New “Generation IV reactors” program at CEA

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CONTEXT OF CEA PROGRAMS DEDICATED TO FNR AND THE CLOSURE OF THE FUEL CYCLE

- **French strategy is translated into the Multiannual Energy Program (PPE) and in the Strategic Contract for the Nuclear Sector**
- **Reprocessing strategy and recycling of nuclear fuel is confirmed and maintained until the 2040's horizon**
- **Since the perspective of industrial deployment of Fast Reactors** is more distant, decision is taken not to go on with further studies and construction phase of the ASTRID Project
- **Yet, the strategy for closure of nuclear fuel cycle with Fast Reactors** (meaning complete recycling of recoverable materials) **is maintained as a long-term objective**, requiring to maintain skill, and to progress on technological barriers and further develop know-how.
- **Challenges for achieving full recycling on the long term:**
  - Need to use FNRs,
  - The sodium FNR technology is the most mature, it should be consolidated + evaluating other technologies is of interest
    →A new CEA R&D program on (S)FR and fuel cycle (2020-2024)
- **Shorter term stakes :**
  - Investigation of nuclear fuel multi-recycling in PWR as a possible intermediate step

THE CLOSING OF THE FUEL CYCLE : CHANGE IN THE WORK PROGRAM ON THE GENERATION IV REACTORS AND ITS RELATED CYCLE

	R&D programs objectives
Future Reactors	■ **Consolidation of technical knowledge on sodium-cooled fast reactors (SFR) and R&D basis to maintain skills and further develop 4th advanced generation technologies (reactors and cycle plants)** ■ **Actions for the development of SFR technologies and, ultimately, qualification of industrial components (using simulation tools and experimental facilities)** ■ **Sketch studies and R&D assessment of other Fast Neutron Reactor (FNR) technologies**
Cycle Back-end	■ **Used fuel reprocessing : advanced processes and technologies for recycling in FNR** ■ **MOX manufacturing for FNR : industrial manufacturing capacity** ■ **Assessment of the consequences of U and Pu multi-recycling on Pu flow and Minor Actinides inventory, in particular in respect to the deep geological disposal**
International	■ **Development of collaborations with foreign partners**

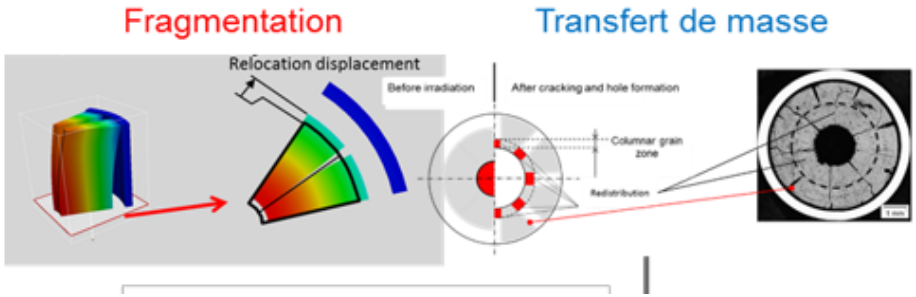
TECHNOLOGICAL DEVELOPMENTS (and numerical simulation)

ONE EXAMPLE : $(U,Pu)O_2$ FUEL PIN PERFORMANCES

Challenge : justification of performances of pins (discharge BU, 120 GWj/t = need to develop a new and performing clad material, ODS is a candidate…)

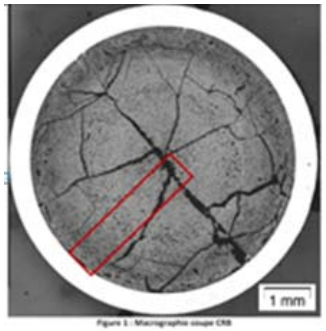
Numerical simulation : continue to develop predictive models of fuel behavior in the fields of application : conventional and innovative cores (axial heterogeneous fuel pin, low linear power of the CADOR concept, high combustion rates, etc.)

