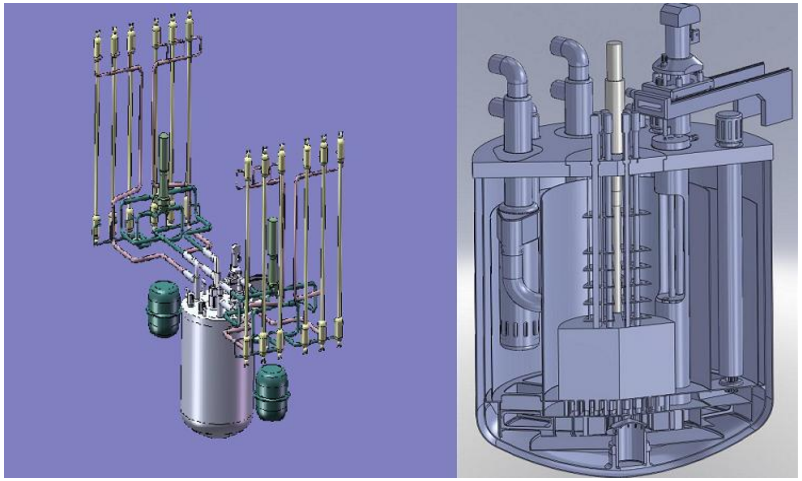
The French Prototype of 4th Generation Reactor ASTRID*

*Advanced sodium technological reactor for industrial demonstration



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What do we expect from GENIV systems in France ?

- Sustainability
  - GENIV systems shall make the best use of U resource, be able to multirecycle Pu, and have the capability to perform transmutation of minor actinides.

  → **This calls for fast neutron reactors and a closed fuel cycle.**

- Safety
  - Improved and robust safety demonstration with regard to former fast reactors
    - → Enhanced prevention of whole core melting accidents
    - → Exclude in a credible way energetic accident sequences
    - → Prevention and mitigation of risks due to sodium chemical reactivity
    - → Robustness to external hazards
  - Safety level at least equivalent to 3rd generation reactors
    - → **And taking into account lessons learnt from Fukushima accident**

What do we expect from GENIV systems in France ?

- Economy
  - GENIV systems shall be competitive, for the same overall performance, compared to other sources of energy at the time they will be put into operation.
  - → **This means a lot of efforts with regard to investment costs but also to availability and operation costs.**

- Proliferation resistance
  - Importance of intrinsic and institutional barriers
  - → **Safeguards have to be fully integrated from the initial planning through design , construction and operation**

Framework on 4th generation in France

2001, Generation IV International Forum

Strong French involvement in the GEN IV Forum which identifying and selecting six nuclear energy systems for the future .

January 2006, French President Chirac declaration

« I decided to launch, immediately, the design, within the CEA, of a 4th generation reactor, that shall be commissioned by 2020. We will associate the industrial and international partners which would wish to join »

June 2006, Law on radioactive materials and waste management

Transmutation of long-lived radioactive elements:
“ Studies and investigations shall be conducted (…), in order to provide by 2012 an assessment of the industrial prospects of those systems and to commission a pilot facility before December 31, 2020”

September 2010, Investment Program for the future

Publication of agreement between CEA and French Government: 650 M€ awarded to CEA to conduct design studies of ASTRID prototype and associated R&D facilities.

French Fast Reactor R&D stratégie

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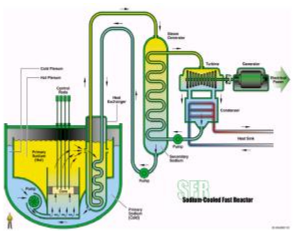
Two fast neutron systems are studied in parallel.

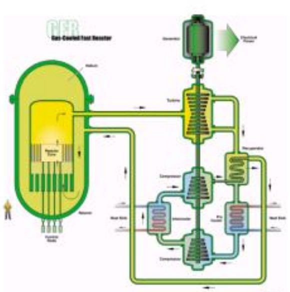
- ***As a <u>reference</u>, the Sodium Fast Reactor:***
  - The most mature option:
    - Safety file is not done from scratch
    - Industrial feasibility is already proven
    - For a commercial reactor around 2040/2050



→ R&D program since 2007 between CEA, AREVA and EDF

  - Most promising potential to reach GENIV criteria
  - ASTRID prototype (600 MWe)

- ***As a longer term option the Gas-cooled Fast Reactor:***
  - The only system selected by GenIV International Forum that combines advantages of fast neutrons and of high temperatures (cogeneration applications)
  - Inert and transparent coolant
  - Difficult technological challenges: materials needed for cladding resisting to very high temperatures, safety demonstration (poor thermal inertia, pressure)
  - Support to ALLEGRO experimental reactor (80 MWth) to be developed in Eastern Europe.



