International Conference on

Fast Reactors and Related Fuel Cycles

FR09

December 7th – 11th, 2009, Kyoto, Japan

Fast Neutron Reactors & Sustainable Development

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Advisor to the Chairman of the French CEA

The first build

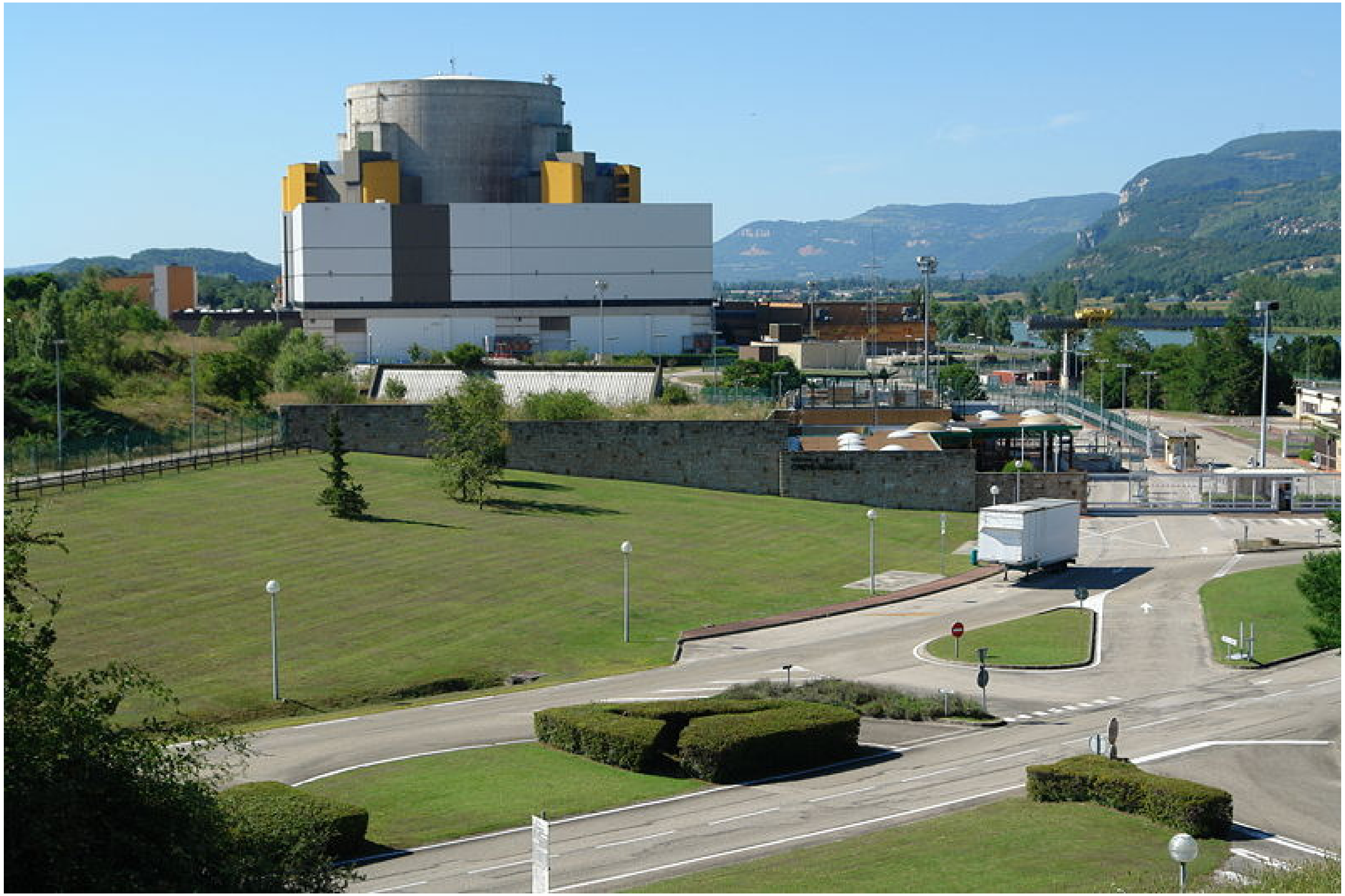
1950s : Nuclear Electricity

EBR 1
(USA, Idaho)

« EBR 1 lits Arco »

➔ **1951 :** the first fast neutron reactor
and the first nuclear electricity production

The CREYS MALVILLE NPP



The History of Fast Reactors

- **Fermi:** The vision to close the fuel cycle
- **50's:** First electricity generating reactor: EBR-I
- **60-70s:** Expected Uranium scarcity – significant Fast Reactor programs
- **80's:** Decline of nuclear – Uranium plentiful

  → USA (& others): once through cycle & repository

  → France, Japan (& others): closed fuel cycles to solve waste issue

- **Late 90's : in the US** Rebirth of closed cycle research and development for improved waste management
- **Now:** Long term energy security and the role of nuclear

The Generation IV International Forum

4th Generation Nuclear Systems for sustainable energy development

- Technical maturity around 2030
- Steady progress
  - Economic Competitiveness
  - Safety and reliability
- Significant progress :
  - Waste minimisation
  - Resource saving
  - Security : non proliferation, physical protection
- Opening to other applications :
  - High temperature heat for industry
  - Hydrogen, drinking water

A Global Solution

-Fast Neutron Reactors

-Closed Fuel Cycle,

-Full Recycling of the Actinides

Uranium Supply will no more be a problem whatever its price

The existing depleted uranium that is stored today in France is worth 5000 years of the country current nuclear production.

The Fuel Cycle of 4th Generation Reactors

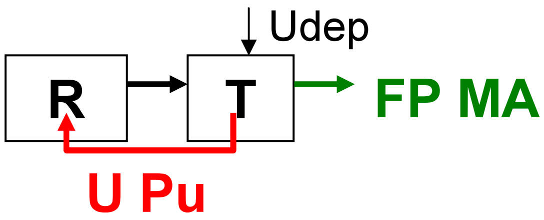
→ Resource Saving

→ Waste Minimisation

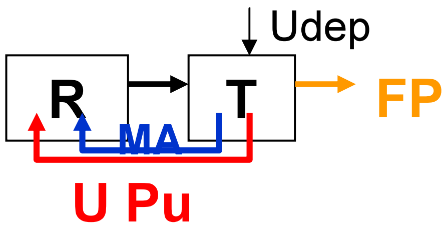
→ Proliferation Resistance

50 times more electricity with same amount of natural Uranium

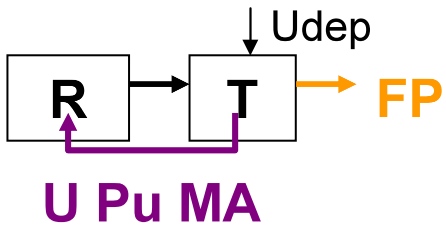
Various Options to be tested by the Prototypes :



