NEXT STEP FOR NUCLEAR POWER PLANT

GENERATION IV

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The rationale of future nuclear fuel cycles in view of sustainability
THE RATIONALE OF FUTURE NUCLEAR FUEL CYCLES IN VIEW OF SUSTAINABILITY

1980 2000 2200 2040 2060 2080 2100

Dates are purely indicative

TOWARDS INCREASING SUSTAINABILITY

Gen. II & III Pu-monorecycling

Gen. IV Pu-multi-recycling

Gen. IV ... + MA recycling

Once-through cycle

Pu-monorecycling - Twice-Through Cycle
- LWR reactors
- Pu-recycling in MOX fuel

Pu-multi-recycling - Multi-Through Cycle
- Fast-Reactors (FR)
- Pu multi-recycling

Pu+MA multi-recycling - Fast Reactors (FR)
- Pu multi-recycling
- MA burning

Main incentives
- 1st step towards U resource saving
- Efficient waste conditioning

Main incentives
- Major resource saving
- Energetic independence
- Economic stability

Main incentives
- Decrease of waste burden,
- Optimisation of the disposal
- Public acceptance
FROM LWRs RECYCLING TO FRs RECYCLING

Pu stored in MOX Spent Fuel recycled in MOX SFR to start the SFRs deployment

Current technologies: a bridge between GEN II/III and GEN IV

Scenario can be flexible
Both systems can coexist during a transition phase

SFR merits as regards to fuel cycle

No front end steps and no enrichment technology / Use depleted U; Use Pu included in MOX Spent Fuel

Multi-recycling of Pu / Possible recycling of Minor Actinides
MINOR ACTINIDES TRANSMUTATION: DRIVERS...

1500 ha total, among which 1175 ha HLW, 7 Mm3 excavated

430 ha total, among which 120 ha HLW, 3 Mm3 excavated

no transmutation  MA transmutation

[Andra-CEA 2012, cooling phase/120 years]

Glass canisters residual heat (diverse fuel cycle options)

No transmutation

Current glasses

Am transmutation

Time (years)

Relative radiotoxicity

U-ore
Pu burning in FRs favors Pu fission, allowing Pu multi-recycle

(1) **Systematic U & Pu recycle**, (2) in **fast neutron reactors**
- for a sustainable management of nuclear materials & waste,
- avoiding increasing of Pu-bearing stockpiles,
- opening the way to a drastic extension of the use of U resource
The ASTRID program

(Advanced Sodium Technological Reactor for Industrial Demonstration)
SFR technological demonstration reactor (*a step before a First Of A Kind*)

- Integrating French and international SFRs feedback
- A GEN IV system

**Safety**:
- Level at least equivalent to GEN III systems
- Progresses on Na reactors specificities
- Integrating FUKUSHIMA accident feedback
- Robustness of safety demonstration

**Durability**:
- Need of Fast Breeder Reactors and a closed cycle
- Pu multi recycling to preserve natural resources
- The use of natural depleted uranium in France by FBRs allow producing electricity for few thousands of years

**Operability**:
- Load factor of 80% or more after first “learning” years
- Significant progress concerning In Service Inspection & Repair (ISIR)

**Ultimate wastes transmutation**:
- Realization of demonstrations on minor actinides transmutation according to June 28, 2006 French Act on Wastes Management

**A mastered investment cost**

**Non proliferation warranty**

- Irradiation services and options test
Enhanced core safety in case of all protection systems failure

« CFV »: no power increase in case of ULOF

Phenix experiments post-irradiation examinations

Irradiations: BFS BOR60, BN600?, Joyo/Monju?

Complementary safety devices

ASTRID mock-up in Masurca ZPR
ACCESSIBILITY: considered at early stages of the design

3 dedicated ISIR paths through the roof

3 chimneys through the redan

Support structure access

END via croisillon creux

Inter-cuves 250mm

+ propagation US dans les voiles

END depuis inter-cuves

SENSEOR DEVELOPMENT
Under and out of sodium

CARRIERS DEVELOPMENT
Under and out of sodium
STRONG IMPROVEMENT FOR SFR DESIGN
SEVERE ACCIDENTS

No early or significant releases in case of severe accident

SIMMER 5 and SEASON: a set of severe accident simulation tools, developed in an international framework

A core catcher:
- Whole core capacity
- Corium transfer devices from the core to the catcher

Plinius 2: a future facility able to manage 500 Kg of corium
Industrial partners: development of a robust layout against large SWR (including cases with addition of air or kerosene).

