Overview of the CEA R&D Programme on Generation IV Nuclear Energy Systems

Frank Carré, Pascal Anzieu, Philippe Billot,
Philippe Brossard, Gian-Luigi Fiorini

Program Direction for Future Nuclear Energy Systems

CEA/Nuclear Energy Division/Division of Nuclear Development and Innovation

CEA R&D on Generation IV Nuclear Energy Systems

Outline of presentation

1 – Generation IV: an International Forum for the development of key technologies for a sustainable nuclear energy

2 – Main focus of CEA with industrial partners on key Gen IV technologies:

2.1 – The Gas Technology Pathway: → HTR/VHTR, GFR
& Nuclear hydrogen generation

2.2 – A new generation of Sodium Fast Reactor (SFR)
& Innovative research on prospective systems *(SCWR, MSR)*

2.3 – Global actinides management

3 – International collaboration as main path forward to enhance Gen IV systems feasibility and performance assessments

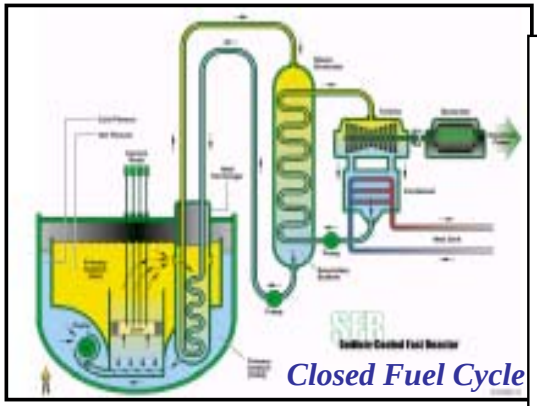
The Evolution of Nuclear Power

Missions of Generation IV systems

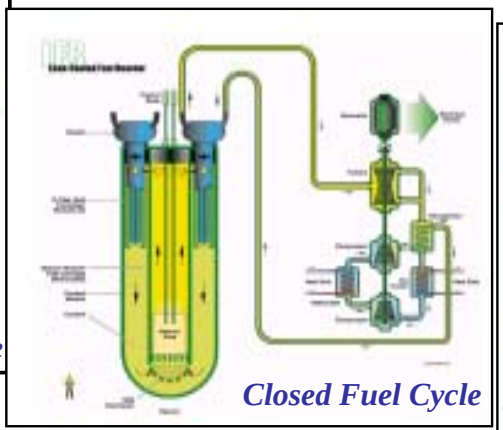
Development of future nuclear energy systems

- **Technical maturity by 2030**
- **With significant advances in :**
  - **Sustainability**
  - **Proliferation and physical protection**
  - **Safety and reliability**
  - **Economics**
- **Competitive in various markets**
- **Designed for different applications**
  - **Electricity, Hydrogen**
  - **Desalinated water, Heat**

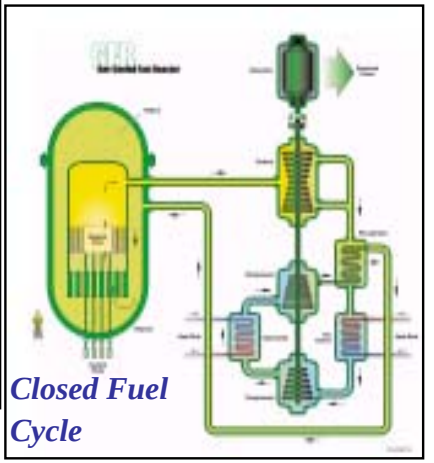
Six Innovative concepts with technological breakthroughs