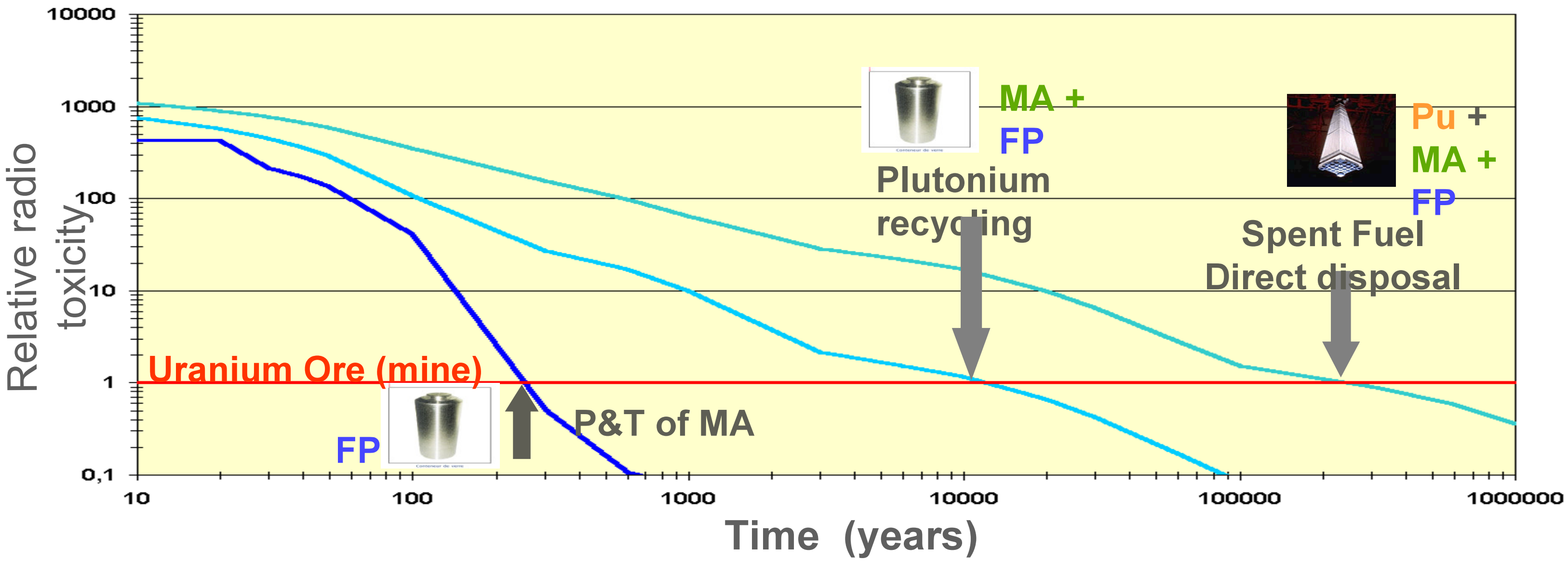
Recycling U Pu only



Heterogeneous Recycling



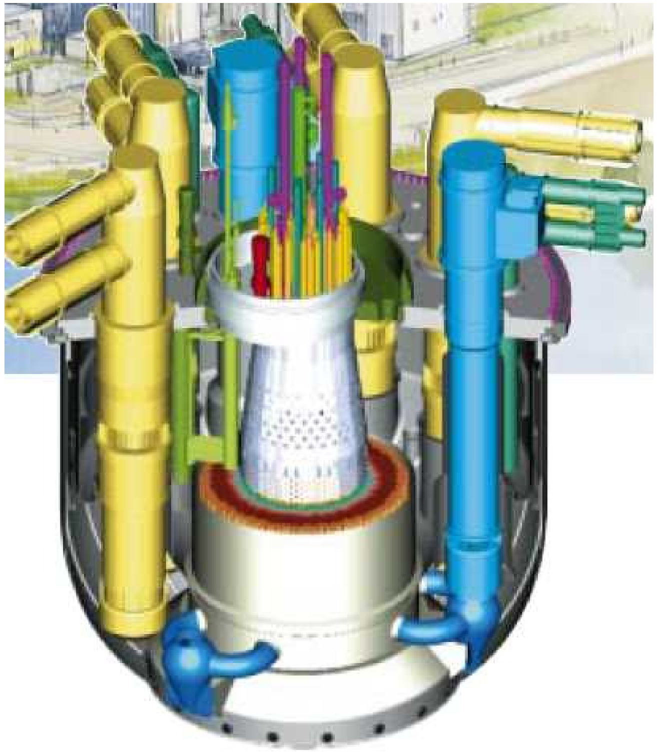
Homogeneous Recycling (GenIV)



Superphenix and the EFR project

Superphenix:

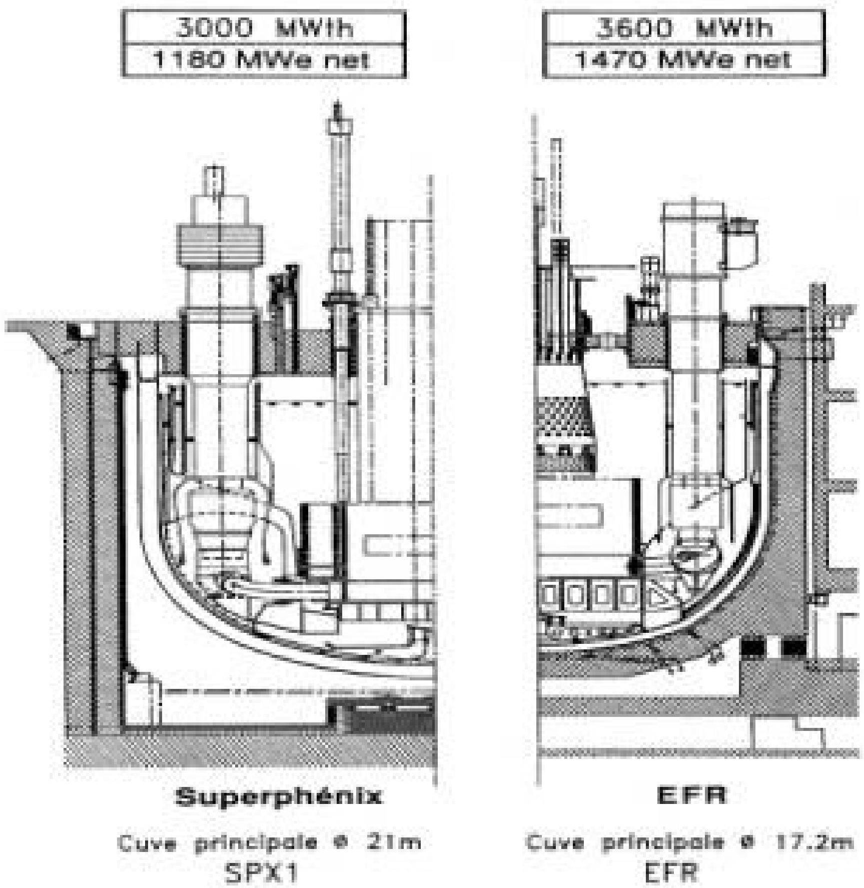
Industrial prototype (1200 MWe),
started in 1985,
shutdown in 1998

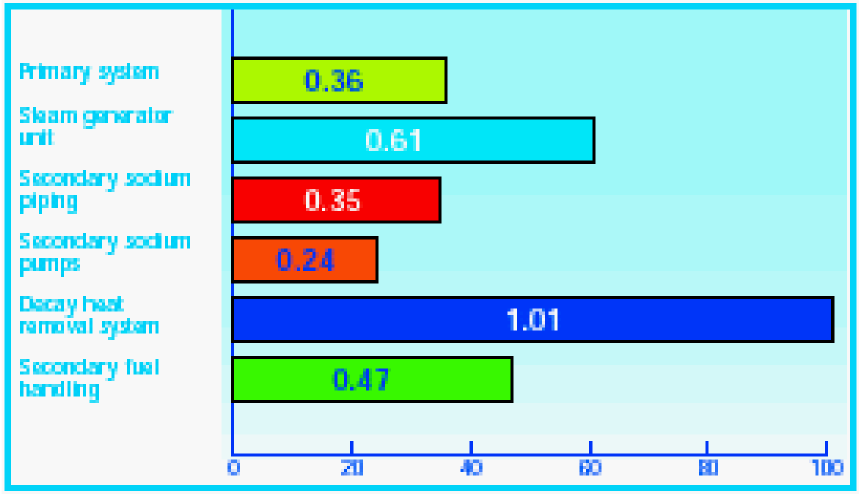


EFR Project
(European Fast Reactor)

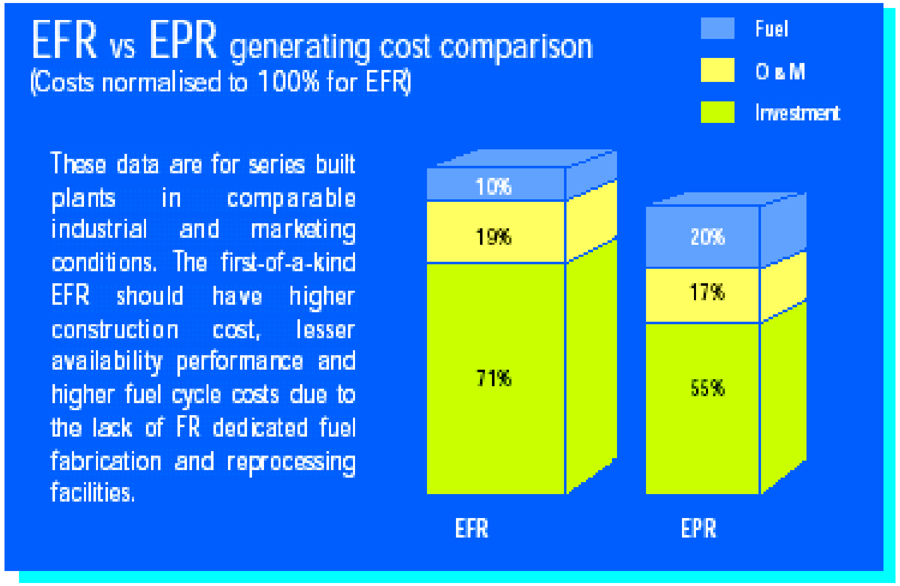
- *1500 MWe*
- *Integrated Concept*

EFR Economic evaluations (1998)





EFR vs SPX1: Comparison of specific steel weight in t/kWe



What coolant for fast neutron reactors?

