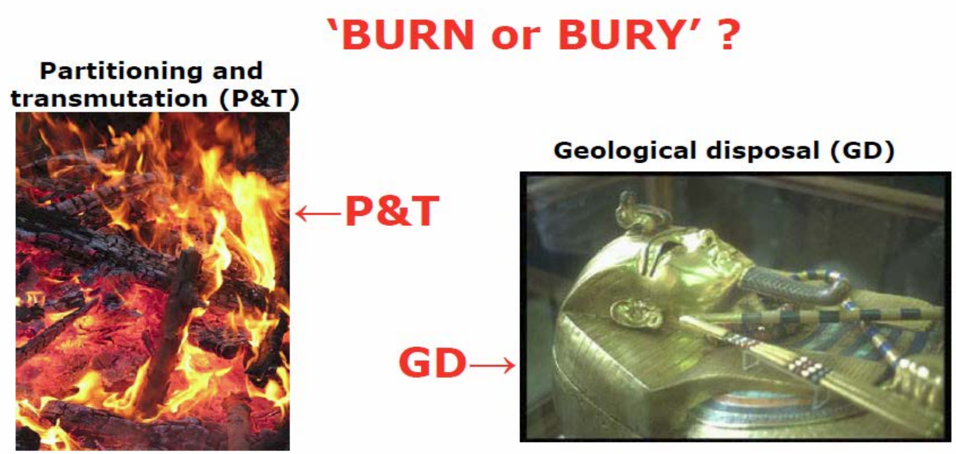
Proliferation Resistance & Physical Protection

GENERATION IV SYSTEMS	ACRONYM
Sodium-Cooled Fast Reactor System	**SFR**
Gas-Cooled Fast Reactor System	**GFR**
Lead-Cooled Fast Reactor System	**LFR**
Molten Salt Reactor System	MSR
Supercritical-Water-Cooled Reactor System	SCWR
Very-High-Temperature Reactor System	VHTR

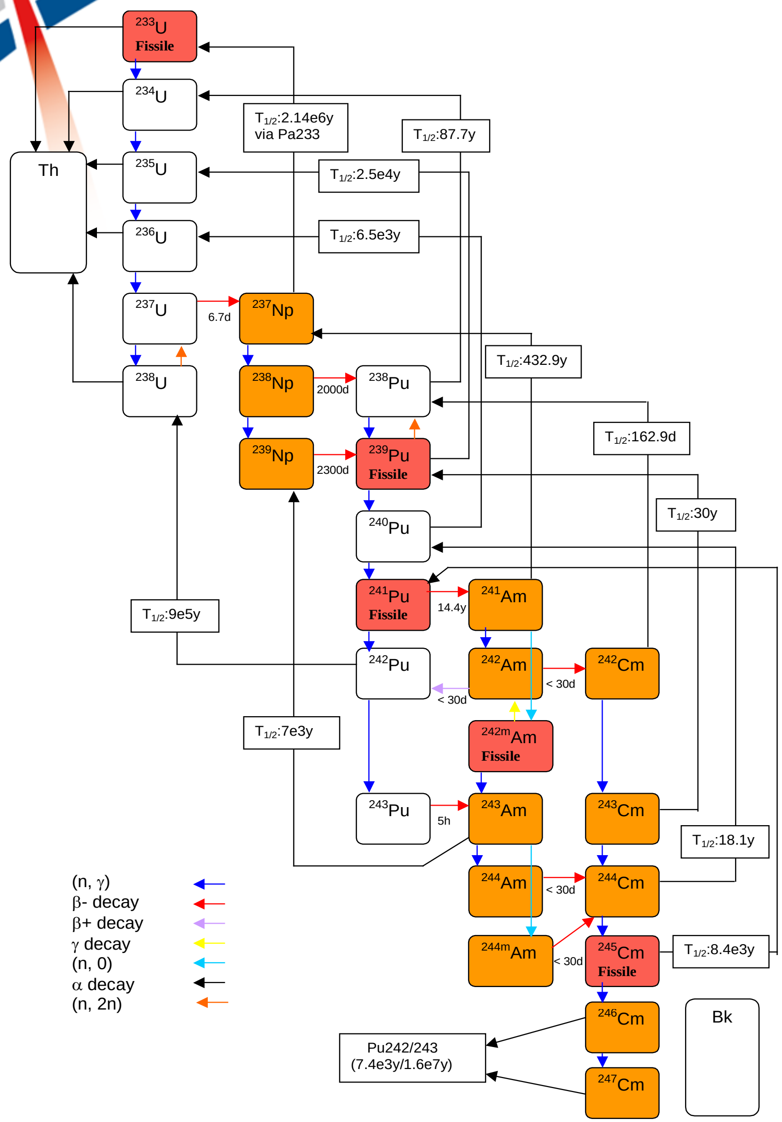
Sustainability:
Partitioning and Transmutation (P&T)

- The radio-toxicity of the fission products dominates the total radio-toxicity during the first 100 years and reaches the uranium ore mine level at about **300 years**
- The long-term radio-toxicity is dominated by the actinides (mainly by the Pu and Am isotopes) and the uranium ore mine level is reached only after more than **120,000 years**
- By recycling and then 'burning' all the MA, the period over which high-level radioactive waste remains hazardous could theoretically be reduced from hundreds of thousands of years down to a **few hundred years**