Favourable characteristics of French SFR

Phénix (1973-2010)

Super-Phénix (1985-1998)

Rapsodie (1967-1983)

- No pressurization of the primary coolant,
- high thermal inertia,
- Large sodium boiling margin
- Natural convection
- Control by single rod position, no xenon effect, no need of soluble neutron poison
- Radiation protection : higher level of protection than LWR
- Few effluents and little radioactive waste
- High thermal efficiency

SFR R&D program

R&D objectives

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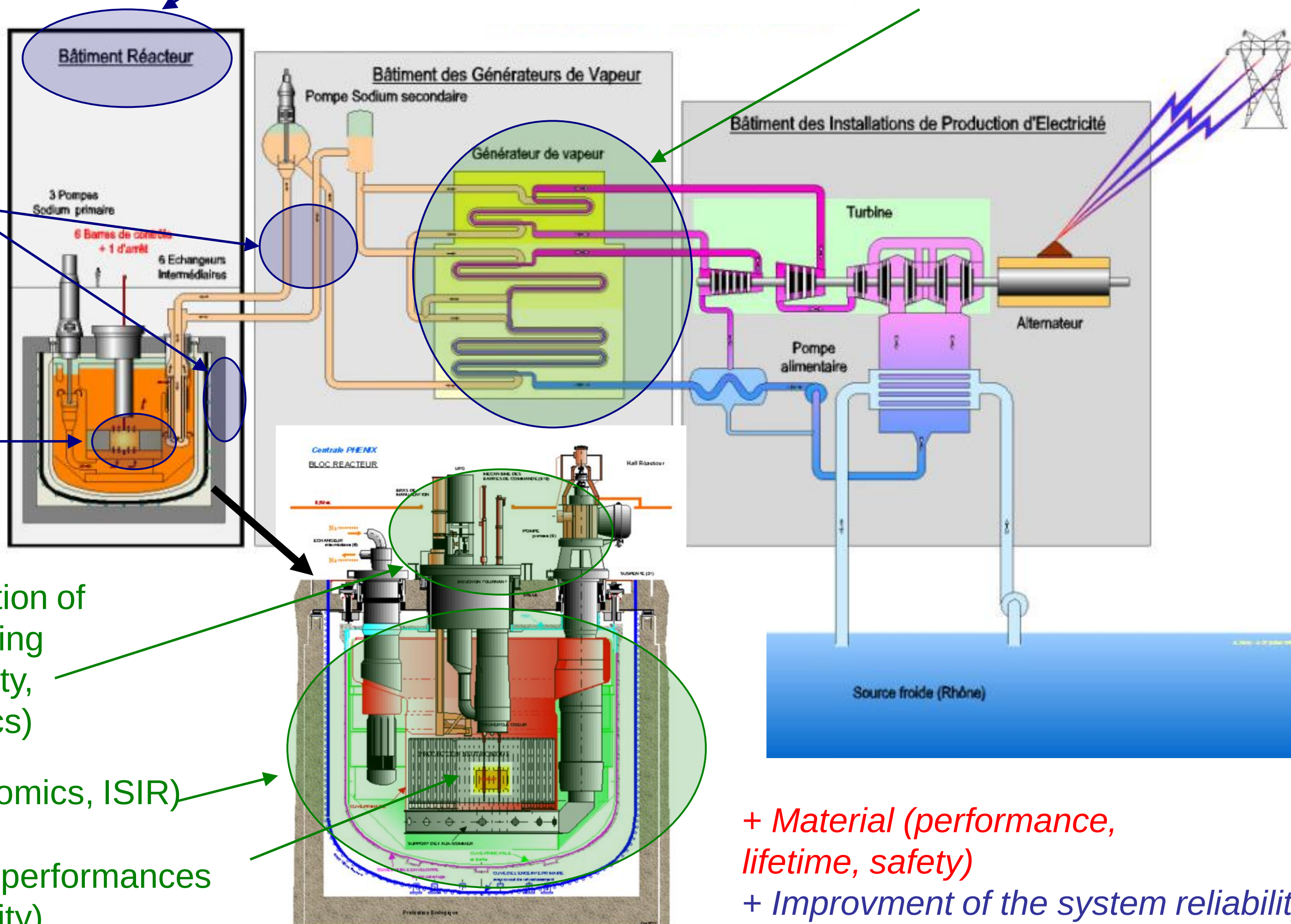
Improvment of the control of the confinement, including Na risk (safety)

Elimination of large sodium-water reactions (availability, economics, safety)

Improvment of the decay heat removal (safety)

Improvment of the reactivity control (safety)



Optimisation of the handling (availability, economics)

Simplification (economics, ISIR)

Improvment of core performances (economic, availability)

+ Material (performance, lifetime, safety)