Sodium = first choice

- ✓ High conductivity
- ✓ Liquid from 98°C to 883°C (at 1 bar)
- ✓ Low viscosity
- ✓ Compatible with steels
- ✓ Industrial fluid
- ✓ Low cost

But reactive with air and water, and opaque

Lead is a variant

- ✓ No reactivity with air and water
- ✓ Good coolant

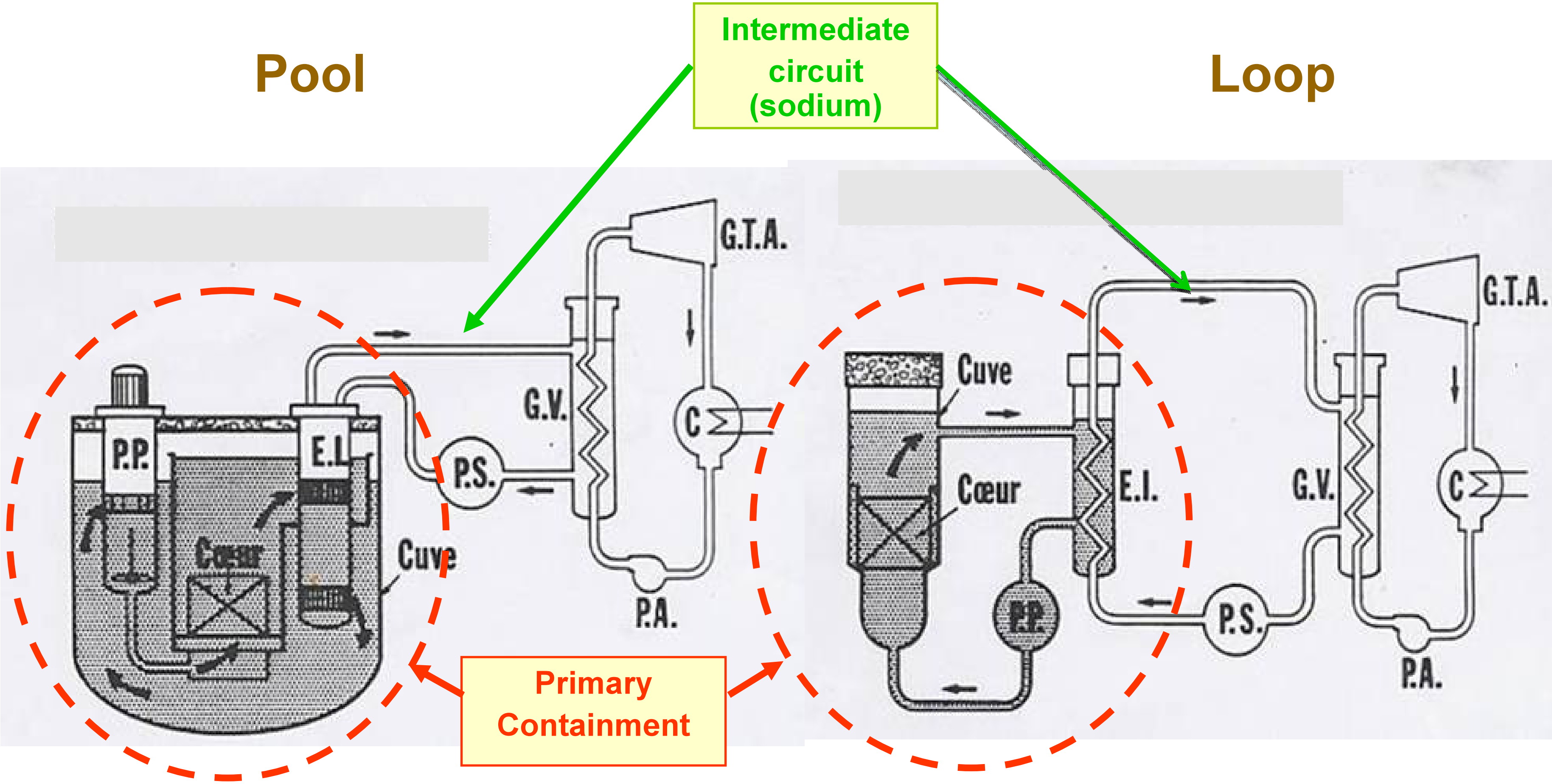
But corrosive, toxic, very dense, opaque (and solid…)