Transmutation chain for the main Minor Actinides



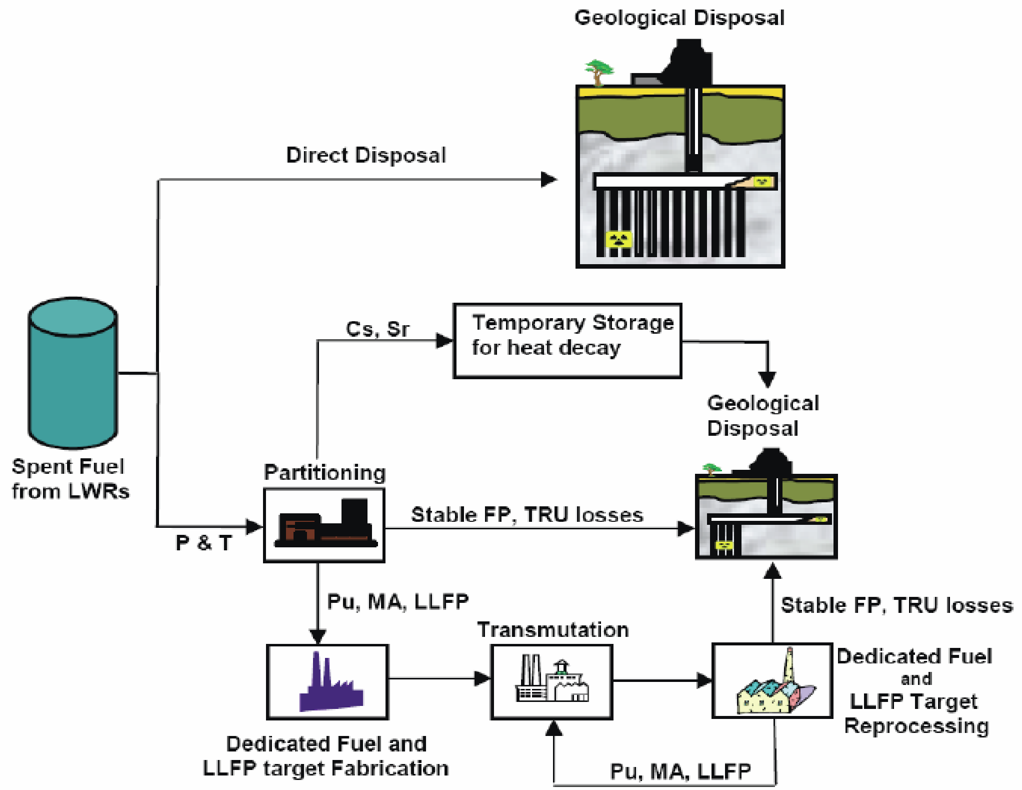
Transmutation chain indicates that following a prolonged period of time out of reactor (over timescales ranging from a few years to millions of years), isotopes of Np, Am and Cm can, by various captures or decays, transmute into a number of fertile or fissile isotopes, including those of Pu and U

The only effective method to reduce MA both in mass and activity is via fission (or incineration, perhaps following a number of intermediate transmutations) and not solely transmutation

Fast spectrum reactor gives better flexibility to transmute and to fission MA (high fast flux can be attained with a useful neutron surplus)

Strategy for Sustainability of Nuclear Energy

- **Once-through cycle** (disposal of spent fuel as it is) does **not** appear to be more **sustainable**
- **Reprocessing** of the spent fuel and **transmutation** of MAs in **dedicated devices** reduces radio-toxic inventory of the disposed waste in geological repositories
- **Geological disposal** of the remaining waste (separation/transmutation losses) will be required



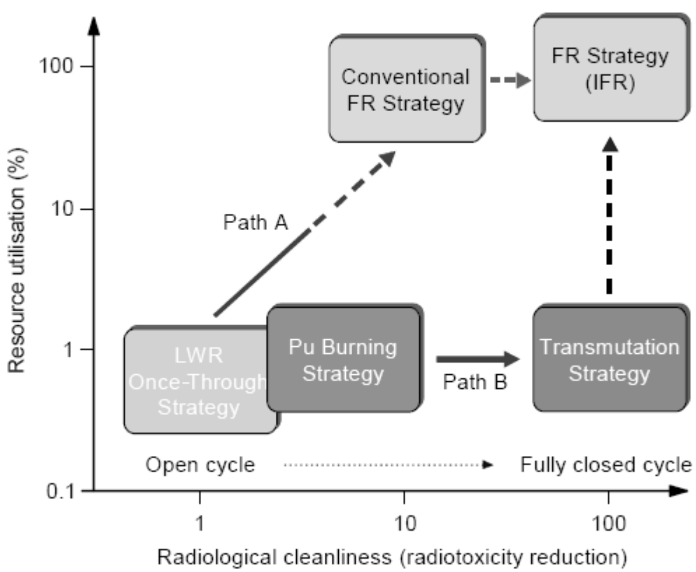
LLFP: Long lived fission products (Tc-99, I-129, Se-79, ...); MA: Minor Actinides (Am, Np, Cm)

Possible schemes for waste management

(Acknowledgement: EUROTRANS)

Strategy for Sustainability of Nuclear Energy

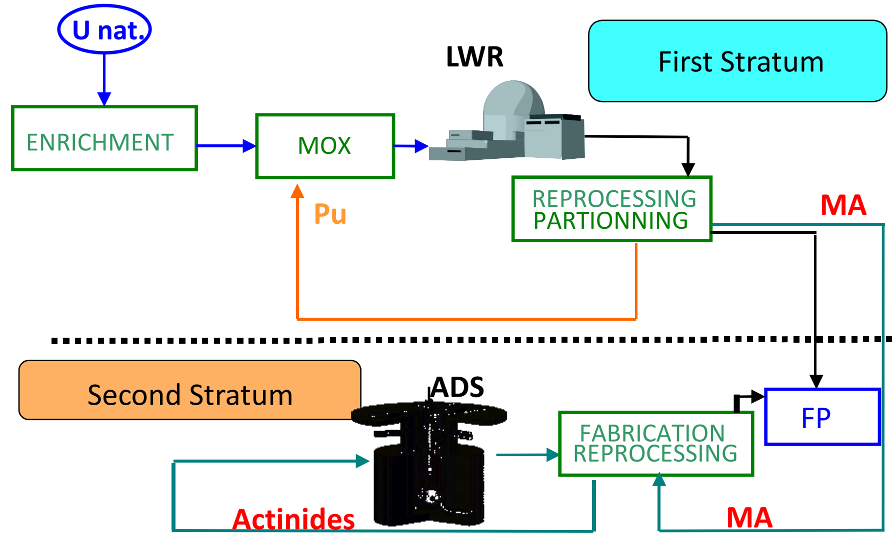
- Present known resources of Uranium represent about 100 years of consumption with the existing reactor fleet
- Fast neutron reactors with closed fuel cycle have the potential:
  - ✓ to multiply by a factor 50 to 100 the energy output from a given amount of uranium (with a full use of U238),
  - ✓ to improve the management of high level radioactive waste through the transmutation of minor actinides
  - ✓ to provide energy for the next thousand years with the already known uranium resources