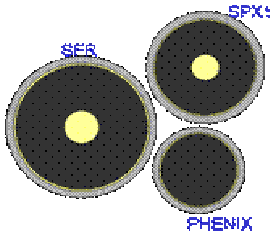
+ Improvment of the system reliability

An attractive core with enhanced safety

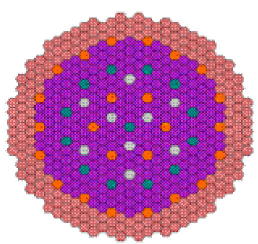
Feedback for SPX and EFR : Type of accidents leading to core melting

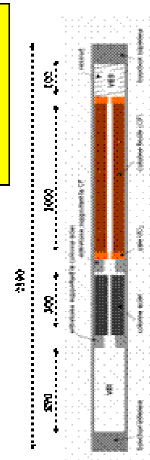
Rod withdrawal ⟶ To reduce the fuel reactivity loss per cycle

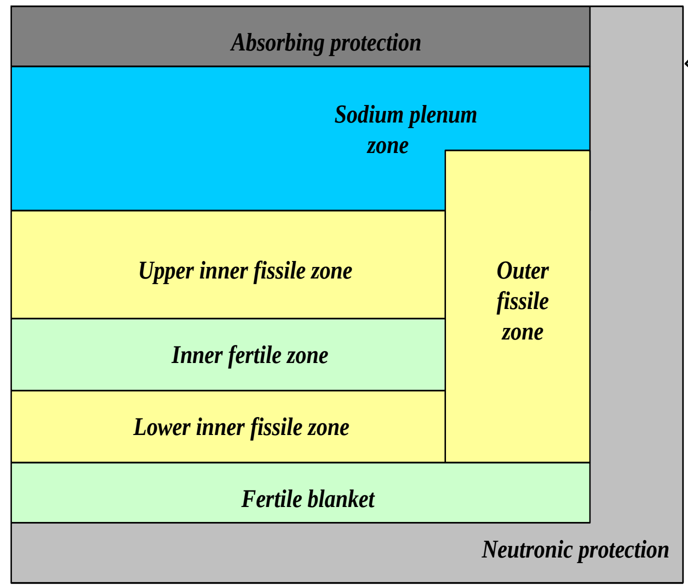
Unprotected loss of flow ⟶ To reduce the sodium void worth



- Grosses aiguilles
- Petit fil
- Gaine sans gonflement







Larger pin and smaller-diameter spacing wire

- Increase of the fuel fraction

-Decrease of the Na fraction ⇒ lower Na voiding effect

Heterogeneous core concept with an optimised sodium plenum

➔ Global sodium void worth strongly reduced to near zero

ASTRID Core concept

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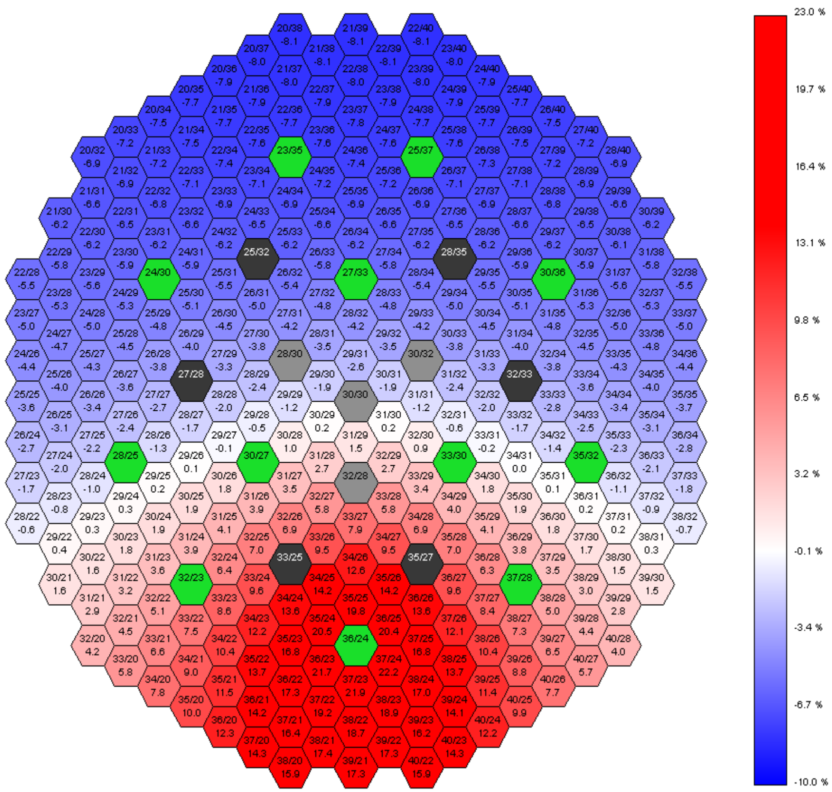
Rod withdrawal