Helium is an alternative

- ✓ No temperature constraints
- ✓ No phase change
- ✓ Inert
- ✓ Transparent

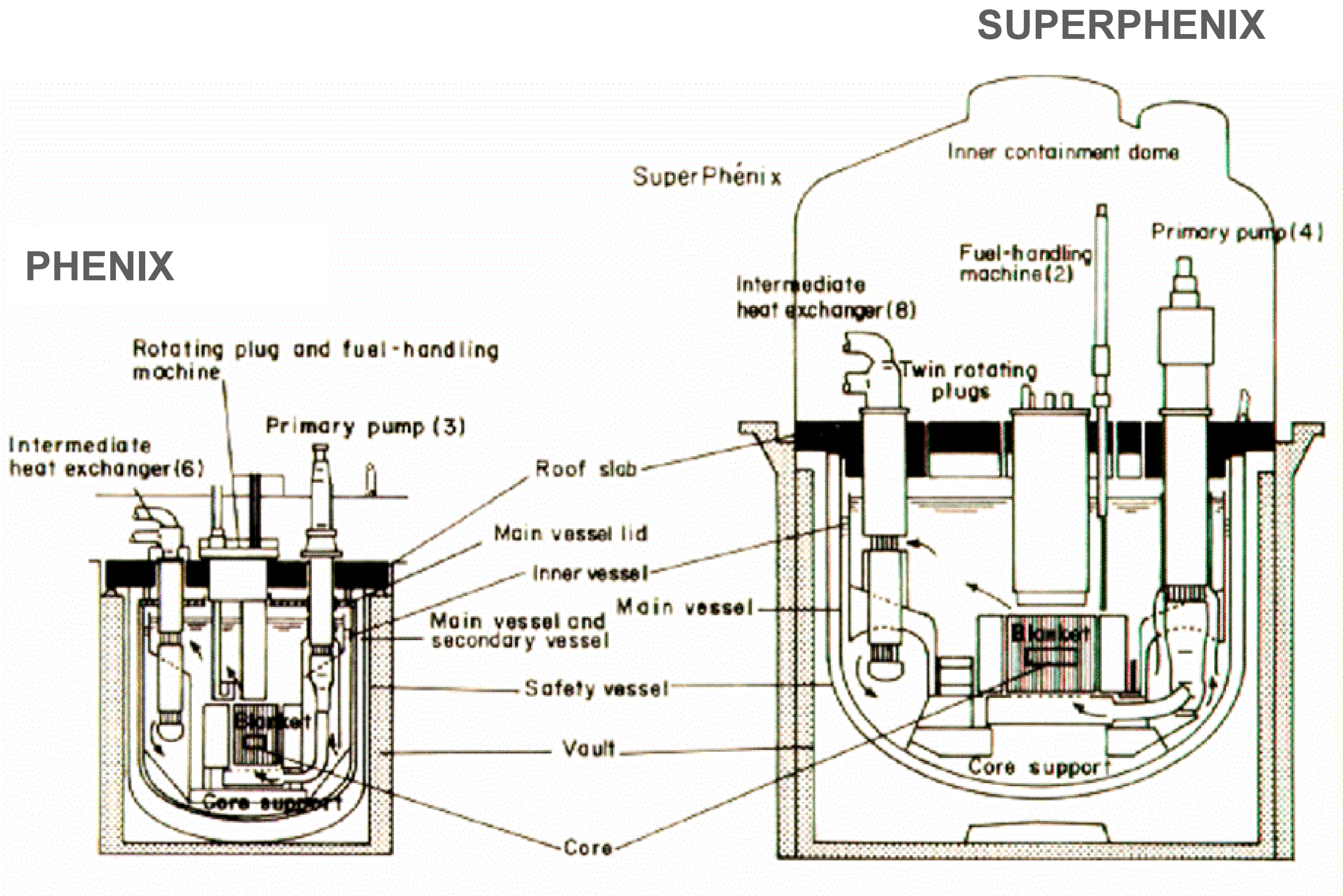
But low density, high pressure

Sodium coolant: the concepts



The integrated concept

Phenix and Superphenix



Phenix

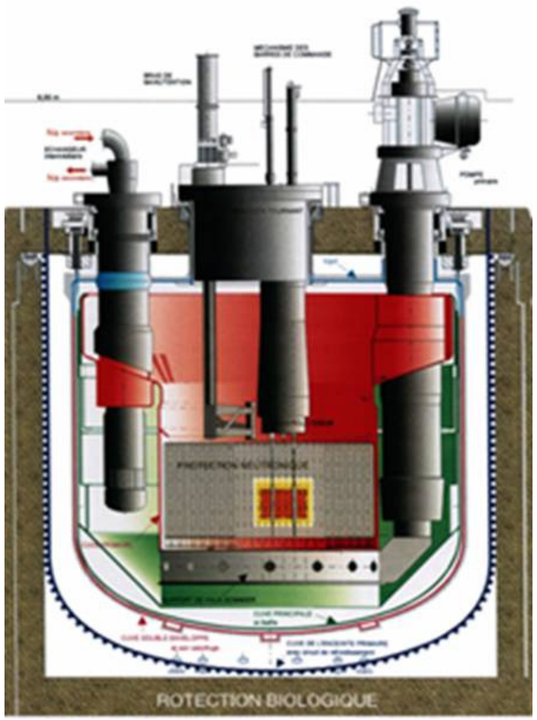
Very good operation

Extensive Feedback Experience: MOX fuel, closed cycle, technology (SG, IHX)

Demonstration of ISI and reparability

Transmutation of minor actinides

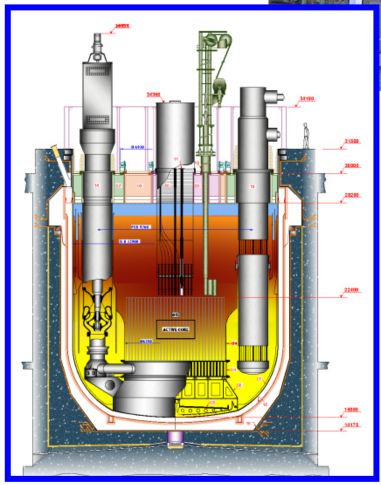
Closing down this year



The Russian Reactor BN 600

Beloyarsk Plant,
600 MWe Reactor, integrated concept, sodium-cooled
Started in 1980, still operating

Other Pool Type Reactors



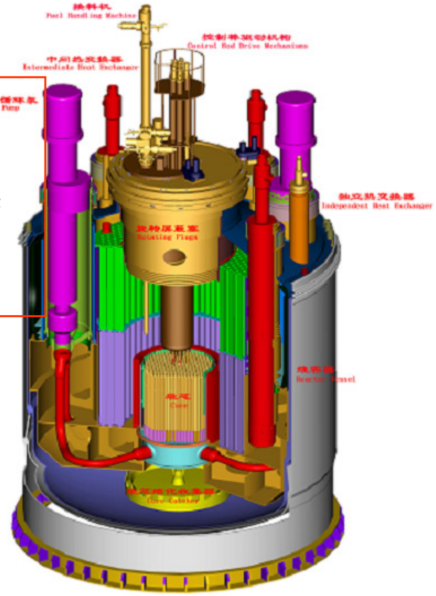
PBFR (India)

500 MWe, 2010

CEFR (China)

65 MWth, 20 MWe

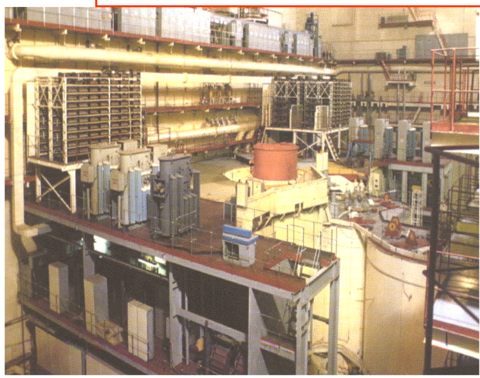
2010

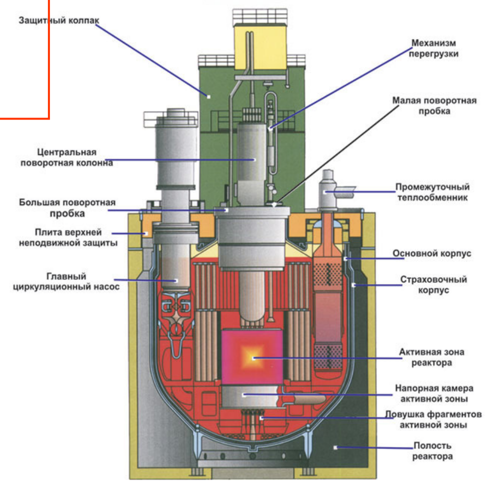


BN600, 1980

BN800, 2012

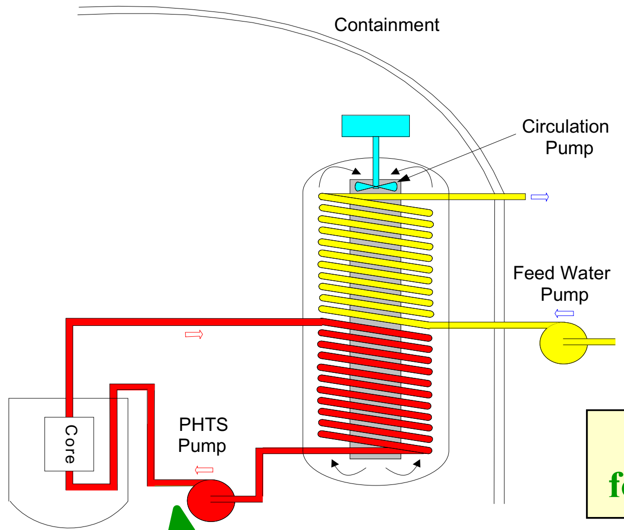
(Russia)

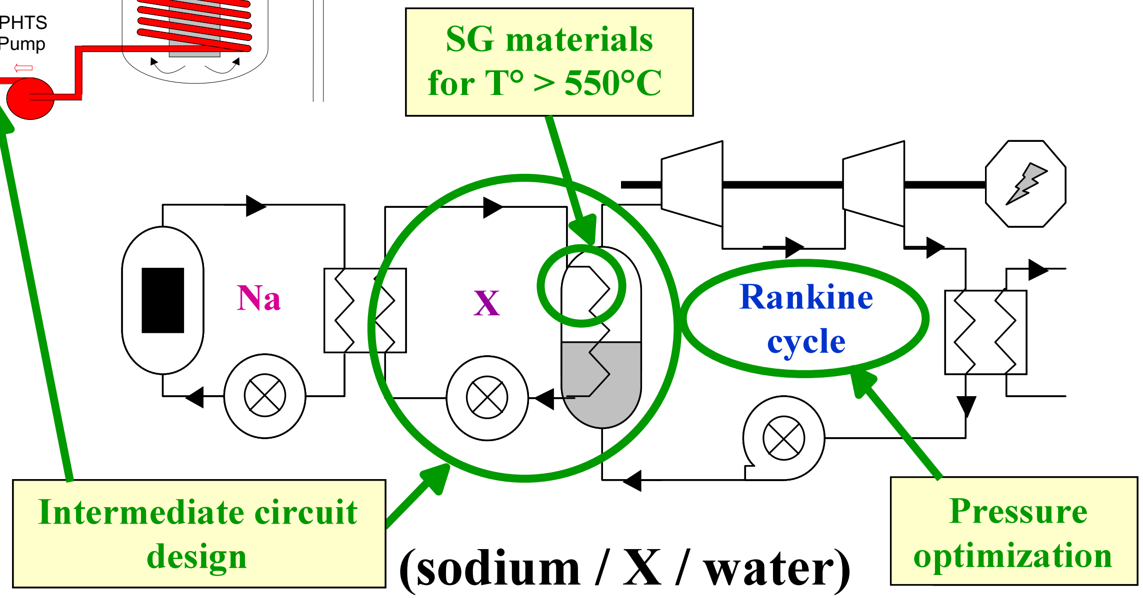




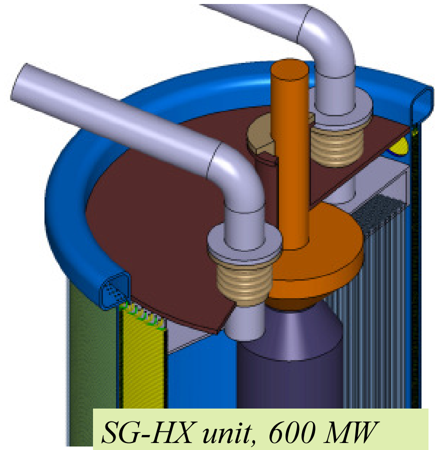
New Options for Energy Conversion

- **Gas cycle conversion (N_2, supercritical CO_2)**
- **Water/steam (Rankine cycle)**
  → Simplification of intermediate circuit and avoidance of sodium/water interaction