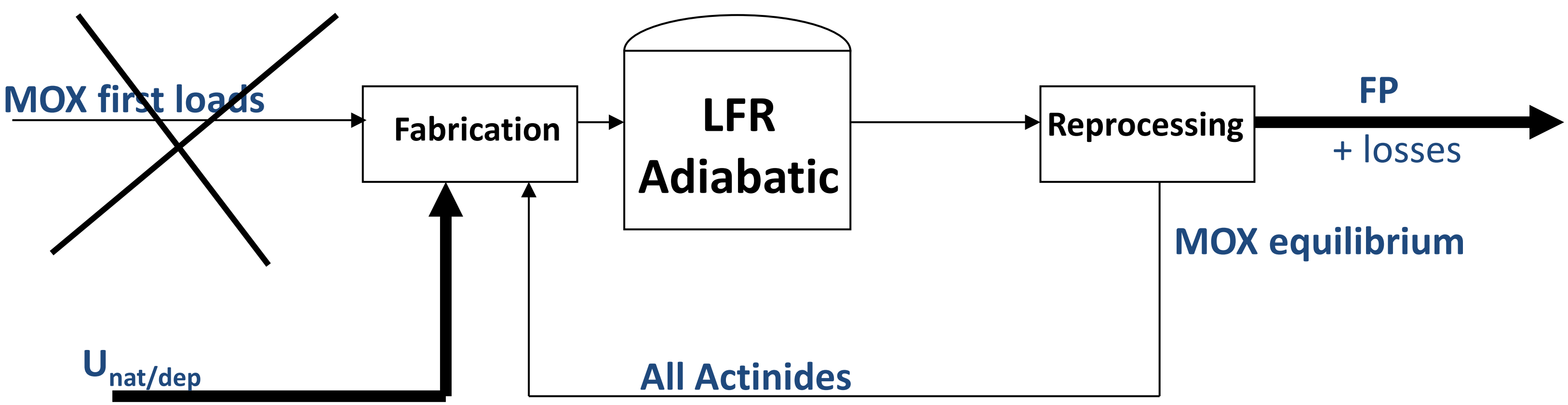
- Both fast spectrum critical reactors and sub-critical ADS are potential candidates for dedicated transmutation systems
- Critical reactors, however, loaded with fuel containing large amounts of MAs might pose safety problems caused by unfavourable reactivity coefficients and small delayed neutron fraction
  - Core fuelled with only MA (Uranium free) has no Doppler nor Delayed Neutrons

Strategy for Sustainability of Nuclear Energy

Example of Double-strata approach with ADS and Light Water Reactors

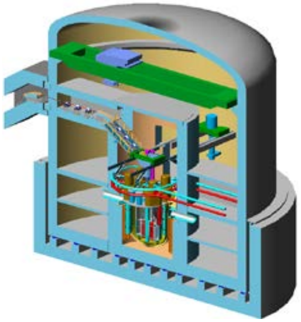


Example of Closed Fuel Cycle in Fast Reactors

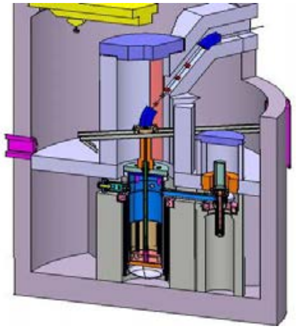


Lead & LBE technology development in Europe

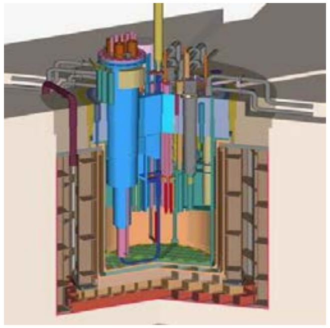
PDS-XADS project 5th EU FP (2002-2004)



80 MW LBE-cooled XADS

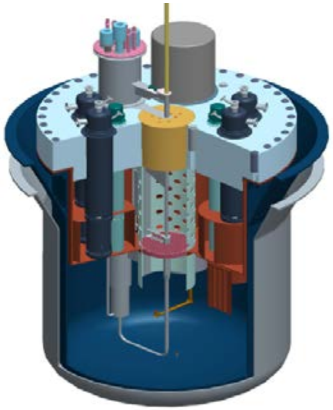


80 MW Gas-cooled XADS

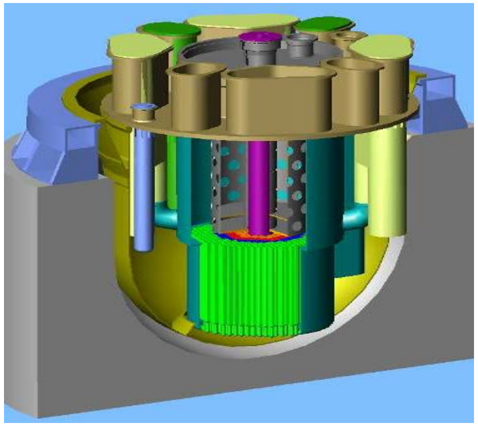


50 MW LBE-cooled XADS
(MYRRHA)

IP-EUROTRANS project 6th EU FP (2005-2010)

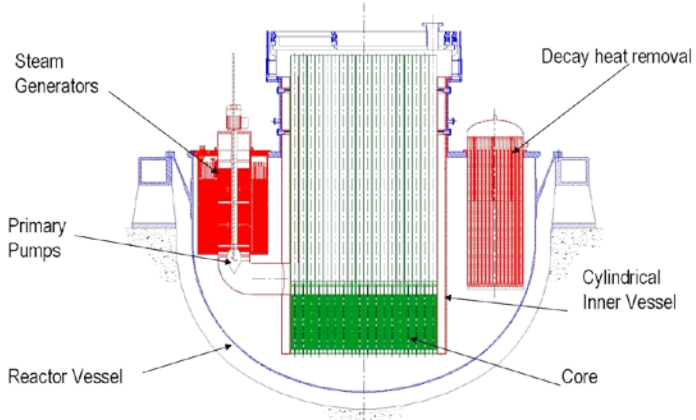


60 MW XT-ADS/MYRRHA



400 MW EFIT

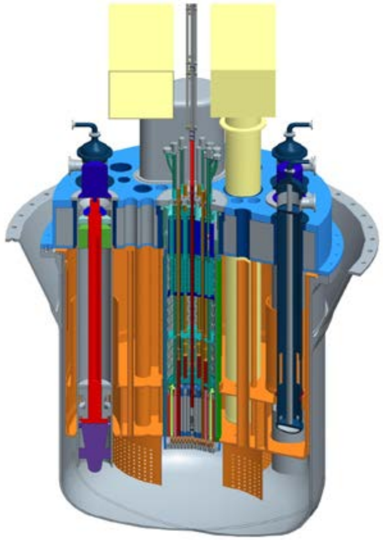
ELSY project 6th EU FP (2006-2010)