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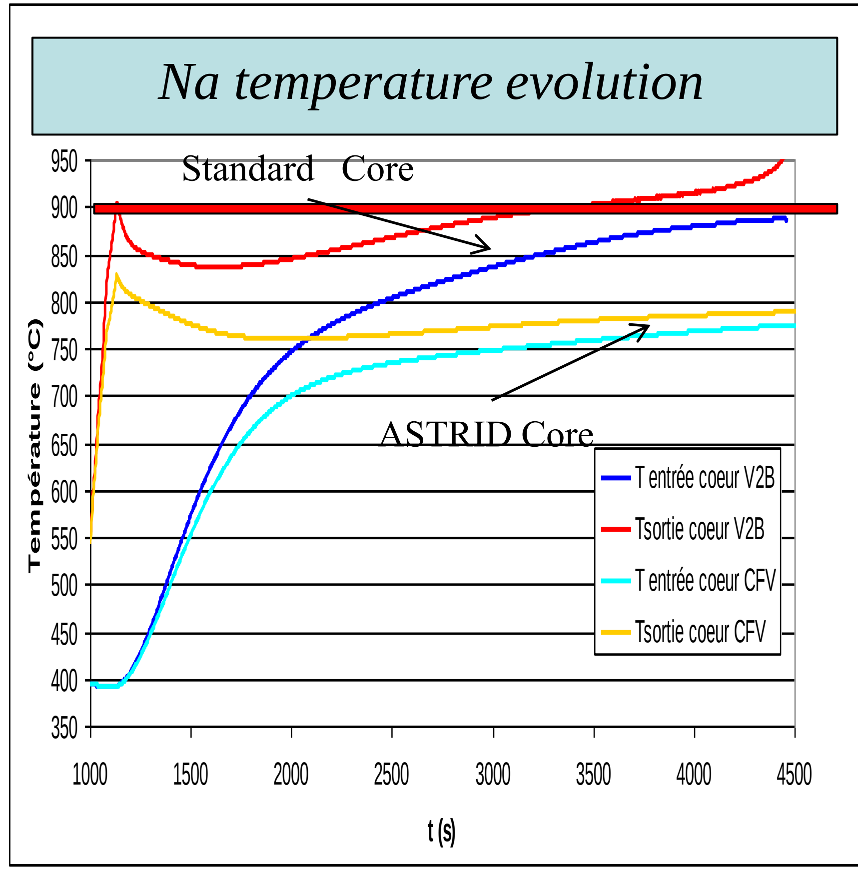
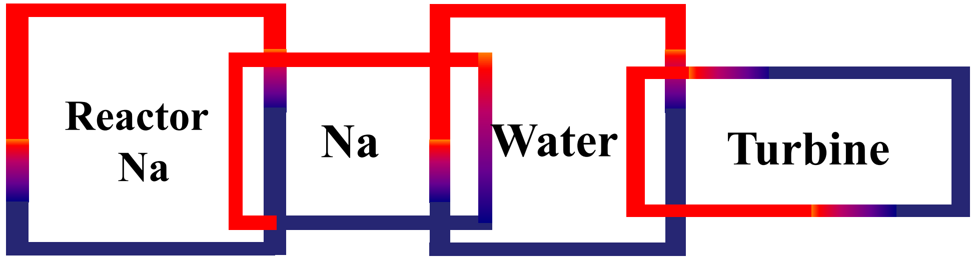
No fuel melting

Unprotected Loss of Flow



No Na boiling

Energy Conversion Systems minimizing sodium risks

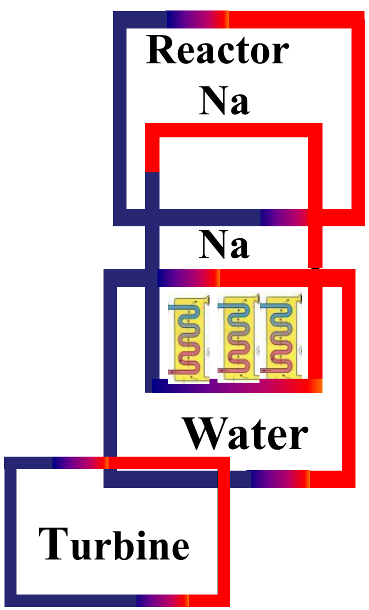


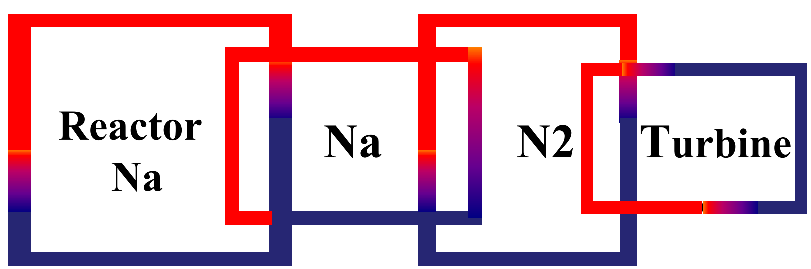
Three ways of improvment :