« Ultra-compact » 3-fluid component (SG-HX)

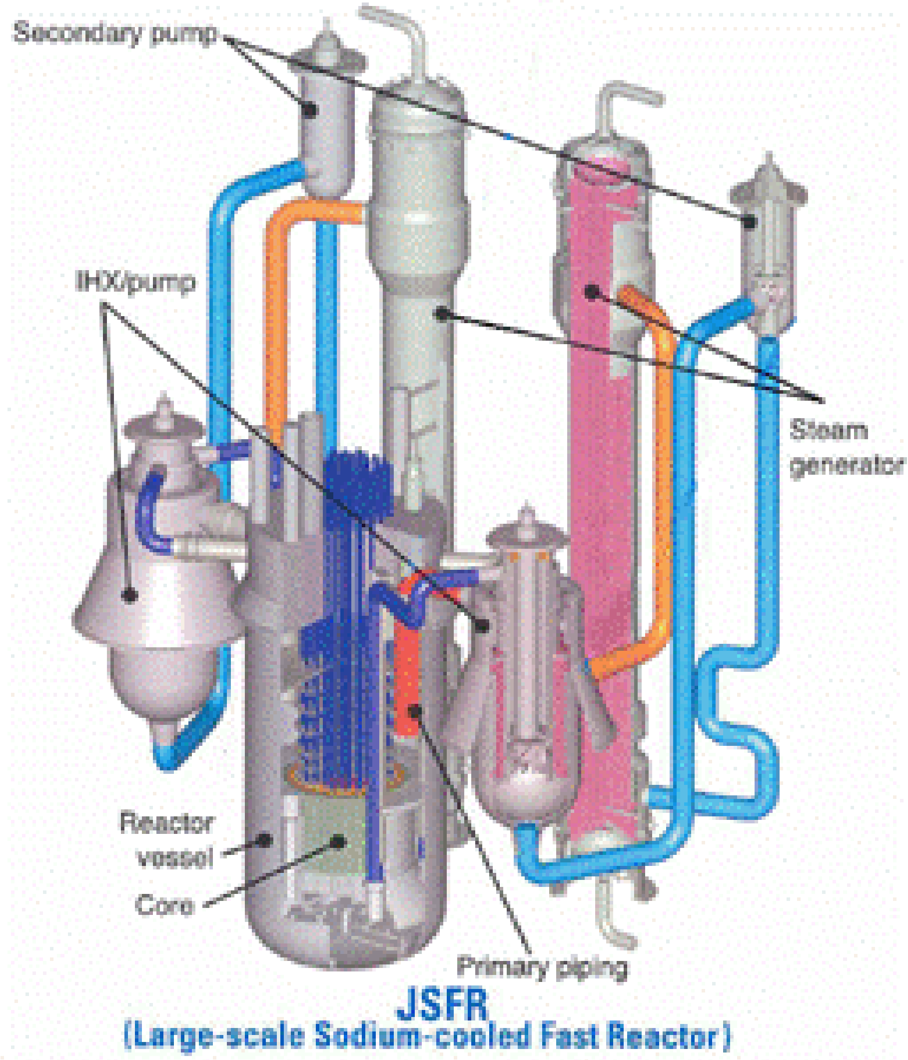


SG-HX unit, 600 MW
Na/Pb-Bi/H_2O
Φ~4m X h~11m

The Loop Concept

Joyo (140 MWt)

Monju (280 MWe)



A Generation IV concept:
JSFR (en project, 1500 MWe, 2025)

The JSFR Project

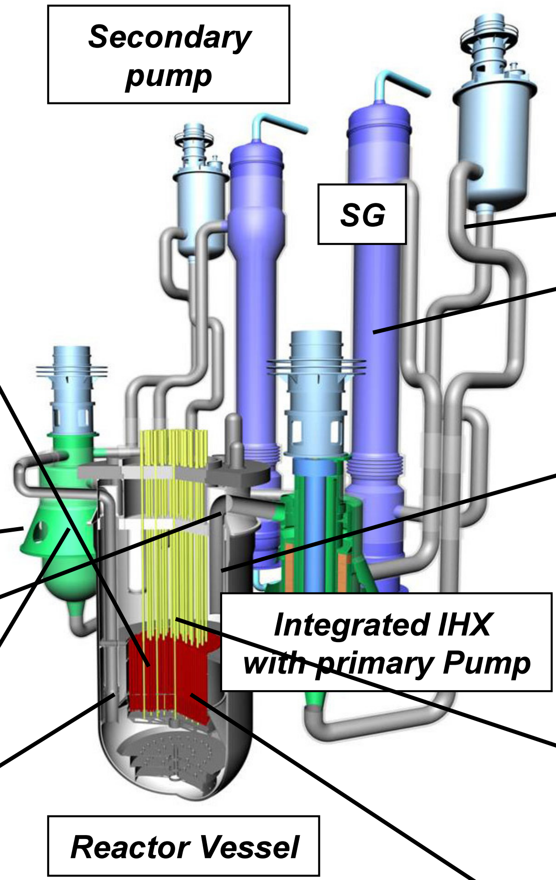
- *1,500 MWe large-scale Sodium Cooled FBR with MOX fuel,*
- *Innovative technologies for reactor core safety enhancement, high economic competitiveness and countermeasures against specific issues of sodium*

Economics

ODS cladding to achieve high burn-up with elevated temperature

Innovative technologies to reduce plant materials and reactor building volume

- *Two-loop cooling system*
- *Shortening of piping with high chromium steel*
- *Integrated Pump-IHX Component*
- *Compact reactor vessel*



Reliability

Prevention of sodium chemical reactions

- *Double-wall piping*
- *High reliable SG with double-wall tube*

Inspection and repair technology under sodium

Safety

Enhancement of reactor core safety

- *Passive reactor shutdown system and decay heat removal by natural circulation*
- *Recriticality free core*

Liquid Metal Fast Reactor Fuel

metal, carbide/nitride or oxide ?

Pu/(U+Pu) = 0.2	Carbide (U,Pu)C	Nitride (U,Pu)N	Oxide $(U,Pu)O_2$	Metal (U,Pu)Zr
Heavy Atoms density (g/cm3)	12.95	13.53	9.75	14
Melting point (°C)	2420	2780	2750	1080
Thermal conductivity (W/m/K)	16.5	14.3	2.9	14