No layout designed during the conceptual design phase; postponed during the preparatory phase of the Basic Design phase (from January to October 2016).
STRONG IMPROVEMENT FOR SFR DESIGN
GAS ENERGY CONVERSION SYSTEM

Nitrogen tertiary circuit to eliminate sodium-water reaction

ASTRID Gas Engine room

Diademo : sodium experimental loop (reduced scale)

Cheops : future sodium experimental loop (scale ~1)

Compact sodium gas heat exchanger
A synthesis file was sent to the government mid 2015:

- **Strategy leading to the choice of Gen IV sodium cooled fast reactor and closed fuel cycle.**
- **Scope statement, with technological choices (including conversion system), issued from Conceptual Design.**
- **Workplan for Basic Design, with associated R&D infrastructures.**
- **Proposal for a revised global planning for the ASTRID project.**
- **A first estimate of operating and building costs.**

Synthesis file summarizing the conceptual design phase (2010-2015) provided in December 2015

Authorization at the end of 2015 from the government to proceed until the end of 2019 (Basic design phase).
• Pool type SFR
• 1500 MWth - ~600 MWe
• With an intermediate sodium circuit
• CFV core (low sodium void worth)
• MOX fuel
• In vessel core catcher
• Diversified decay heat removal systems
• Fuel handling in gas, internal storage
• Conical "redan" inner vessel adopted
• Lay-out at the end of Conceptual Design:
  ✓ 3 primary pumps
  ✓ 4 intermediate heat exchangers
  ✓ 4 secondary circuits
  ✓ 5 decay heat removal circuits

*Experimental capabilities: to contribute to the qualification of transmutation, fertile or burner subassemblies*
Main buildings on isolated raft (HR, HL, HWx)

Turbomachinery building (HM)

Special handling building (HVX)

Fuel building (HKL)

Annex buildings (HDx)

Workshop site
PARTNERSHIPS AROUND ASTRID PROGRAM

Steering by CEA

EDF R&D, PSI, Sweden (KTH, Chalmers, Uppsala), HZDR, KIT, ENEA, JRC/ITU, NNL, CIEMAT, ...

CNRS (NEEDS), Universities (thèses)
ASTRID PROJECT ORGANISATION

About 600 people

- R&D
  - JAEA
  - MFBR
  - Mitsubishi
- EDF
- European R&D labs
  - ARBEDCO
- ASTRID Project team Operational management
- Industrial architect
- Contracting authority Strategic management
- ASTRID relay team in Marcoule
- EDF assistance

Reliability, availability, maintainability

- AIRBUS DEFENCE & SPACE

Search for innovations

- CNIM
- Technetics GROUP
- YELAN
- TOSHIBA
- Rolls-Royce
- ONET

External assistance

- Innovation, Qualifications, Codes,
  - Specific developments,
  - Expertises

R&D

14 industrial partners and 6 R&D partners

Design

- Reactor core
  - CEA
- AREVA

Nuclear Island

- AREVA
- JAEA
- MFBR
- SEIV

Hot cells

Power conversion systems

- GE

Civil engineering

Balance of plant and infrastructures

- JACOBS

About 600 people

- EDF assistance
ASTRID FUEL CYCLE

Reprocessing

1st STEP

Astrid

2nd STEP

Pu from MOX-LWR

Appropriate Fuel Cycle facilities

AFC

TCP

Pu from MOX-LWR

ATC

AFC

ASTRID

ASTRID

ASTRID

ASTRID
Conclusion
Nuclear energy is in 2015 a well proven source of large baseload electricity, with no GHG emissions. It will remain one of the pillars of the future French low carbon energy mix.

The closed fuel cycle associated with FNR will lead to drastic improvement in U resources management, and important reduction in footprint and radiotoxicity of final wastes.

French program on Generation IV is based on ASTRID program.
- Basic design phase on-going (2016-2019).
- Schedule and organization for next phases under preparation with French government and industrial partners.

FNR is also developed in other countries, following the same strategy than France.