Illustration : initial gap closed by pellet cracks motion and fuel material relocation



Phénix

CEA HotLab (Cadarache + Marcoule + Saclay)



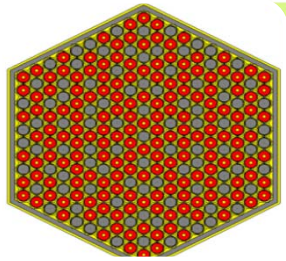
PAVIX 8

Heterogeneous column (CFV type)
AIM1 Cladding
Max burnup : 13 at%
Max damage : 100 dpa
Exams in progress

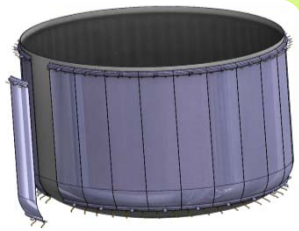
WHICH OBJECTIVES FOR THE SKETCH STUDIES?

Examples of possible axis	Possible activities
Feedback from SFR studies: SFR feasibility has been demonstrated, but there is a need to enhance economics while maintaining a high safety level	Technological elements studies Threshold effects on the power from a safety and economic point of view → studies on the potentialities of SMR and micro-reactors **→ Sketches allowing identification of potential evolution in the design, assessment of performance and safety ; orientation of the R&D, as well as and safety methodologies**
Material management and radioactive waste inventory reduction	Reconsider core concepts dedicated to transmutation (long cycle adaptated spectrum…) Impact of the orientation dedicated to transmutation on the design choices and reachable performance evaluations
Other applications in the frame of future energy mix: manoeuvrability, heat valorisation / higher temperature range, …	Studies of advanced energy conversion system for: - Combined electricity-heat valorisation - Unused energy storage Reconsider studies for hydrogen production, among which HTR Potentialities of micro-reactors
Alternative technologies of FR (lead, molten salt, gas) : feasibility to be demonstrated	**Assessment of "fast spectrum molten salt reactors" feasibility through sketch studies (economic, safety, material management …) and identification of feasibility issues and challenges** *(salts, corrosion / durability, online processing, safety…)* **→ proposal for a enlarged R&D program**

How to simplify the design and make it economically viable with a high level of safety ?
➔ SMRs allow more easily the implementation of technological breakthrough

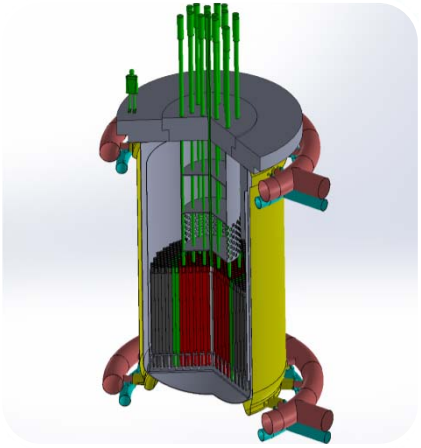


Inherent safety by core design ➔ Practical elimination of the whole core melting ?



Passive Decay Heat Removal systems

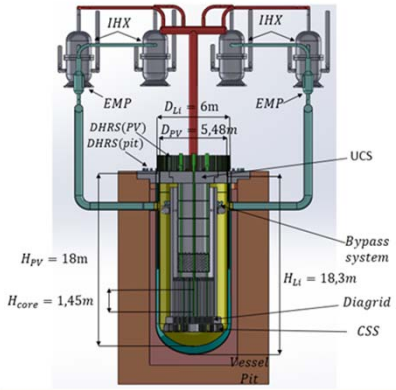
➔Breakthrough in the diversification & reliability