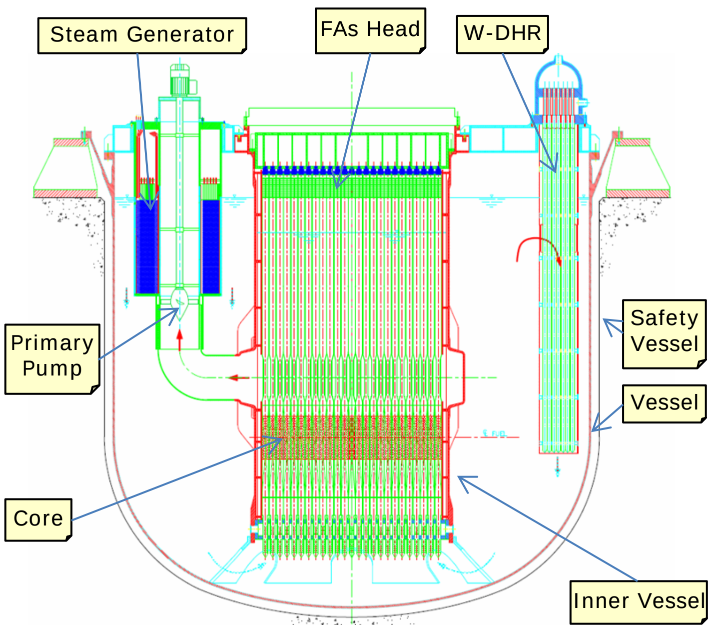
1500 MW ELSY

Lead & LBE technology development in Europe

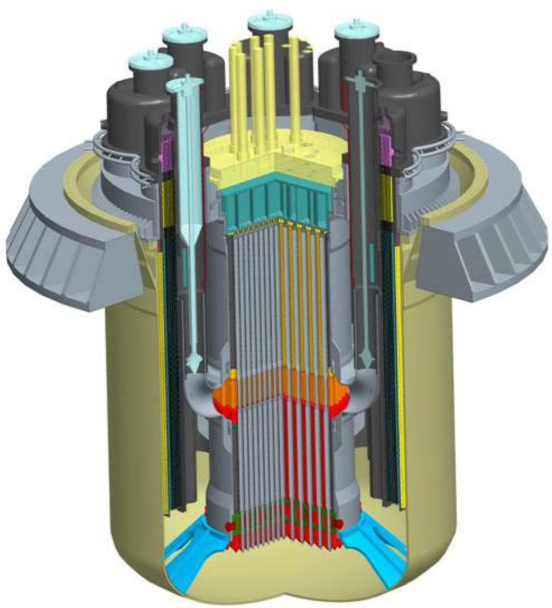
CDT project 7th EU FP
(2009-2012)



100 MW FASTEF/MYRRHA



1500 MW ELFR

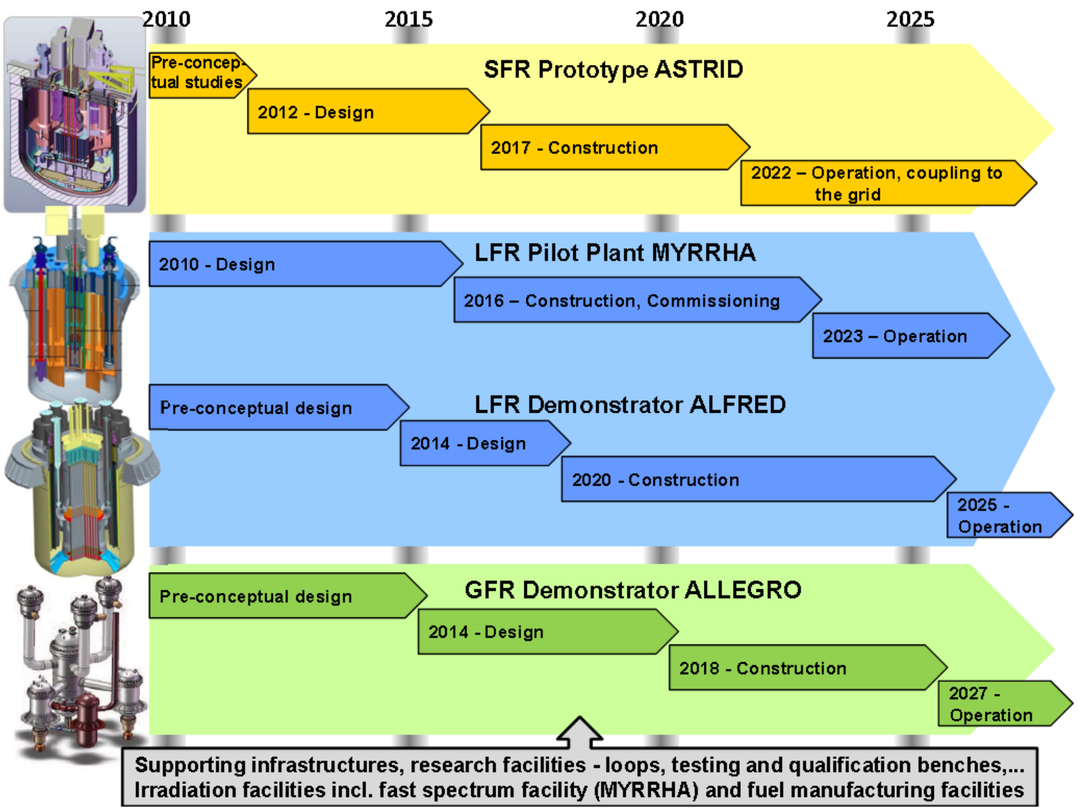


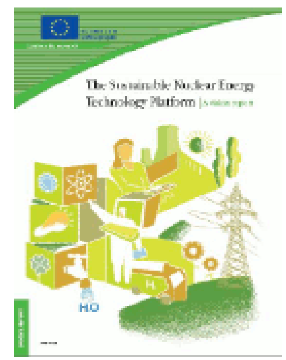
LEADER project 7th EU FP
(2010-2013)