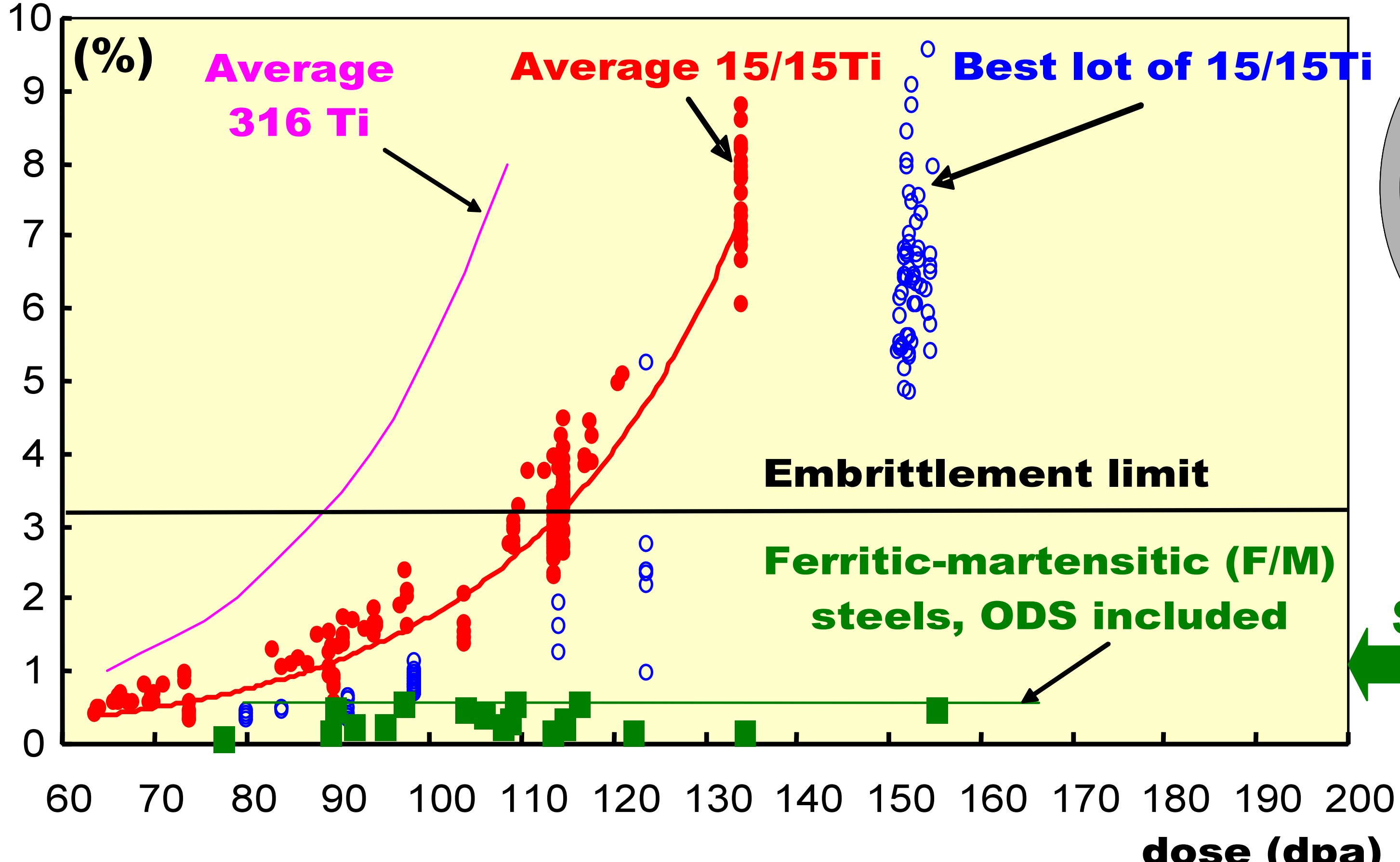
- ➔ Metal fuel was developed in the US (EBR2)
- ➔ MOX fuel feedback experience is the most extensive
- ➔ Carbide and nitride enable to increase the margins with respect to melting (gain in performances or in safety)

Cladding material

- Large pin diameter
- high burn up (dose > 200 dpa)

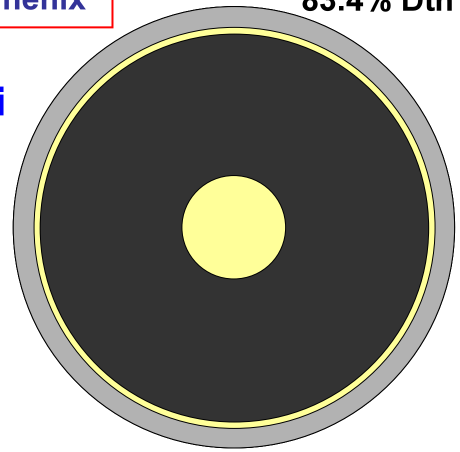
→ Cladding with no swelling

Swelling of advanced austenitic steels and ferrito-martensitic steels used as fuel cladding in Phenix



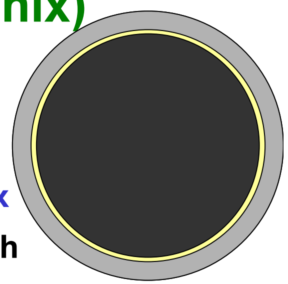
SFR V2

83.4% Dth



Large-diameter pins, small-diameter spacing wire

SUPERNOVA (Phenix)



Phenix

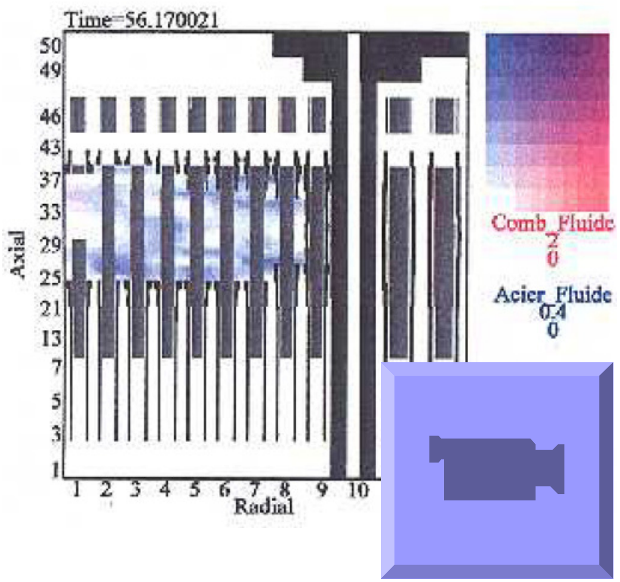
88% Dth

Advanced fuel cladding: 316 Ti → 15-15 Ti → F/M ODS

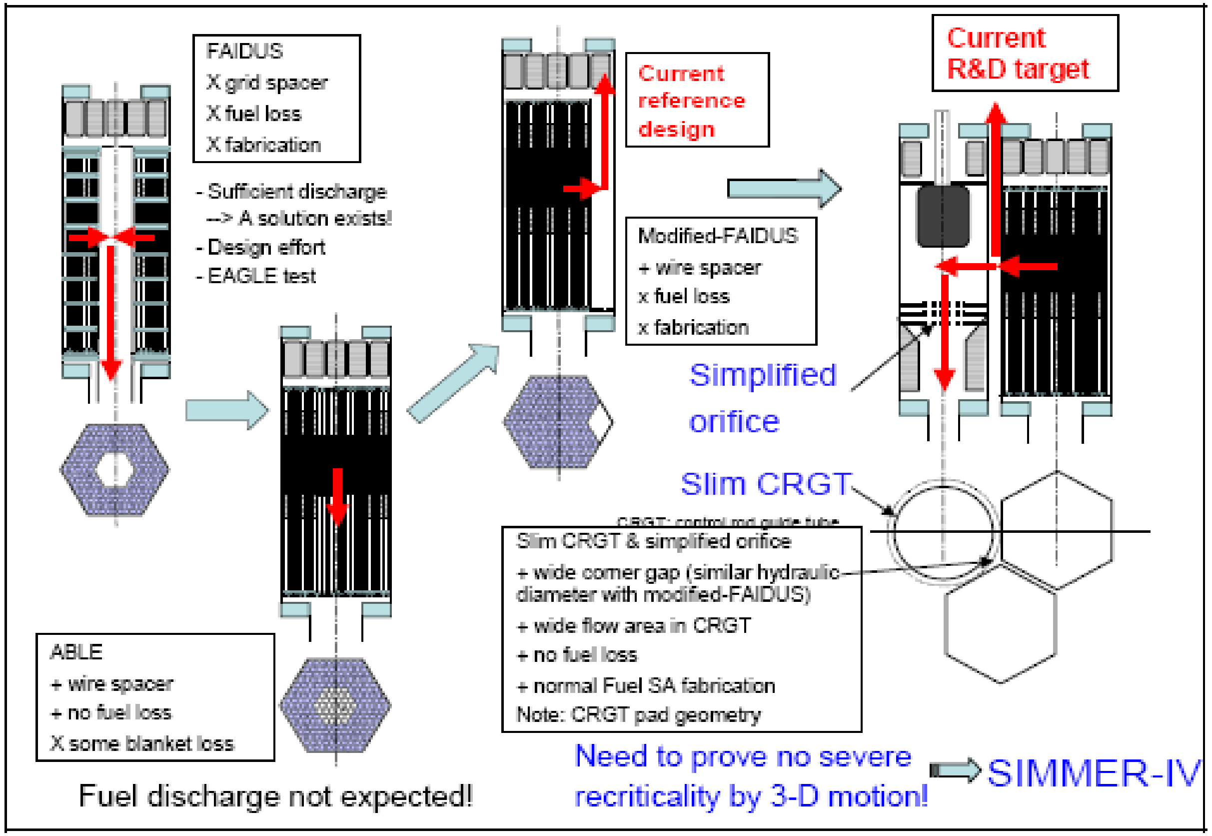
Safety Studies

A strategy for severe accident management

Provisions for mitigating the core melting risk
and, in the event of a core meltdown,
for preventing high-energy accident sequences