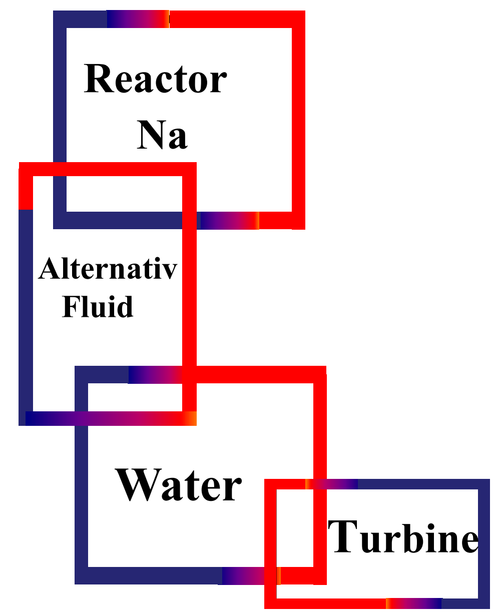
To reduce Na-water reaction risks ⟶ New type of steam generator: modular, inversed

Eliminate water: Energy conversion system using gas (Brayton cycle)

Use a compatible fluid with sodium and water in secondary circuit (organic fluid, Pb-Bi …)







Decay Heat Removal : Fukushima key point

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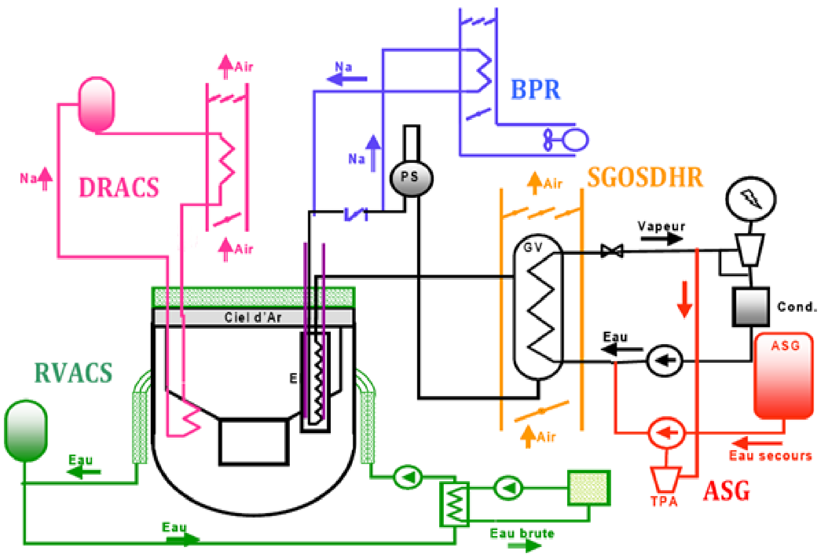
➢ **Feedback PHENIX et SPX: various types of decay heat removal systems, passive and active, using two cold sources : water and air**

➢ **<u>Standard system</u> : by third circuit**

➢ **<u>Emergency systems</u> :**

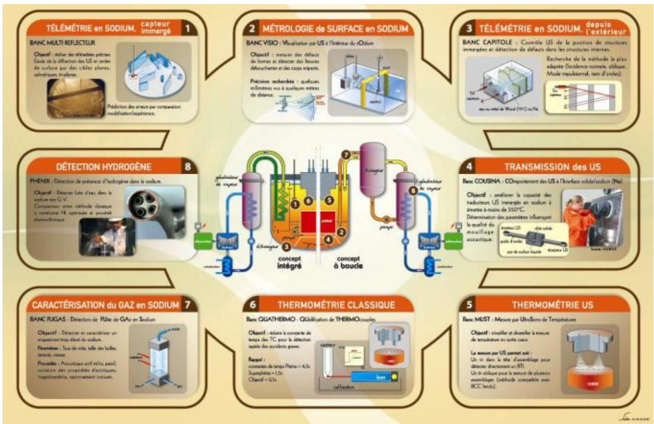
- **By the steam generator**
- **By the second circuit (Na- Air exchangers)**
- **By systems in primary circuit (Na - Na + Na- Air exchangers)**