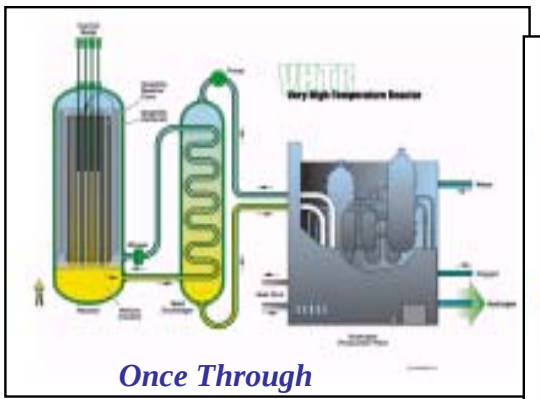
Sodium Fast reactor



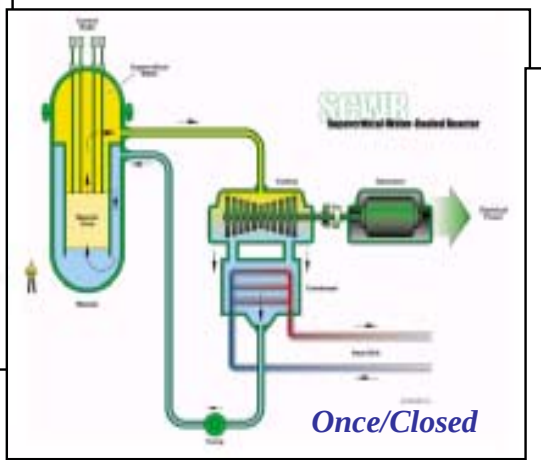
Lead Fast Reactor



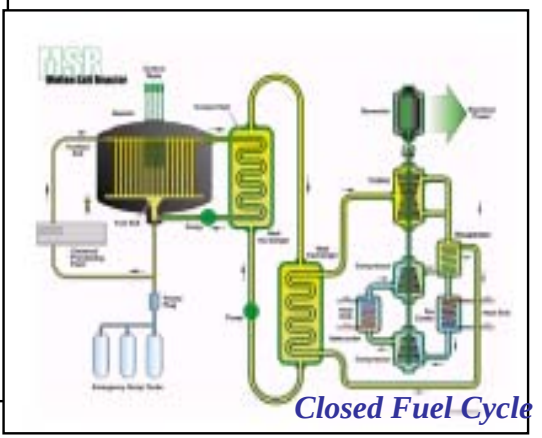
Gas Fast Reactor



Very High Temperature Reactor

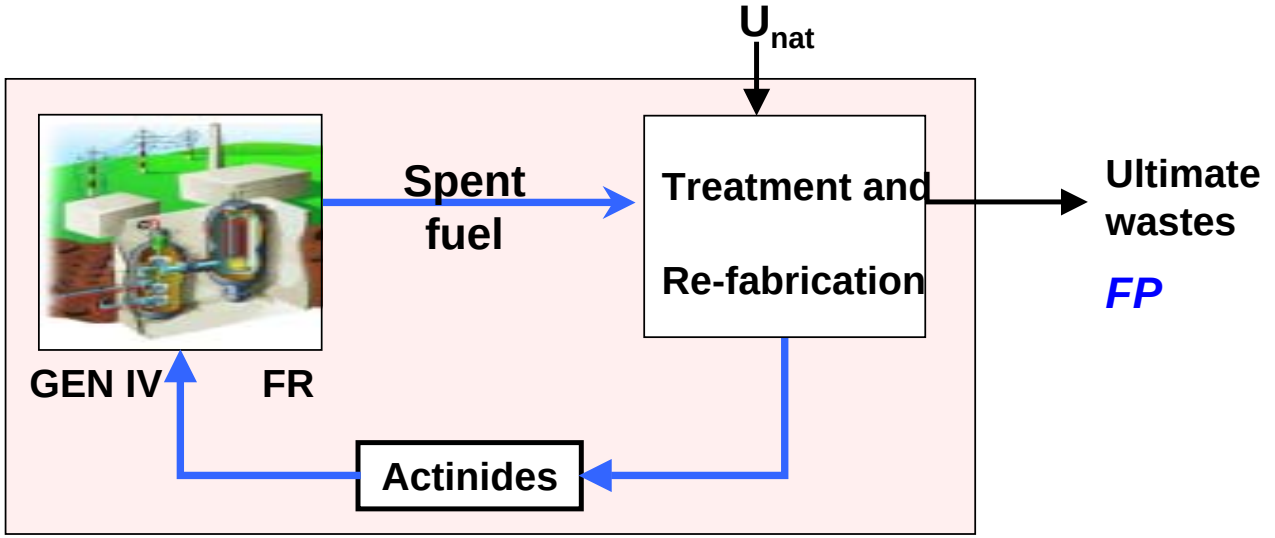


Supercritical Water Reactor



Molten Salt Reactor

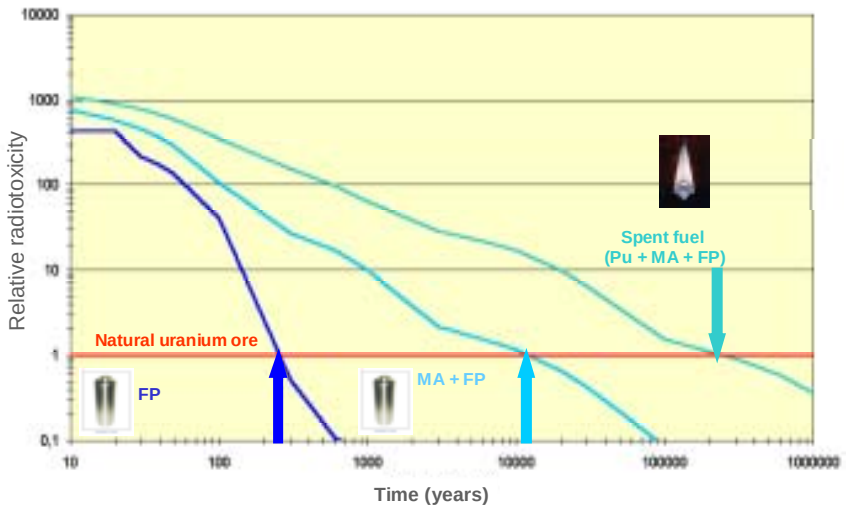
Gen IV Systems: an integrated cycle with full actinide recycling



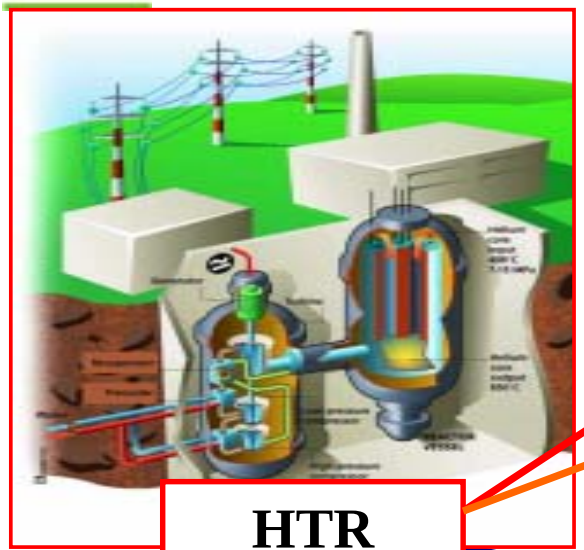
➢**A drastic minimization of ultimate wastes :**

- very small volumes,
- hundreds of years versus hundreds of thousands

➢**An optimal use of energetic materials**



Generation IV: R&D on Gas Cooled Reactors

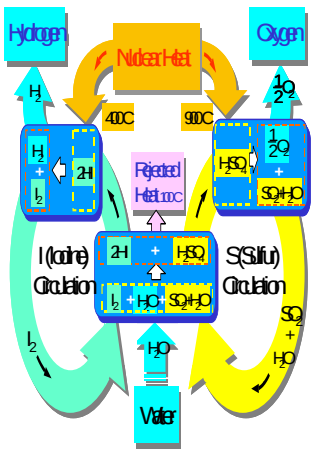


HTR

R & D
- Fuel particles
- Materials
- He systems technology
- Computer codes
- Fuel cycle

ETDR

R & D
- VHT materials
- IHX for heat process
- I-S cycle : H_2 production
- ZrC coated fuel



VHTR

GFR

R & D
- Fast neutron fuel
- Fuel cycle processes
- Full actinide recycling
- Safety systems

ETDR : Experimental Technology Demonstration Reactor

CEA program on Generation IV nuclear energy systems

- **Main involvement : A consistent technology development line of HTGR : VHTR and GFR**

Key technologies

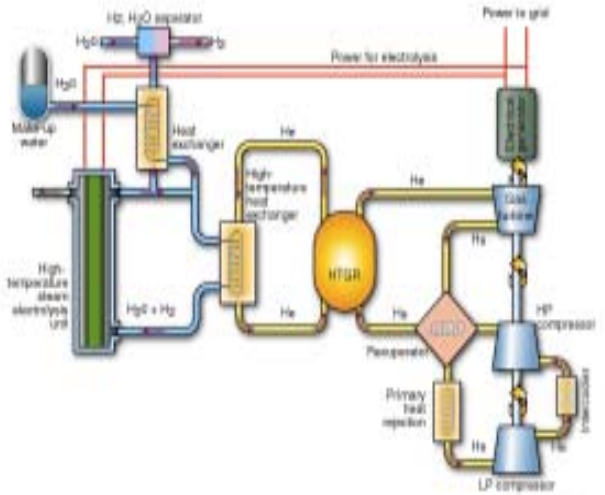
Common HTGR	VHTR	GFR
➢Material & Components ➢BOP	➢Design & Safety ➢Fuel particles ➢Hydrogen	➢Design & Safety ➢Fuel & Fuel Cycle

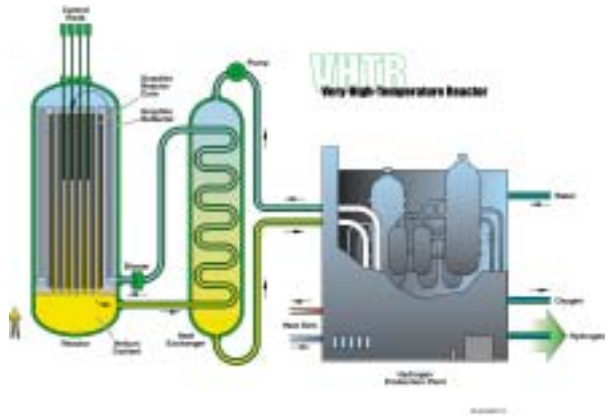
- **Support SFR**
  - ✓ Fuel cycle
  - ✓ Design optimization
    - ISIR, pool/loop design, secondary coolant, economics
- **Fuel Cycle**
  - ✓ Advanced fuel cycle processes for a global actinides management