Simulation of *BTI in Phénix (SIMMER-III code)**



Passive devices for corium channeling (FAIDUS, Japan)

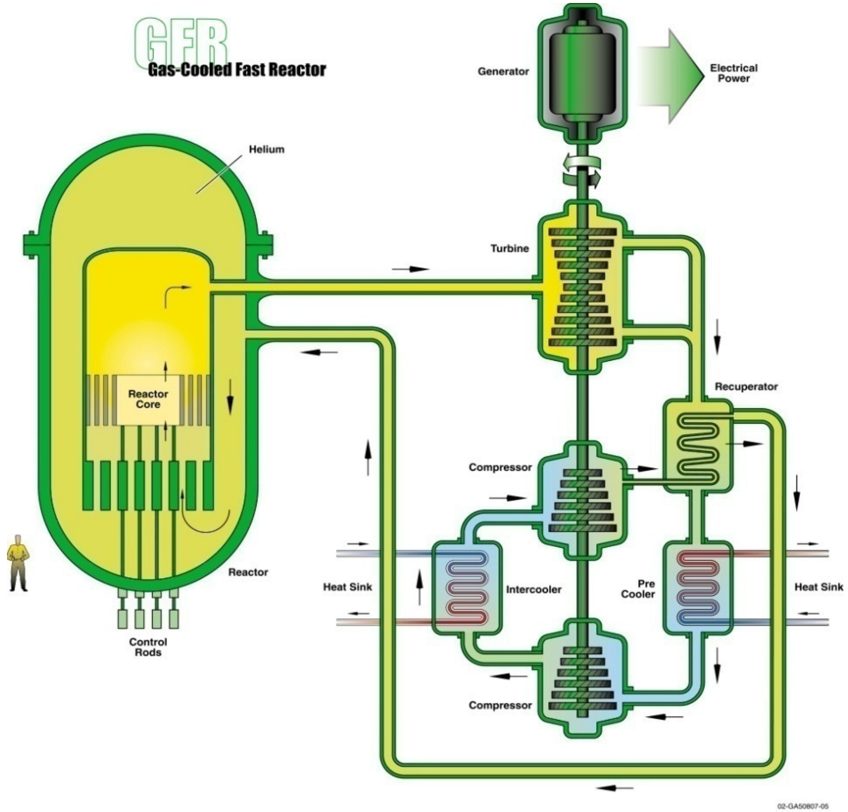
*BTI: Total Instantaneous Blockage of a fuel assembly

The GFR

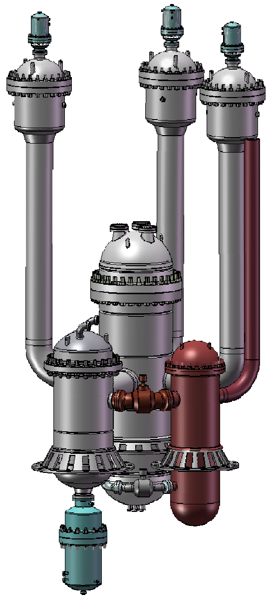
Objectives :

- Gas : an alternative to liquid metals for fast reactors
- **Power range 300 – 1200 MWe**
- Outlet temperature of helium ~ 850 °C

- **Robust fuel**
- **Active + passive safety approaches**
- **Cogeneration electricity + hydrogen**

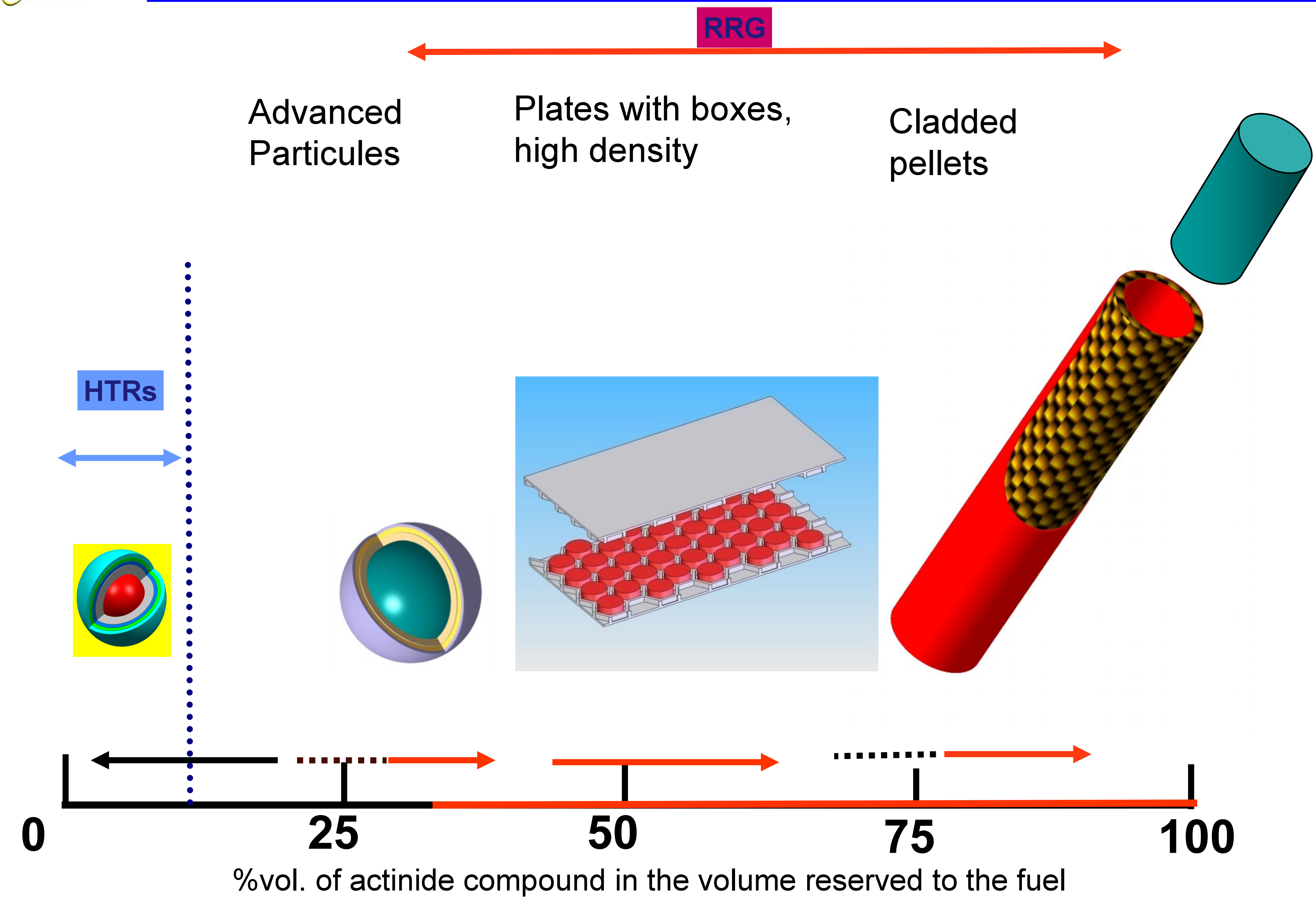


The Gas Fast Reactor (GFR)