300 MW ALFRED

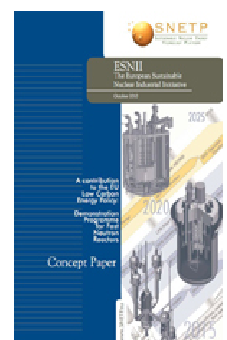
Fast Neutron Reactors in the frame of the European Sustainable Nuclear Industrial Initiative (ESNII)

- European Nuclear research-orientated organisations and nuclear industry stakeholders launched in 2007 the Sustainable Nuclear Energy Technology Platform (**SNETP**) aimed to integrating and developing R&D capabilities
- SNETP is structured in 3 main pillars and one of them **ESNII** (European Sustainable Nuclear Industrial Initiative) promotes advanced Fast Reactors with the objective of resource preservation and minimization of the burden of radioactive waste

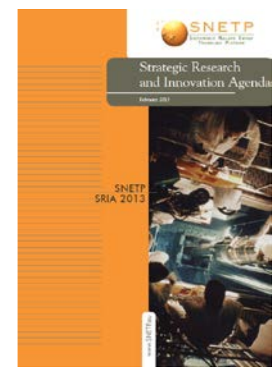




Vision Report
[2007]



Concept Paper
[2010]

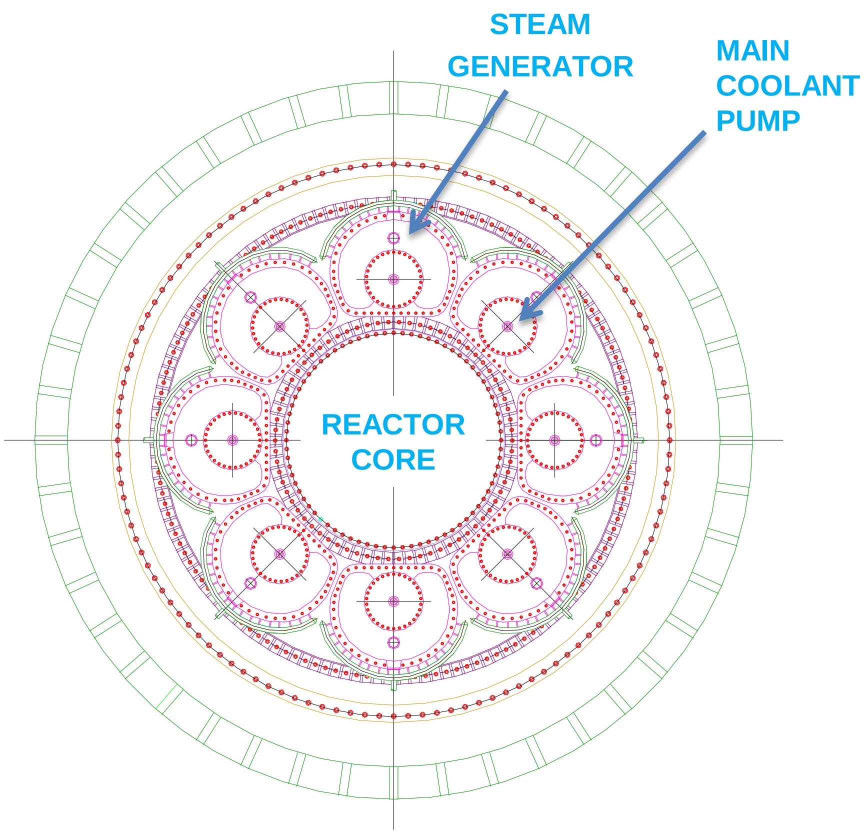


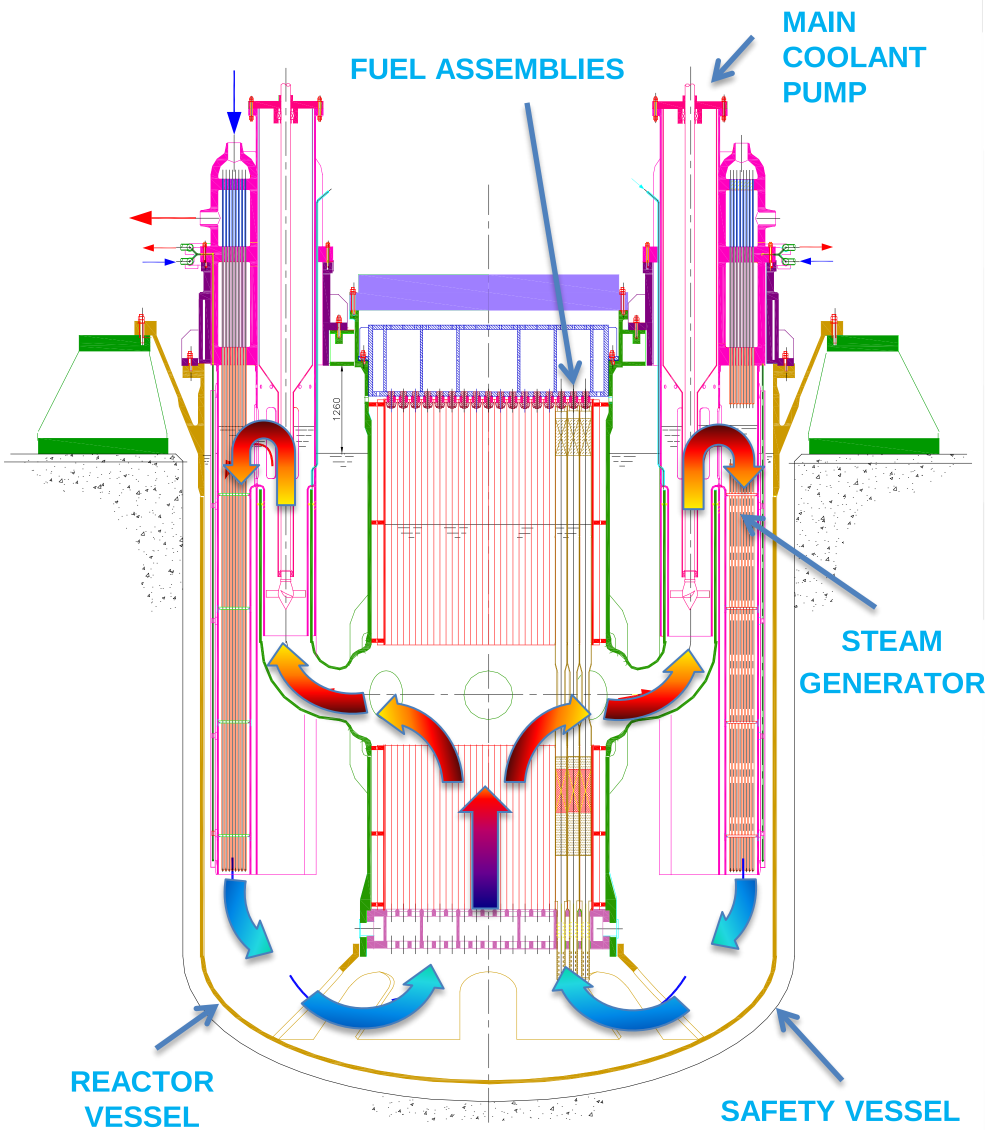
Strategic Research and Innovation Agenda
[2013]