International collaboration on the VHTR

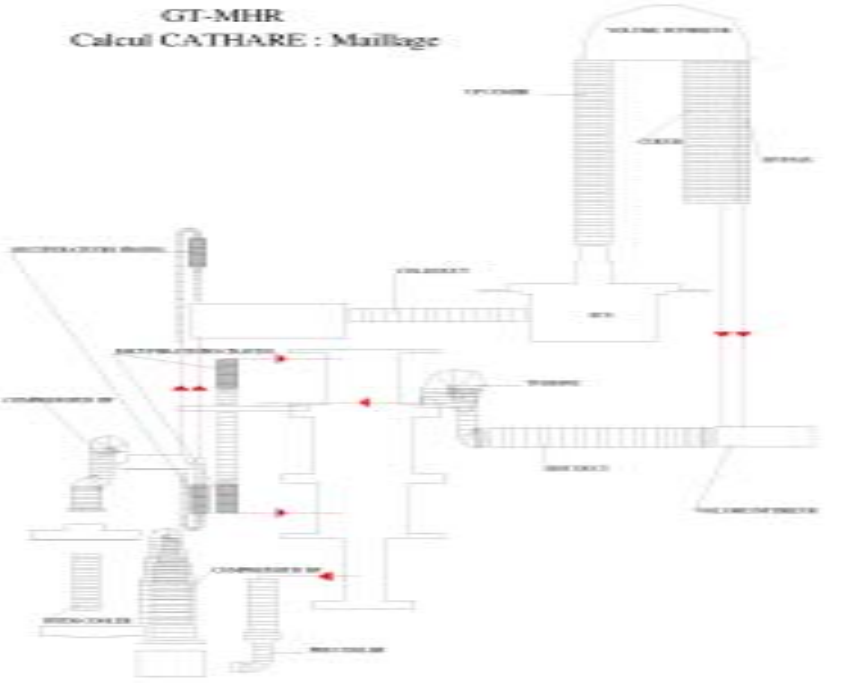
VHTR Objectives

- Bridge to Hydrogen economy
- Hydrogen & electricity production (> 1000°C)
- 600 MWth as reference concept
- Thermal neutron spectrum
- Thermo-chemical or electro-chemical water splitting
- Deployable in 2020 (possibly by 2015-2017)