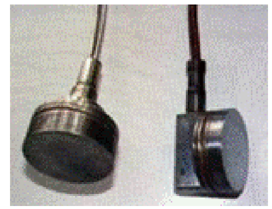
- **By structures : vessel**

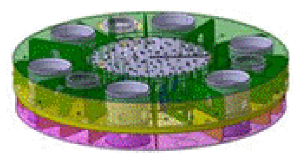


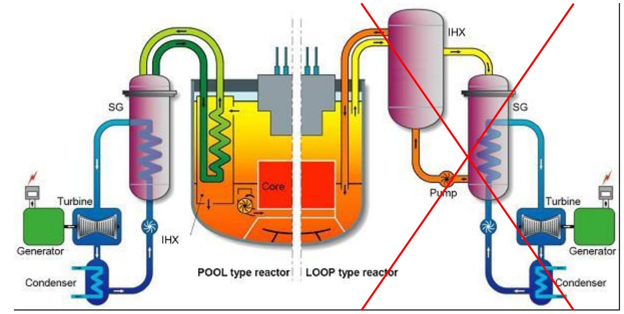
General lay-out, ISIR and components

Definition of a coherent and innovative program on ISIR (major issue) ➔New technologies

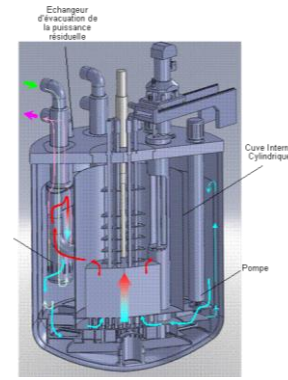


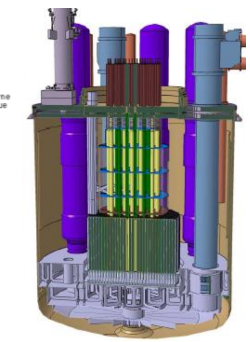






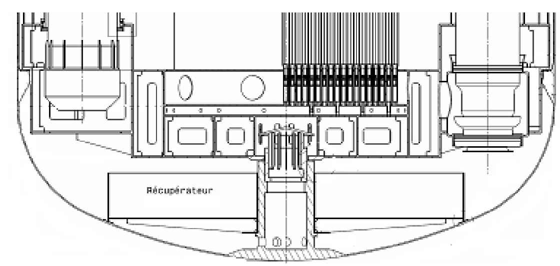
Proposals of innovative pool designs





Establishment of a development plan of Na technological facilities for ASTRID and R&D needs :

- Refurbishing of CEA existing loops
- Use of foreign means
- New loops (CEA and international)



(ICAPP'11, AREVA & CEA)

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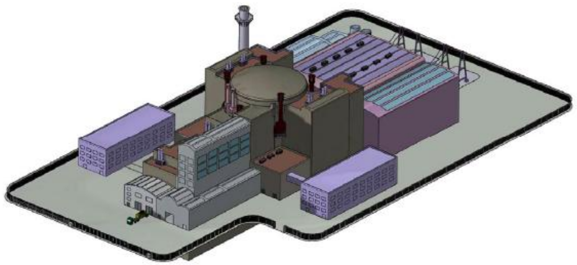
The ASTRID prototype

Advanced sodium technological reactor for industrial demonstration (ASTRID)

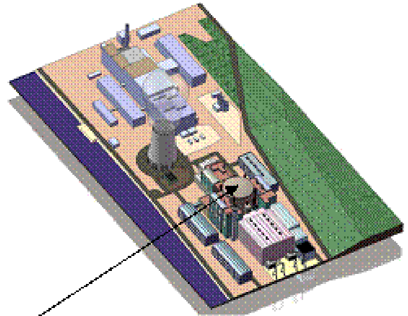
- Industrial prototype (step before a First Of A Kind)
- Integrating French and international SFRs feedback



- A Generation IV reactor
  - Safety :
    - Level at least equivalent to GENIII systems
    - + lessons learnt from Fukushima accident
    - With significant improvements on sodium specific issues
  - Operability :
    - Validate on the long term an ambitious load factor
    - Significant improvements concerning ISI&R
  - Ultimate waste transmutation :
    - Continue experimentation of minor actinides transmutation, up to large scales if so decided
  - An investment cost under control

- Irradiation services and testing of longer term options

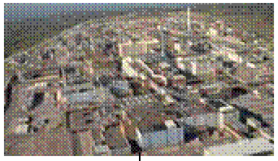
The ASTRID program



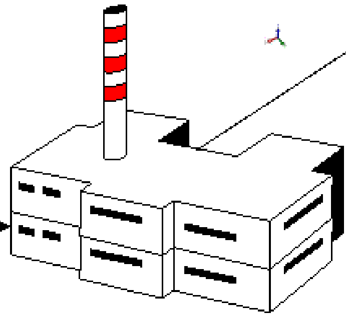
ASTRID reactor

➔An industrial prototype

➔An irradiation tool



U, Pu



The core fabrication workshop (AFC)