ADS is not considered as a potential energy production system (economic reasons), but as a fast neutron irradiation and testing tool which can support the development of FNRs

ALFRED - Reactor Configuration from LEADER

Power:	*300 MWth (125 Mwe)*
Primary cycle:	*400-480 ℃*
Secondary cycle:	*335-450 ℃, 180 bar*

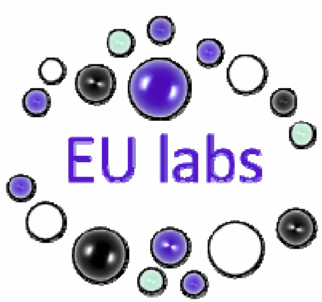




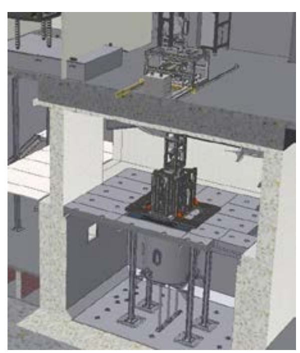
Roadmap towards an industrial LFR fleet in Europe
Facilities for LFR technology development

For the demonstration of the LFR technology chains, further facilities (either existing or under construction) are required to provide the overall frame for LFR technology development, like:

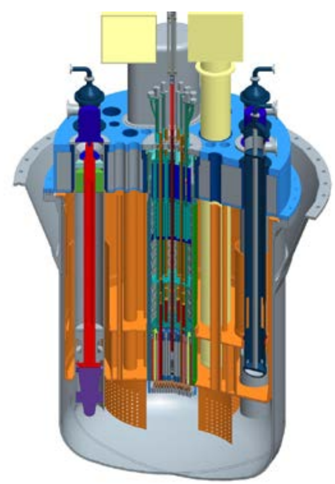
- Existing and planned **EU lead labs** focused on thermal/hydraulics, materials development and corrosion testing;
- Zero-power facility **Guinevere**, already operating in Mol, Belgium;
- Irradiation facility and pilot plant **MYRRHA**, to be built and operated in Mol;
- European training facility **ELECTRA**, planned for realization in Sweden



EU LABS (Materials & T/H test facilities)



Guinevere

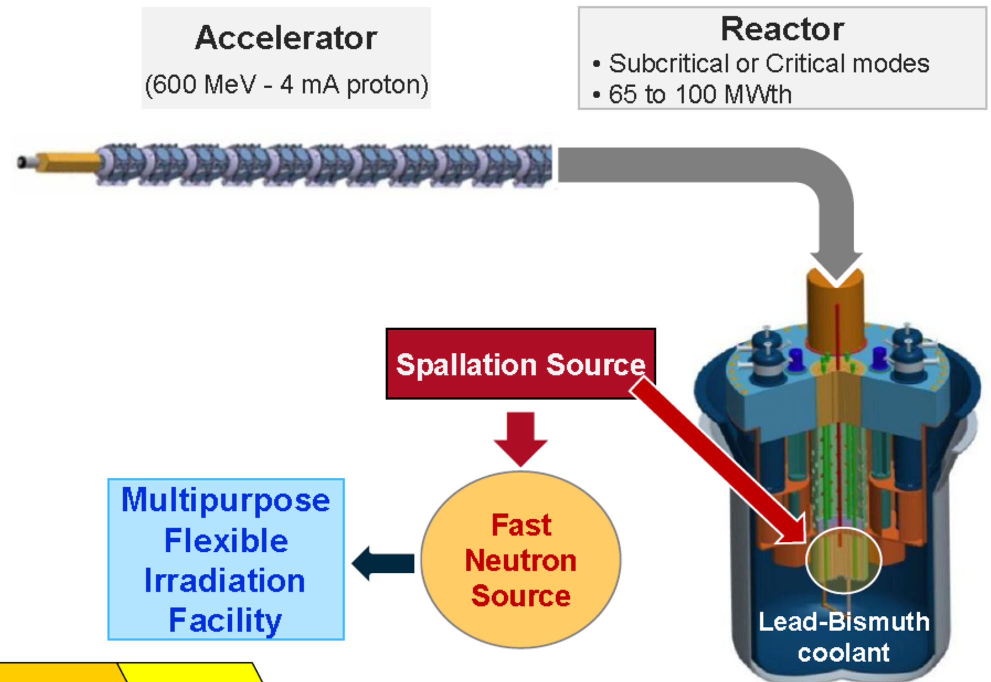


MYRRHA

ELECTRA

MYRRHA

Concept



- **2010-2014** Front End Engineering Design
- **2015** Tendering & Procurement
- **2016-2018** Construction of components & civil engineering
- **2019** On site assembly
- **2020-2022** Commissioning
- **2023** Progressive start-up
- **2024-** Full exploitation