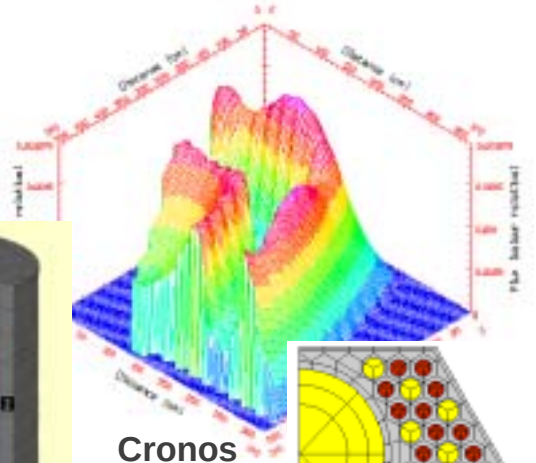




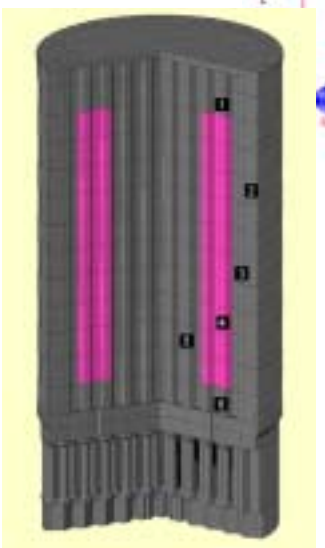
HTR-VHTR Computational tools



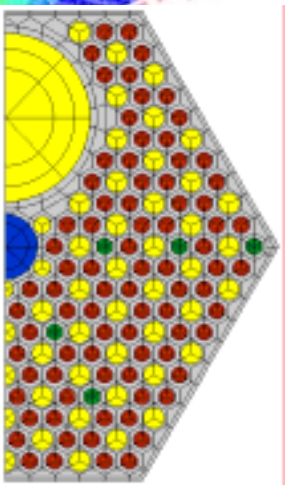
3D Modeling of the core



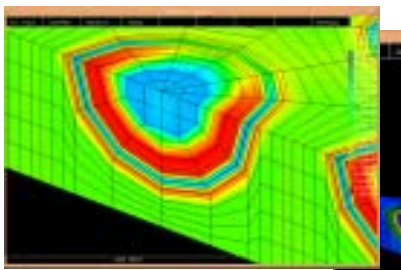
Cronos

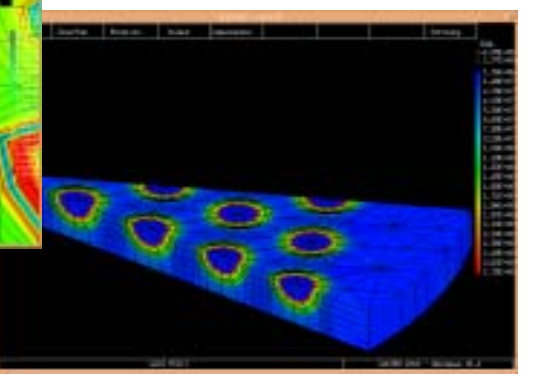


GT-MHR core



Apollo

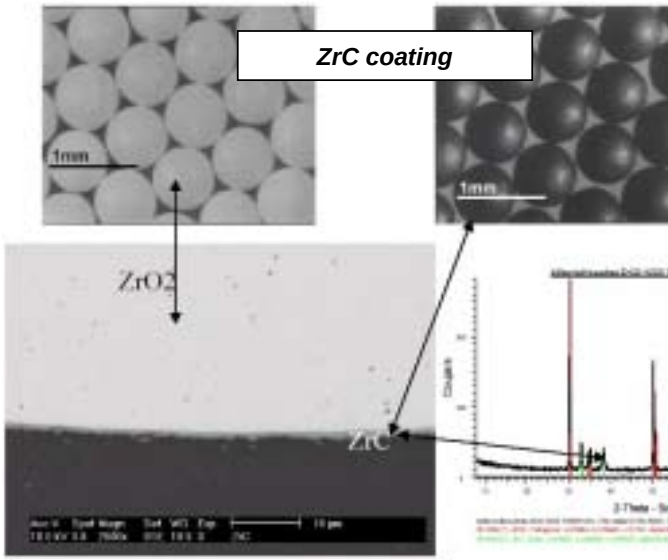


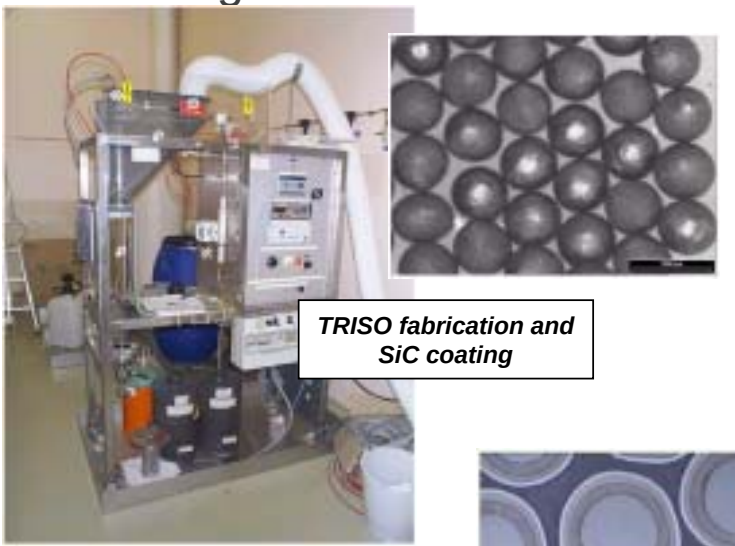


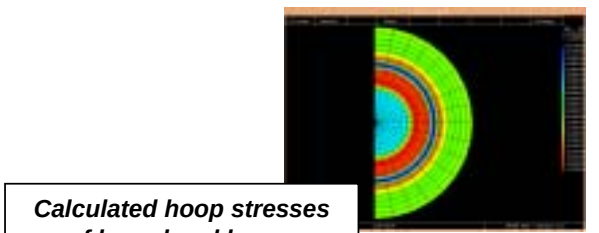
Fuel particle Thermomechanical behaviour

VHTR fuel & fuel cycle

- TRISO fuel development and waste management

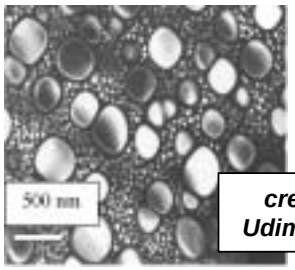






Material and Components for VHTR & GFR

- **Develop and qualify materials for >850°C operation:**
  - **Primary vessel**
  - **Internal structures**
  - **Components**

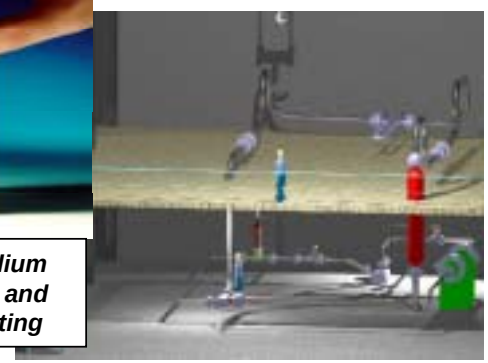


creep resistant Udimet 720 grades

Heat exchanger in SiC brazed with Brasic®

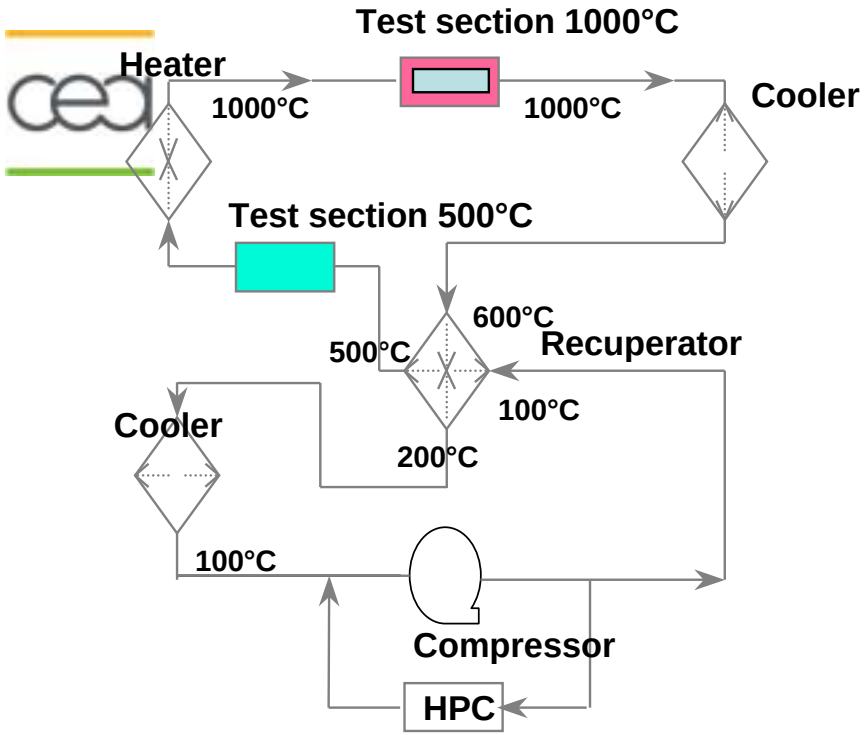
- **Test and optimize HT components:**
  - Thermal insulation, instrumentation, gas purification, valves and fittings, …
  - IHX, Blowers, Coolers, Recuperators

High Temperature helium benches



Dynamic helium loop for IHX and blowers testing

Helium loops test facilities



HELIUM TECHNOLOGY LOOP *(Helite)*

(1 MW, Q ~ 0,4 kg/s, T < 950°C, P > 7 MPa)

REX from German loop KVK (10 MW)

> 2006: Components qualification *(recuperator, IHX, cooler, instrumentation)*
Helium purification & quality control
Thermal transients, Modeling

2007-2012: Thermomechanical tests of HX mock-ups *(He/He recuperator, He/N_2 IHX)*

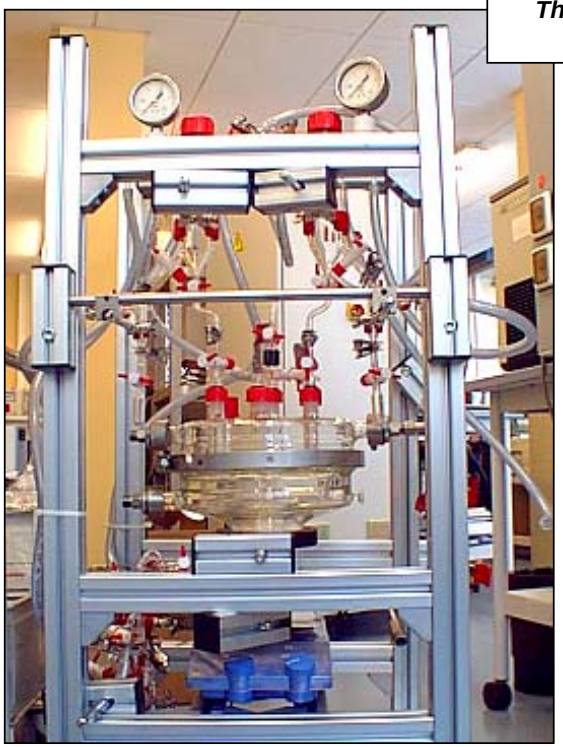
- ***Thermomechanical behaviour***
- ***Flow distribution & pressure drop***
- ***Non destructive examinations***
- ***Simulation of accidental transients (Depressurization…)***