➔MOX fuel

➔A few tons per year

Full scale components testing

➔Refurbishing/ realisation of technological facilities

➔Components qualification

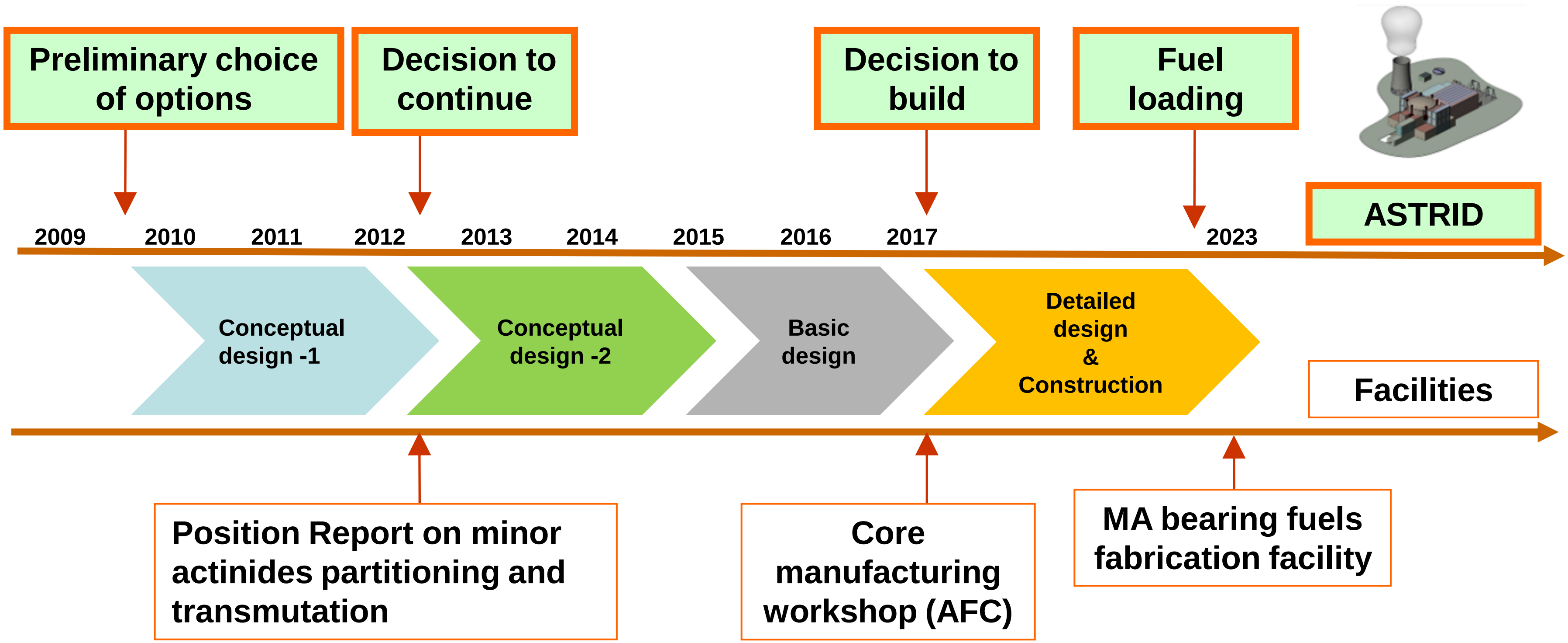
\+

- **Refurbishment of MASURCA critical mock-up for ASTRID core qualification**
- **Severe accidents experimental program**
- **Feasibility study of a facility for minor actinides bearing experimental fuels fabrication**

Schedule for ASTRID and associated facilities

➢ The pre-conceptual design will consider some open options. Innovation and technological breakthroughs will be favored, while maintaining risk at an acceptable level. During the pre-conceptual design phase, start of the interactions with the Safety authorities on safety objectives and orientations.

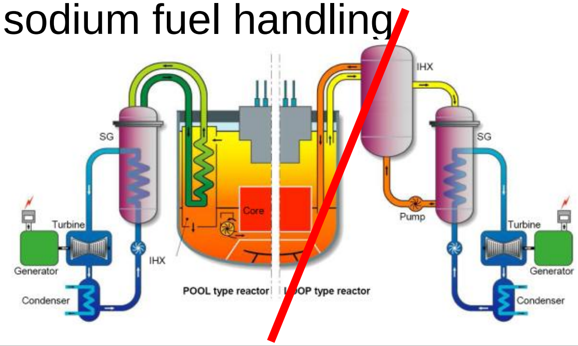
➢During the conceptual design phase, the ASTRID design choices will be finalized and the Safety Option File will be submitted.



ASTRID : preliminary design choices / open options

Main features

- 1500 MWth, ~600 MWe reactor
- Pool type reactor
- With an intermediate sodium circuit
- Preliminary strategy for severe accidents (core catcher…)
- Oxide fuel for starting cores
- Transmutation capability
- High level expectations in terms of safety demonstration
- In sodium fuel handling
- …



Many of these options will be decided during the pre-conceptual design up to 2012, some will remain open and be decided during the conceptual design.