Minimise technological risks	Accelerator x	Spallation target x	Sub-critical reactor
Secure the licensing	**PDP** preliminary dismantling plan	**PSAR** preliminary safety assesment	**EIAR** environmental impact assesment
Secure a sound management and investment structure	Central Project Team	Owner Consortium Group	Owner Engineering Team

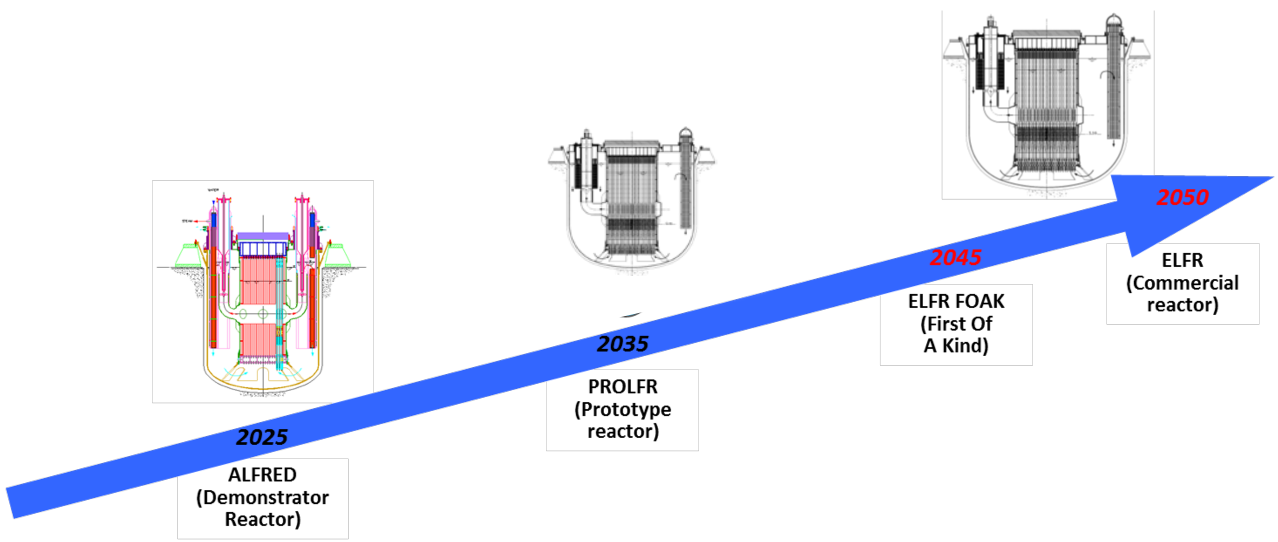
→ **FEED** (Front End Engineering Design)
2010-2014

Project Schedule

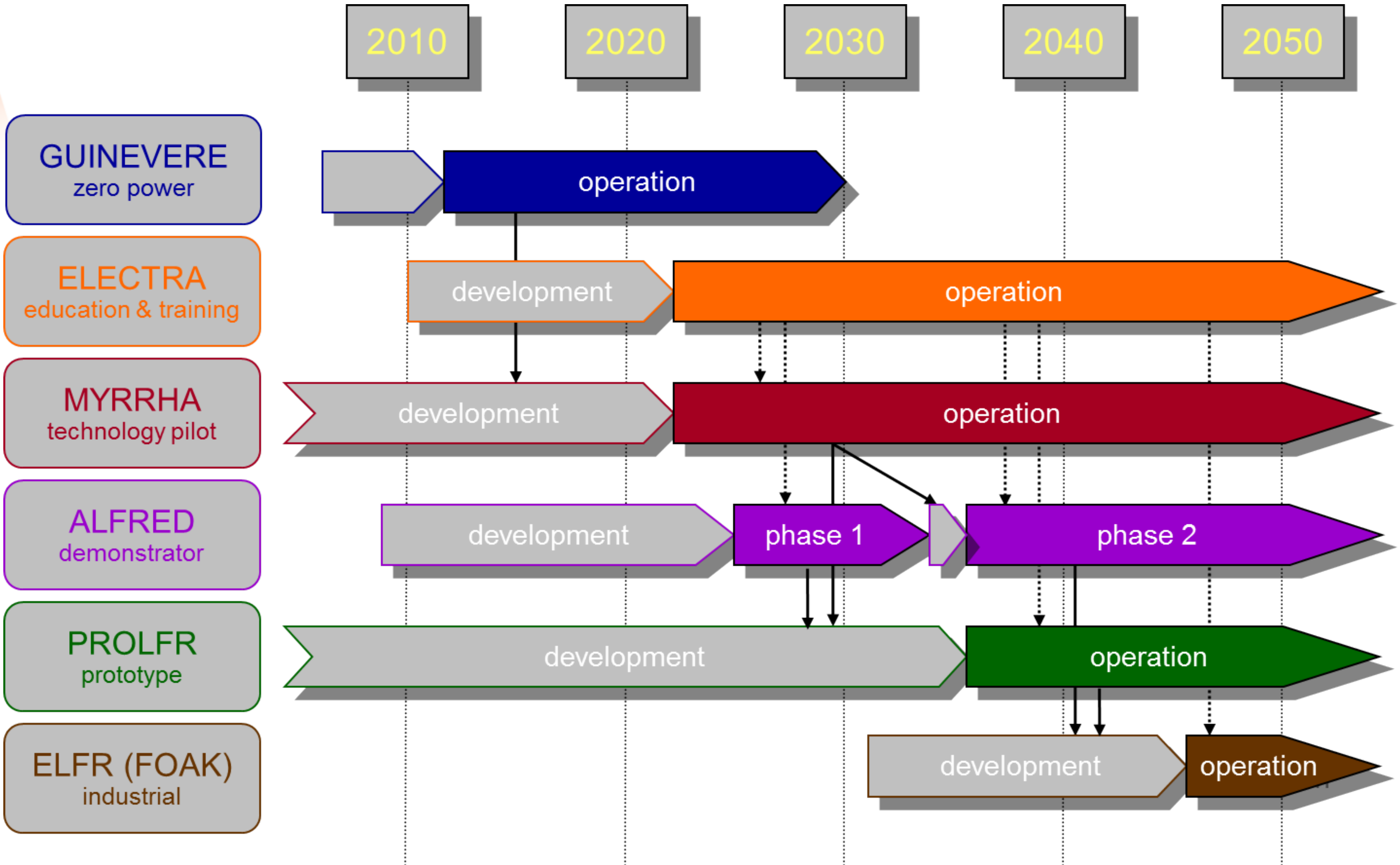
ELFR Roadmap towards industrial deployment