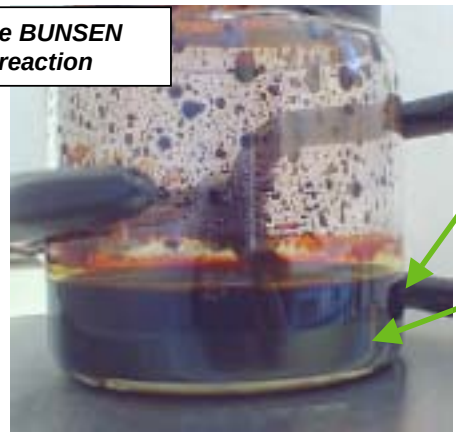
OTHER TEST LOOPs

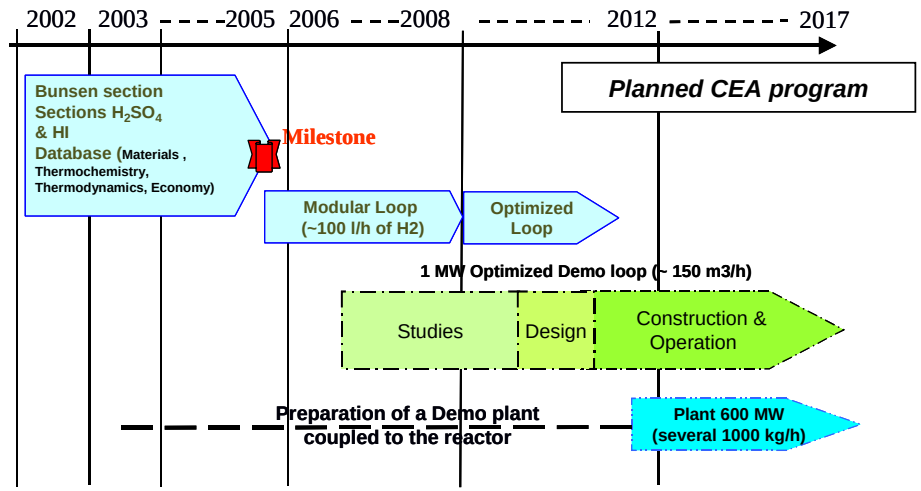
- **Large air flow rate loop (> 3kg/s) to test large component sections**
- **10 MW helium loop to test component mock-ups**
- **Small scale system loop for testing direct conversion cycle operating modes**
- ***Collaborations : OKBM, JAERI, Von Karman Institute***

VHTR Hydrogen Production Process

- Developing & optimizing the S/I thermo-chemical HT process
- Testing a HT Electrolysis stack



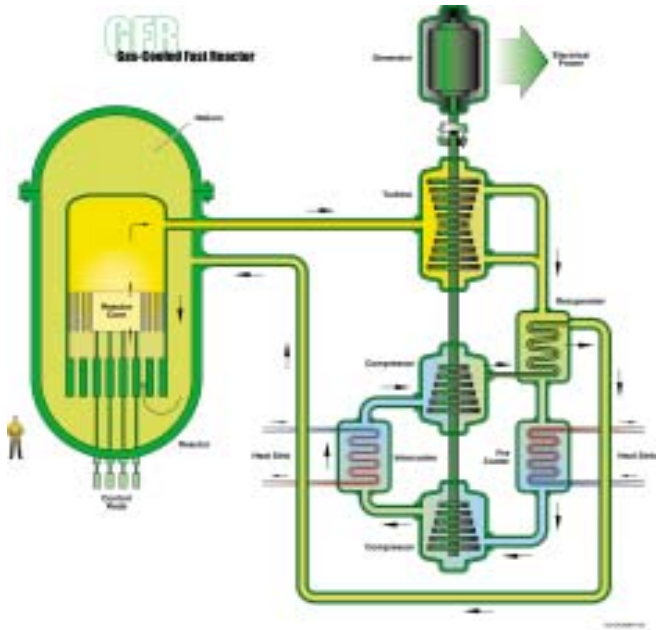




International collaboration on the GFR

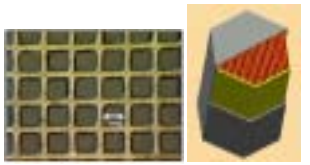
GFR Objectives

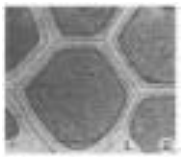
- High sustainability with a closed fuel cycle and full TRU recycle
- Fast-spectrum core – [300-1200 MWe]
- High level of safety
- High-efficiency energy conversion + H2
- Estimated deployment time: 2030



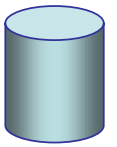
GFR Candidate Fuel Concepts

Composite Fuel (ceramics)