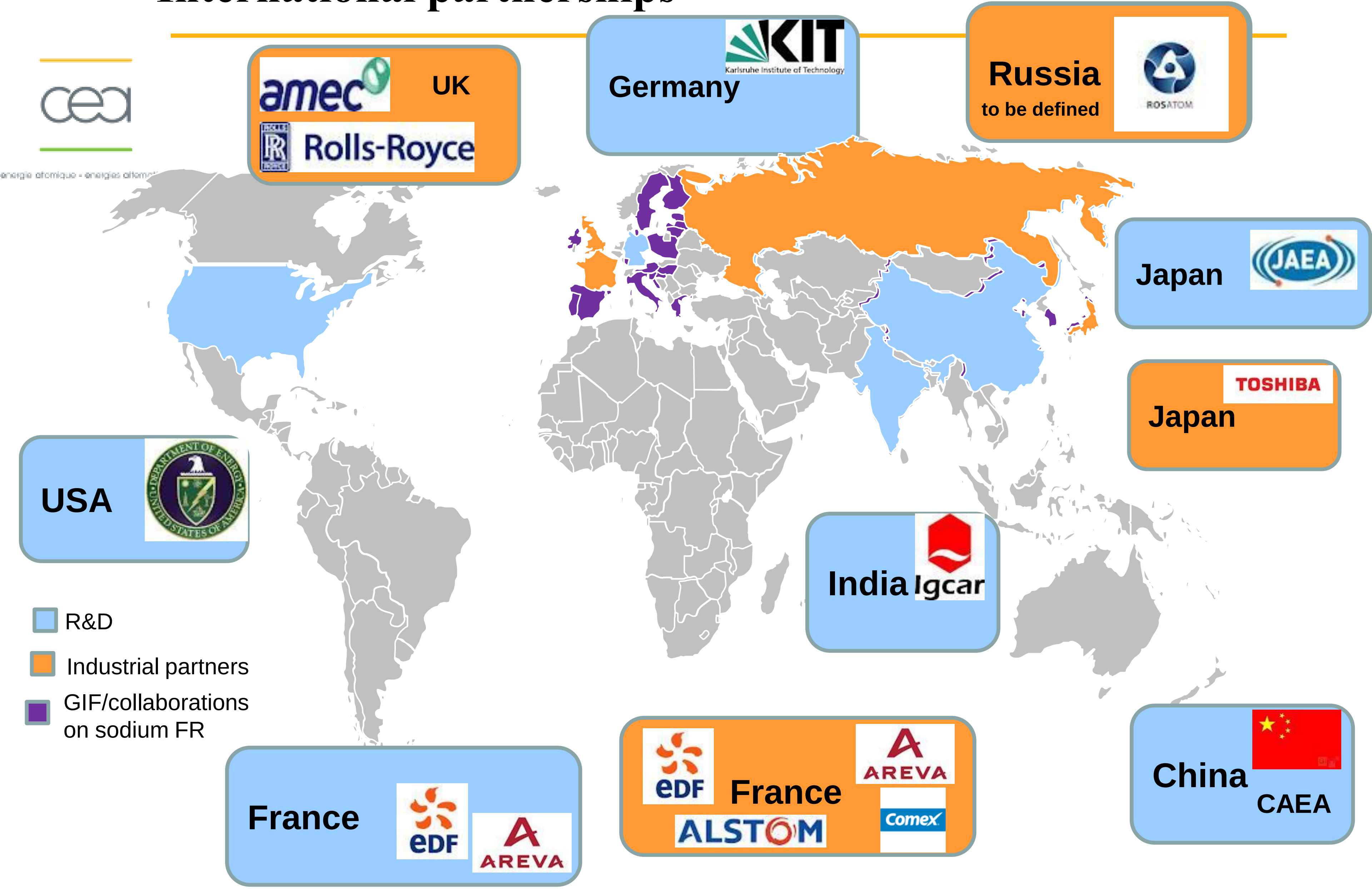
Open options

- Energy conversion system
  - Reference : water/steam
  - Alternative : N2
- Number of loops
- Devices to eliminate severe accidents (i.e. 3rd shutdown level)
- Corium catcher technology
- SGs materials and technology
- Innovative technologies for Na fires detection and extinction
- Inspection & Control
- …

Innovative options to be tested

- Carbide Fuels
- SiC-SiC Materials
- …

International partnerships



Conclusion

- R&D results [CEA-AREVA-EDF] obtained from 2007 to 2009 have contributed to ASTRID mid 2010 choice of preliminary options
- ASTRID has the objective to demonstrate at the industrial scale improvements to the identified SFR weaknesses (safety, operability, economy) and to perform transmutation demonstrations
- The first important milestone is end of 2012 (2006 Act on waste):
  - ASTRID pre-conceptual design studies: 2010-2012
  - First investment cost estimate
  - First discussions with safety authority
- Opportunity to develop 4th generation reactor