- First: a Demonstrator reactor (**ALFRED**) for proving the viability of reliable electricity production for LFR systems (125 Mwe)
- Second: a Prototype reactor (**PROLFR**) envisaged for testing the scaling laws at an intermediate step according to a common approach focused both on plant size and representativeness of the target reference system (300÷400 Mwe)
- Third: a First-Of-A-Kind (**ELFR-FOAK**) representative of a commercial **ELFR** fleet (600 Mwe)

Note: ALFRED and PROLFR could be also have its own development as SMR



Overall LFR Road Map

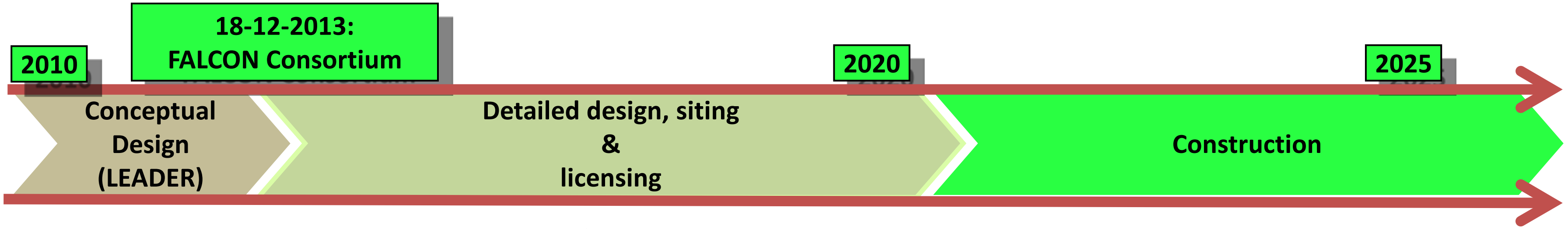


ALFRED Implementation plan

ALFRED realisation includes several phases

- International consortium FALCON has been set-up on December 18th 2013 (Ansaldo Nucleare, ENEA and ICN)
  - ✓ Site for construction has been chosen at Mioveni in Romania
  - ✓ First consortium act, according to ESNI Implementation plan, is to search funding

- Several design steps have been individuated:
  - ✓ Conceptual design, LEADER project (2010-2013)
  - ✓ Basic design, siting and pre-licensing
  - ✓ Detailed design and licensing
  - ✓ components construction, civil engineering, on site assembly and commissioning
- Support R&D program will provide answers to remaining technical challenges



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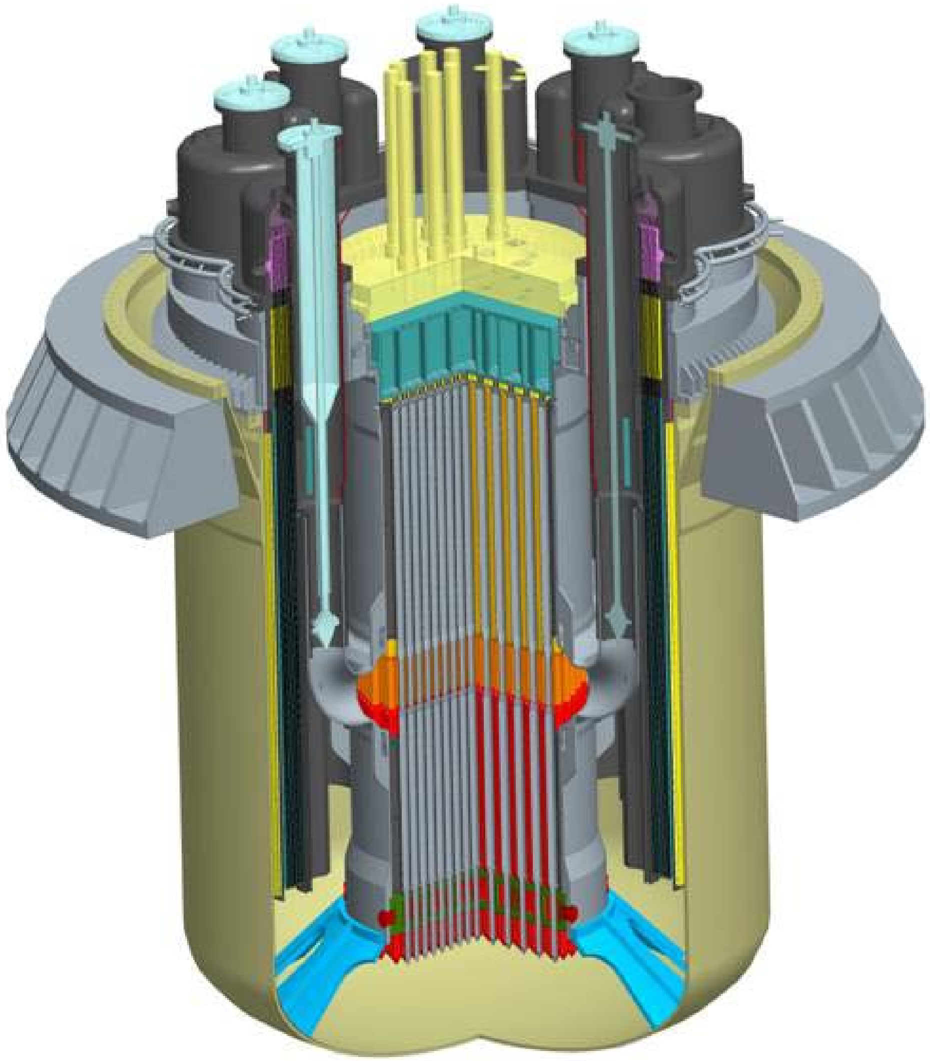

ALFRED