Fuel Pins

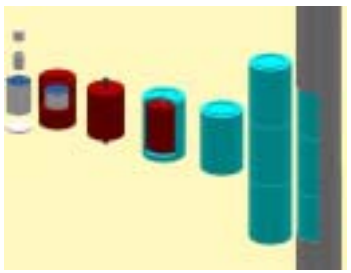


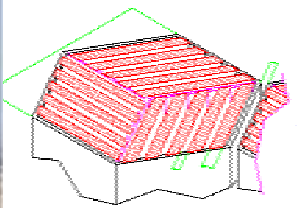
Advanced fuel Particles

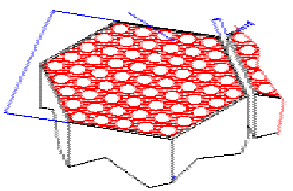
0 — 25 — 50

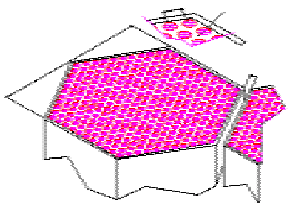
40 % Gas
10 % Structures

% vol Actinides Compound



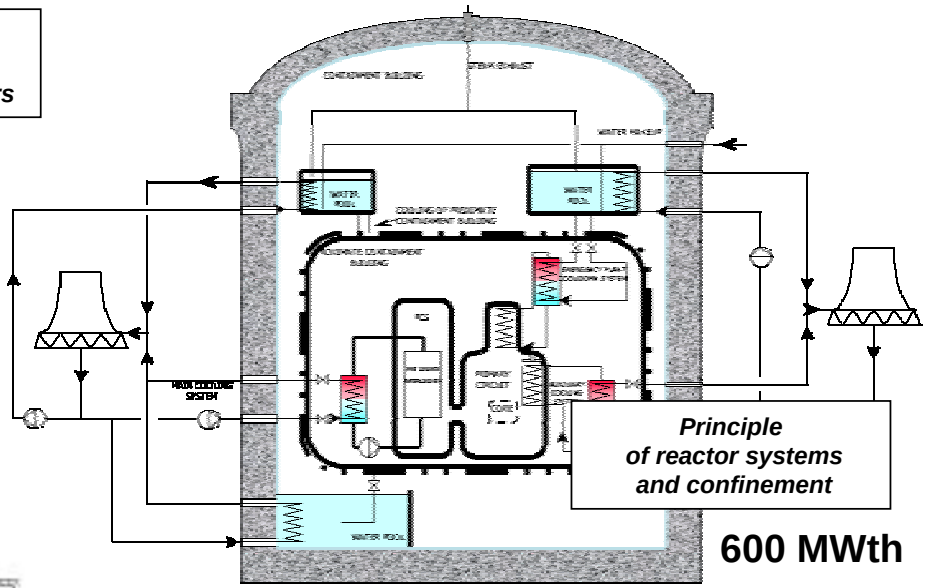






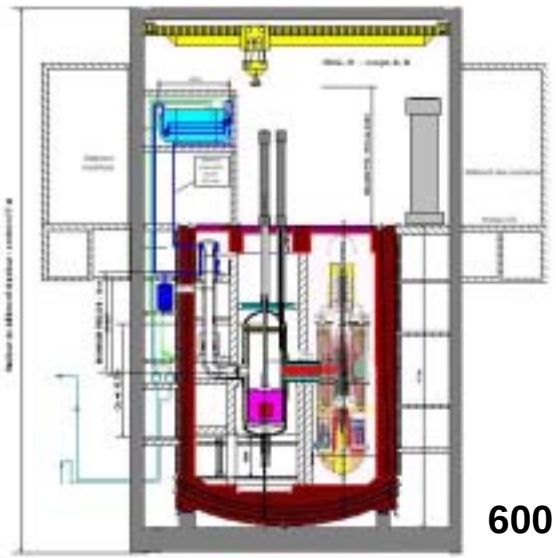
GFR core and system design

MASURCA
critical facility
for gas cooled reactors

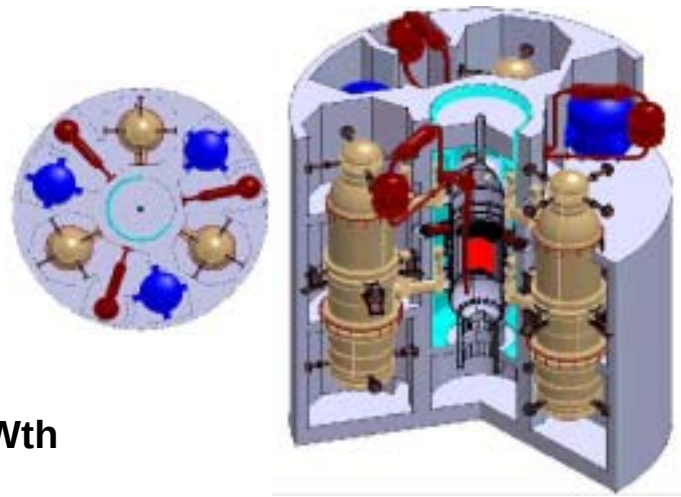


Principle
of reactor systems
and confinement

600 MWth

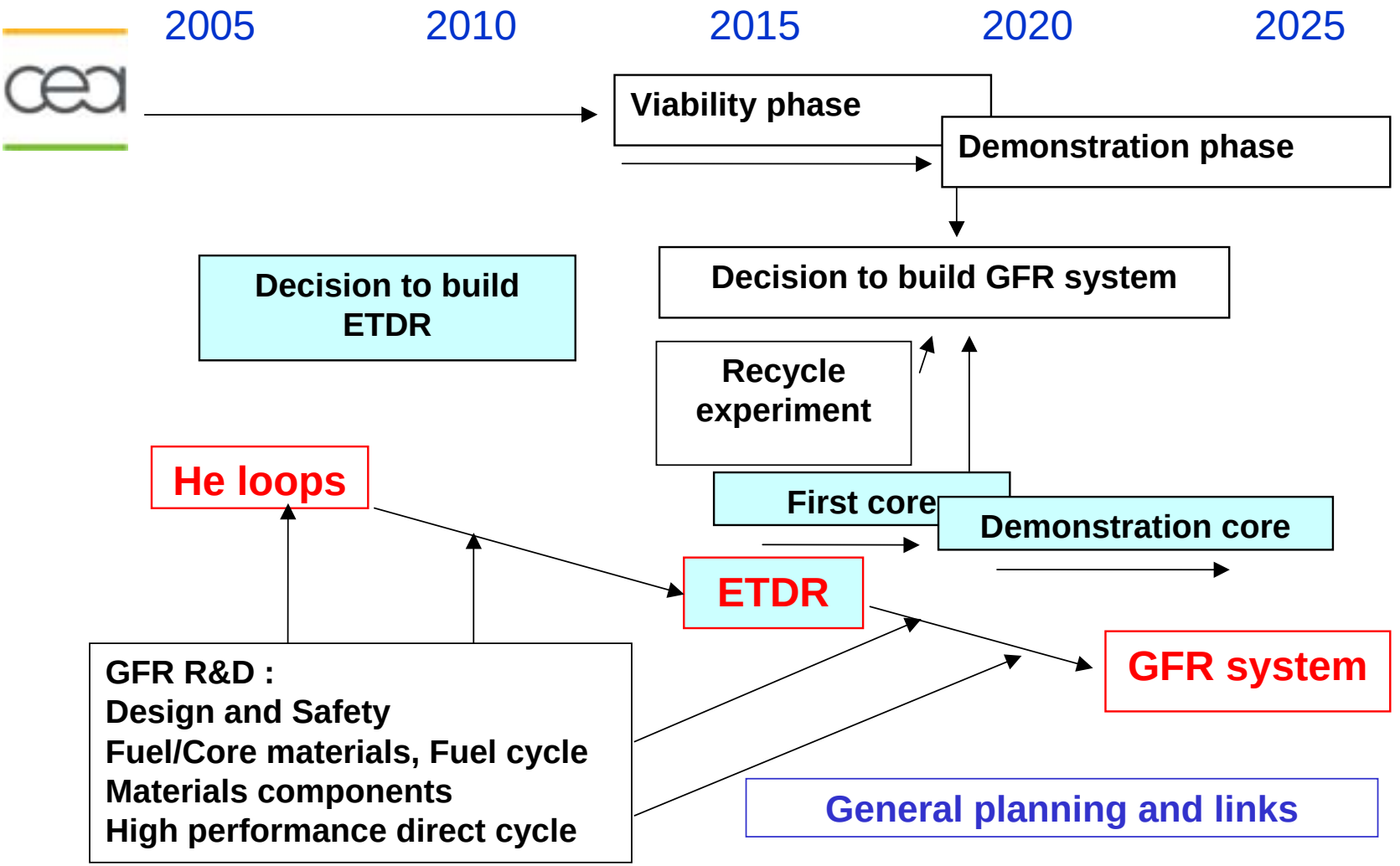


600 MWth

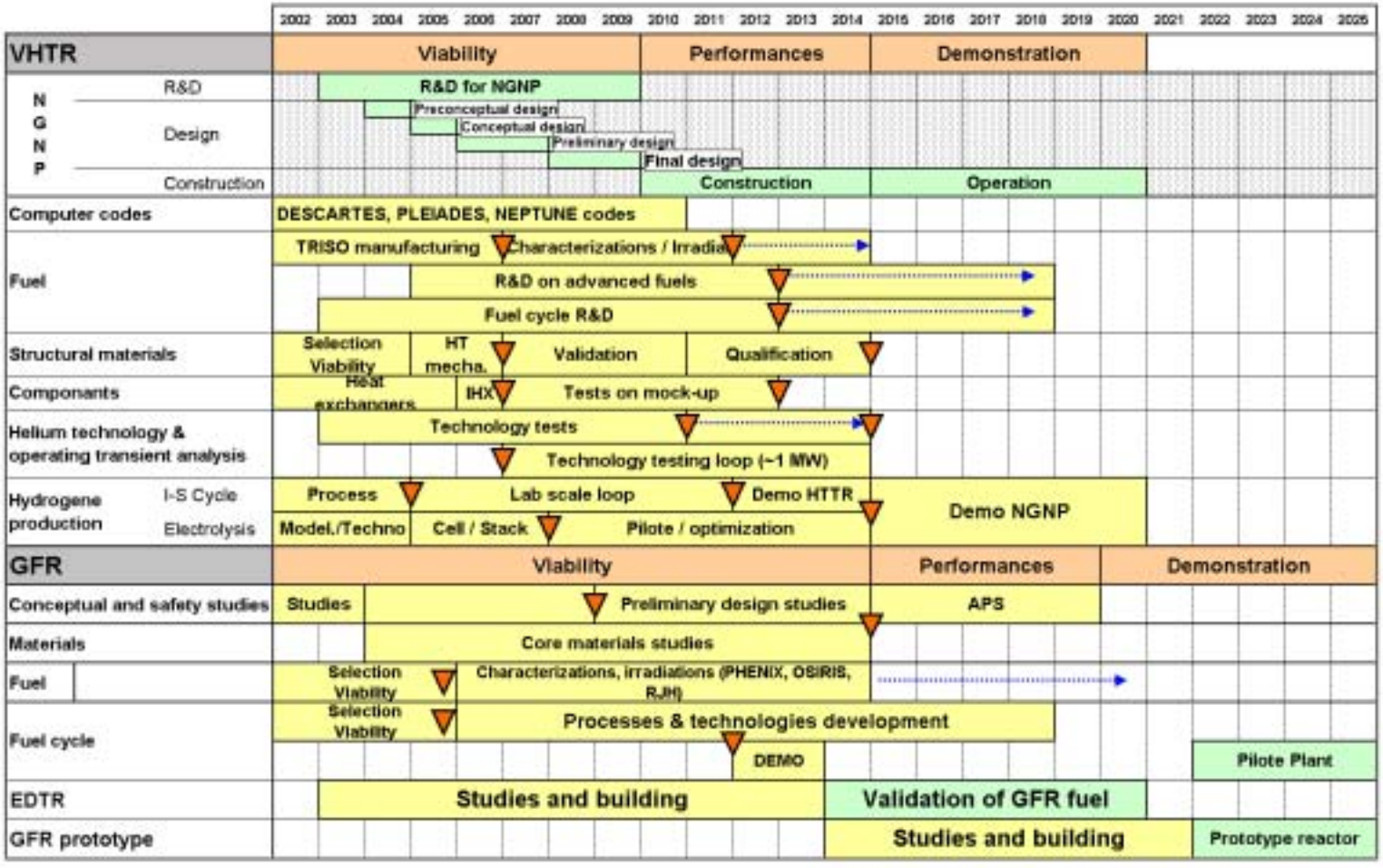


2000 MWth

Logic of the GFR R&D plan