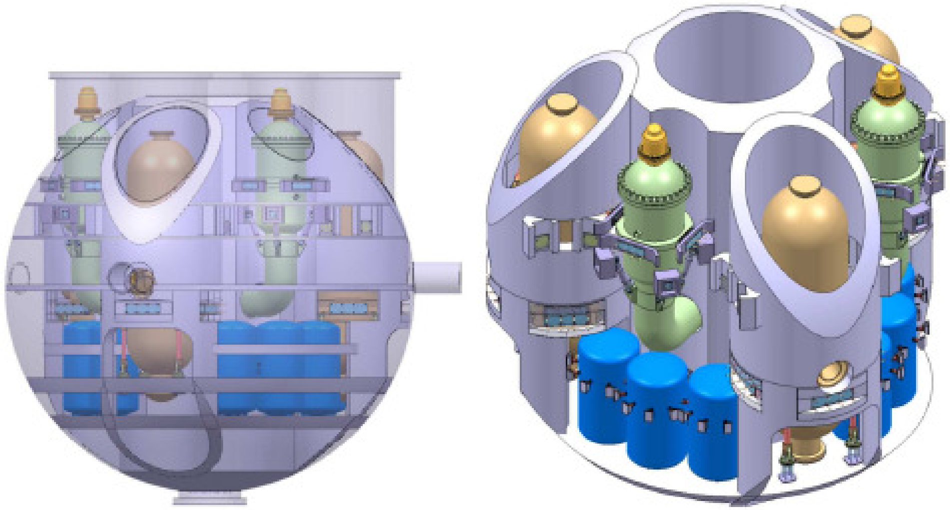
OBJECTIVES : To concentrate on main problems (fuel and safety) in order to build in Europe, by the end of the next decade, a small experimental gas-cooled fast reactor (ALLEGRO)

Choice of fuel for Gas Fast Reactors



Safety Studies

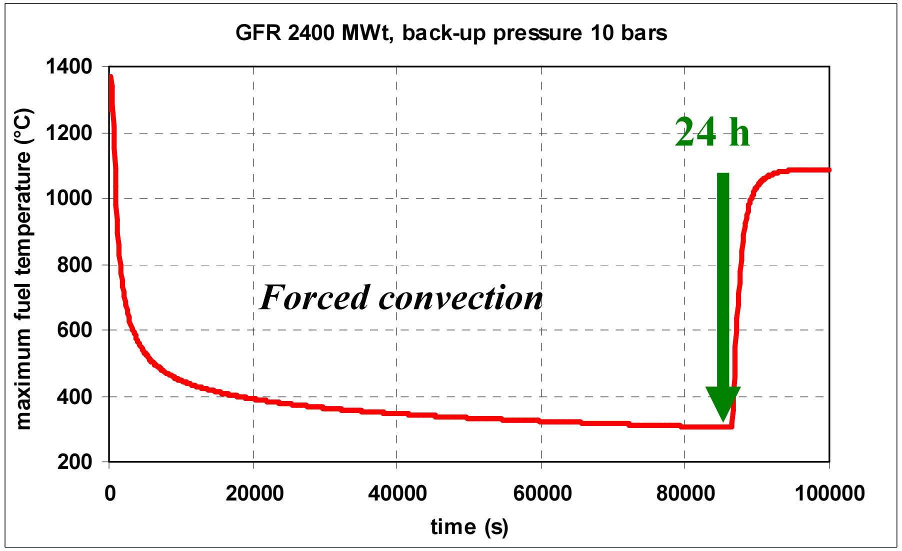
Analysis of GFR fast depressurization accident



GFR guard containment

(metallic sphere 33 m diameter)

+ gas injection tanks



Confirmation of DHR system performance (LOCA) with CATHARE

Efficiency of DHR systems and control of fuel temperature < 1600°C

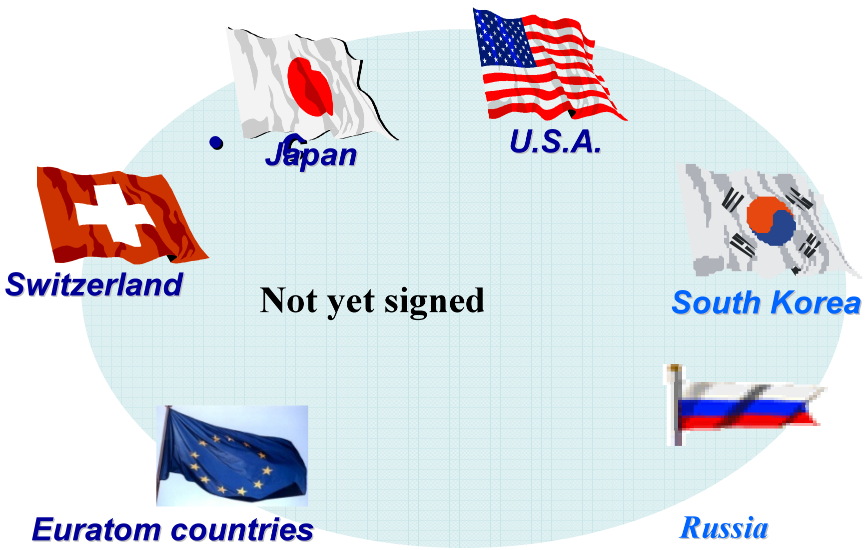
- **24 hr in forced convection (small pumping power ~ 10 kWe)**
- **For longer term, natural circulation at 1.0 MPa**

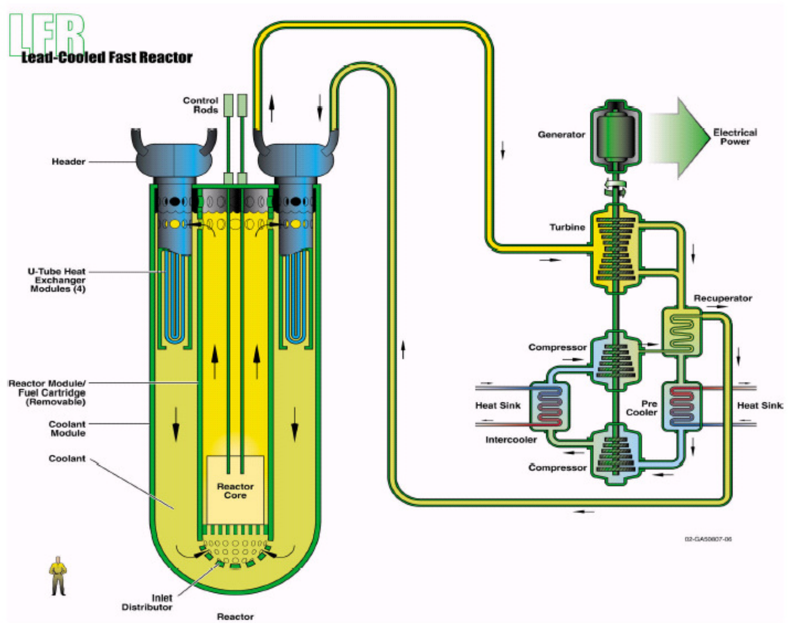
The LFR

Objectifs :

- Power reactor of 1200 MWe
- Modular reactors of 300-400 MWe

- Coolant Pb or Pb-Bi
- Material resistant to corrosion by Pb at 550-800 ° C
- Fuel with actinides
  (metal or nitrate)
- Nuclear Battery 50-100 MWe –
  cycle of 10-30 years





The French ASTRID Prototype Project

End of Pre-Conceptual Design

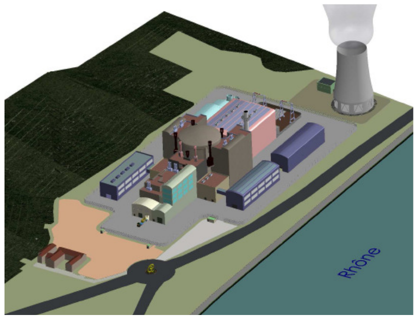
*Technological Studies
*Choice of ASTRID Power

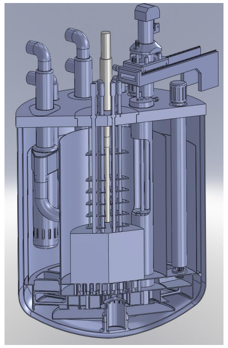
Decision to continue

End of Conceptual Design

Fuel Loading

2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 ~ 2020





Conclusion

The Need for Harmonization and Coordination at International Level

- Harmonization of different national prototype / experimental reactor construction projects:
  ➔avoid duplication, seek complementarities

- Pooling of efforts, sharing of R&D tools / construction capabilities
  ➔optimisation of means

- Establishment of international safety standards, owing to the fact that safety and licensing are largely congruent among the international community
  ➔reference regulatory practices and regulations
  ➔international consensus on common (or compatible) high level safety philosophy