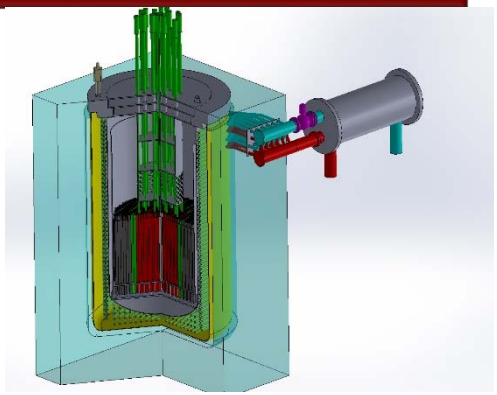
Simplifications

- No secondary circuit
- Simplified fuel handling
- Less sodium circuits
- Fabrication process (in Factory)
- No safety vessel
- Modularity

Electricity production 150MWé



Heat production 50MWth

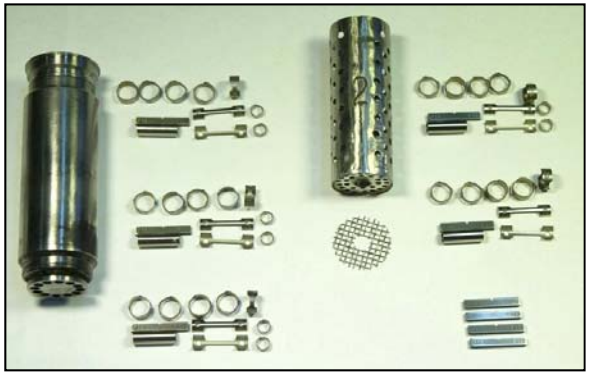


To perform its GEN-IV work programme (calculation codes validation, innovative technological options testing…) CEA will need facilities for irradiation in fast reactor environment, with valuable capacities of experimental supports (in-pile instrumentation, loop facilities, hot cells…).

Particularly, CEA interests are in the continuity of past and present experiments performed in BOR-60 reactor :

- irradiation capabilities of **inert materials** that could be used for future nuclear systems
- irradiation capabilities of **fuel rod samples**, including fuel with minor actinides
- experimental features to test fuel behavior in **abnormal conditions**

MACARON absorbing pins



TIRAMISU samples

POTENTIAL INTERESTS IN IRRADIATION MEANS

- **Fuel study**
  - Fuel pellets, samples, complete pins, pins bundles
  - MOX with or without minor actinides – High Pu content, degraded isotopies…
  - UO_2 with minor actinides, U issued from PWR assembly recycling
  - Behavior in abnormal conditions (open clad breach, flow decrease, temperature increase, power increase / margin to melt…)
  - Advanced fuels: dense ceramics, non-standard geometries…

  ➔ *Interest for large diameter MOX fuel pellets with Pu coming from recycled PWR-MOX*

- **Cladding with inert materials**
  - Advanced cladding (ODS…), wrapper tubes performances, inert materials for reflector, moderator or neutron shielding
- **Absorbing materials** : Innovative absorbing materials or pin designs
- **Testing sodium instrumentation**

CONCLUSIONS

CEA R&D program on SFR technologies will address some of the ASTRID project needs (generic ones), also, take advantage of innovative methodologies developed outside the FR scope (*HPC, advanced manufacturing processes, …*)

Numerical simulation tools - the best knowledge and understanding of physics make it possible to develop new/improved models and integrate them in scientific computing tools - the justification of uncertainties is still to be completed (*experimental data already exist for many physics, new exp. data are necessary for severe accident physics*).

Technological developments – targeted action plan focused on key technologies which are major issues and challenges for the SFR deployment (fuel and core materials, reactor materials/60 years lifetime, dispositions for mitigation of severe accident, ISIR technics)

Surveys and Sketches - CEA program will assess the value of different innovations /breakthrough in the designs of SFR, also it will consider alternative technologies of FR (molten salt, lead, gas) for which the feasibility is to be demonstrated

To perform this R&D program, CEA will need **facilities for irradiation in fast reactor environment**, with valuable capacities of experimental supports.

THANK YOU FOR YOUR ATTENTION