R&D planning of CEA contributions to VHTR and GFR

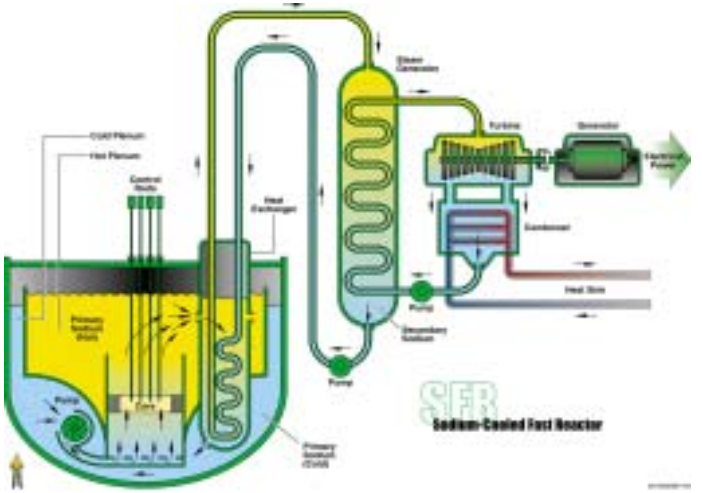


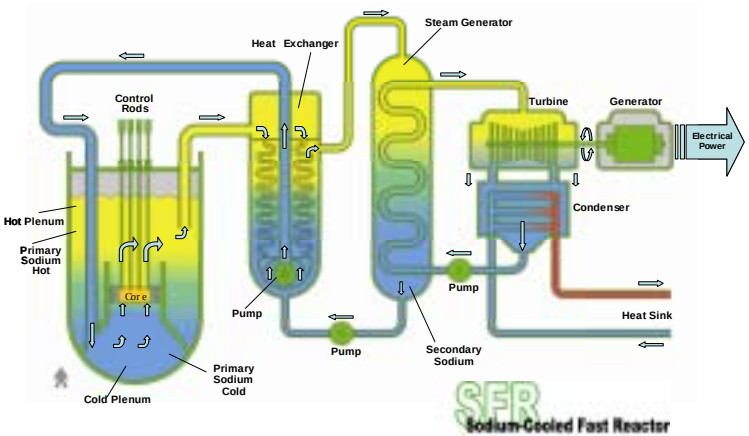
International collaboration on the SFR

SFR Objectives

Closed fuel cycle system with full TRU recycle and burning for sustainability

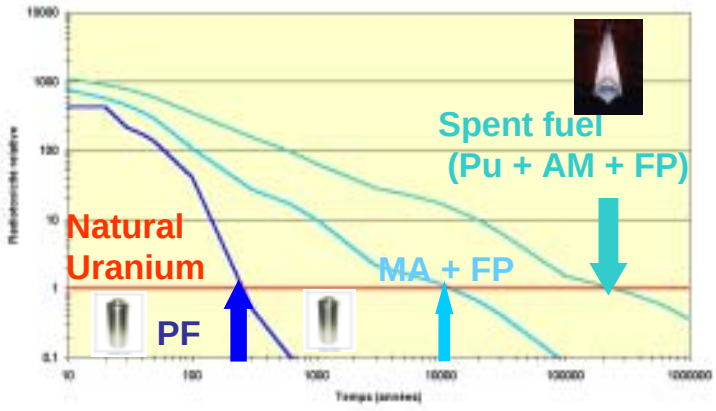
- **High level of safety (passive safety)**
- **Cost reduction (High burn-up fuel, new material, ISI&R)**
- **Estimated deployment time: 2015**

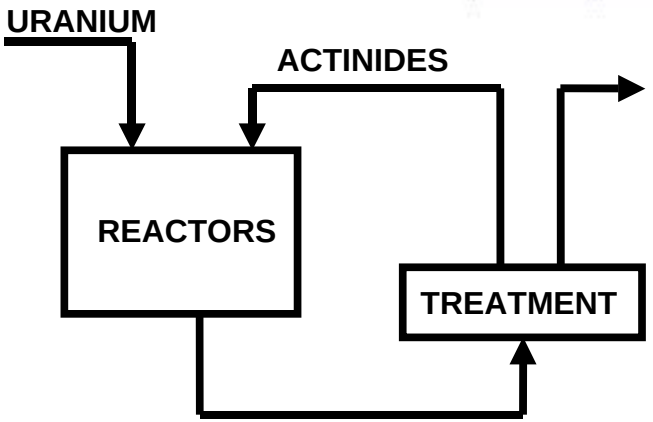




Generation IV fuel cycle options

- Recycling of all Actinides
- Group separation of all Actinides
- Integration of treatment and re-fabrication processes and technologies
- Minimizing waste



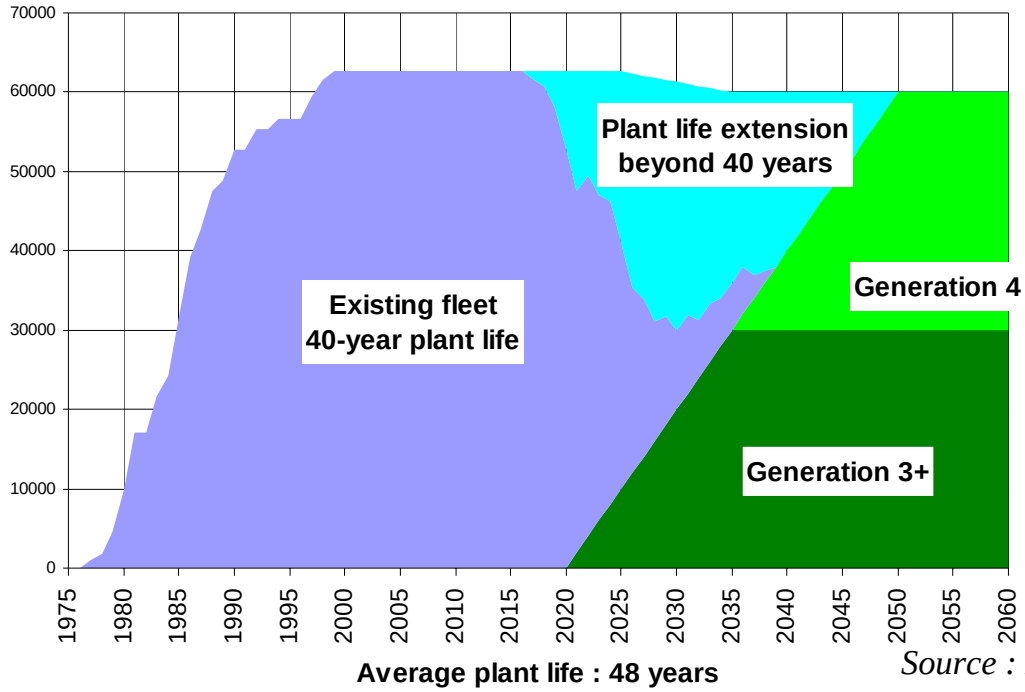


Drastic reduction of ultimate waste long-term radio-toxicity

Process of "external gelation"

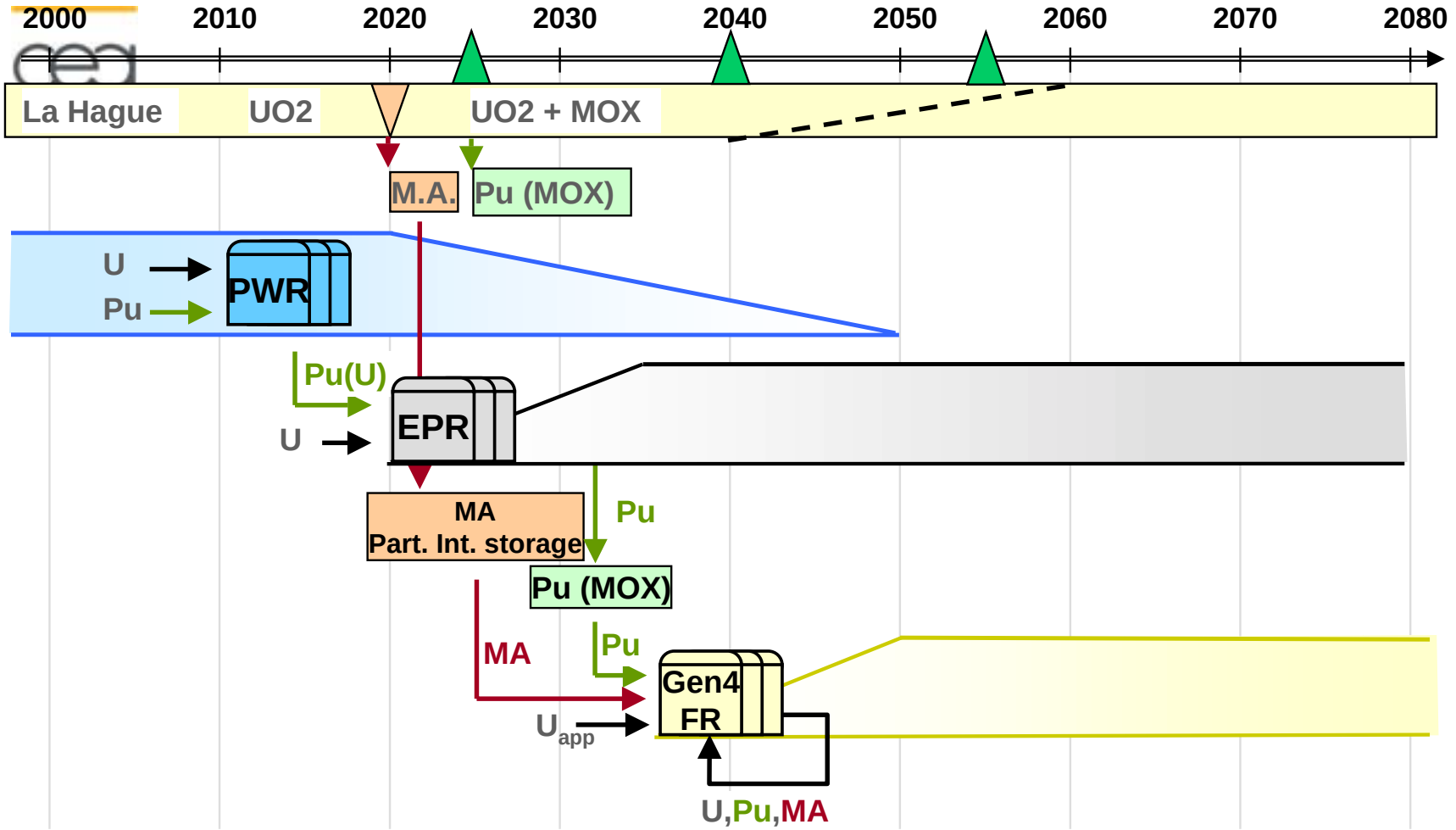
Transition scenarios between reactor generations

- **A transition step awaiting future nuclear energy systems**
- **Major role of LWRs in the 21st century**
  - Current Gen II LWRs : life time extension
  - Gen III/III+ : Replacement existing LWRs →2015
    Will be in operation until the end of the 21st century



Source : EDF, ENC 2002

Global Actinides management scenario with fast neutron Generation IV systems around 2035



CEA R&D on Generation IV Nuclear Energy Systems

Summary

- To develop with FANP and EDF a consistent set of gas cooled nuclear energy systems within the framework of the Generation IV Forum

HTR / VHTR – GFR

- VHTR: To be with FANP and EDF active partners of the Generation IV VHTR system + Demonstration projects *(NGNP)*

- GFR: To confirm the viability and the performances of the GFR system + To launch a successful international collaboration on GFR fuel & fuel cycle + To reinforce the ETDR as international demonstrator of GFR technologies

- SFR: To support the development of the Gen IV Sodium Fast Reactor

- Fuel cycle: To develop effective processes for the integral recycling of spent fuel + To collaborate on investigating scenarios of global Actinides management principles from LWRs to Generation IV fast neutron systems