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Design features of Advanced Sodium Cooled Fast Reactors with Emphasis on Economics

B. Riou	AREVA NP
D. Verwaerde	EDF-R&D
G. Mignot	CEA Cadarache

Outline

- French SFR program
- SFR program requirements
- Main assumptions and operating parameters
- Core and fuel
- Robust Safety Demonstration
- Optimized Energy Conversion System
- Improved ISI&R capabilities
- Improved O&M capabilities
- Twinning and Modularity
- Conclusions

French SFR program

- **Objective and context**
  - **Evaluate the industrial prospects of waste transmutation to respond to June 2006 French law on the management of nuclear waste and resources**
  - **Program in tight cooperation between CEA, AREVA and EDF**
- **Main milestones**
  - **2009 : selection of the main tracks for R&D and design studies**
  - **2012 : selection of the main design options and assessment of the industrial capabilities of SFRs for waste transmutation**
- **Next steps**
  - **Decision of launching the design and construction of a prototype**
  - **Industrial deployment of the new generation of SFRs (2040-2050)**

SFR program requirements

- **Financial risk at the same level as for other plants**
  - Extended (60 years) and reliable lifetime
  - Robust design, tolerant to equipment or operators faults
  - Improved inspection and repair capabilities
  - Improved maintenance capabilities
  - Investment and operation costs close to Generation III plants
  - Decommissioning taken into account at the design stage
- **Flexibility of management of nuclear materials**
  - Closed Pu cycle, conversion ratio ≥ 1
  - Flexibility for nuclear materials recycling/burning (plutonium, minor actinides)

SFR program requirements

- **Robust safety demonstration for the core and the reactor systems**
  - **Safety requirements at least as severe as those for Gen III+ reactors (EPR™)**
  - **Prevention and mitigation of risks due to sodium chemical reactivity**
  - **Prevention and mitigation of severe accidents**
  - **Robustness to different scenario analyses (no cliff edge effect)**
  - **Robustness to external hazards**

» **Overall, very challenging and often contradictory requirements : need to reassess the feedback from previous projects and operation and to investigate innovation tracks to solve or alleviate difficulties**

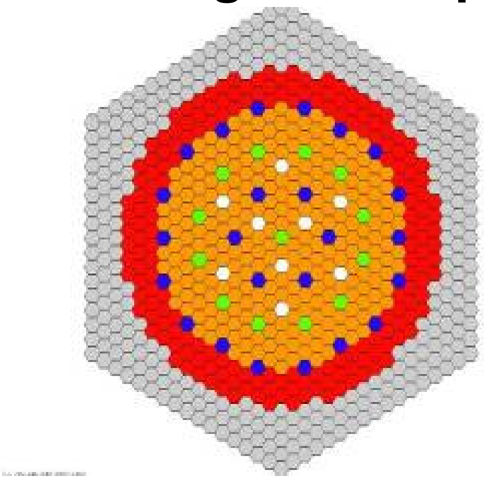
Main assumptions and operating parameters

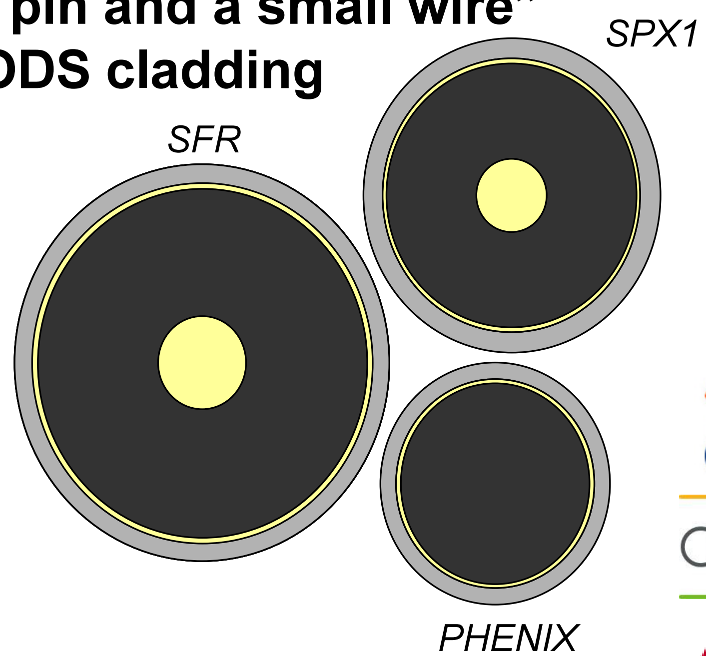
- **Reactor power level**
  - **Up to 3600 MWth (1500 MWe)**
    - Take maximum benefit of the size effect to improve economics
    - Take advantage of earlier studies (RNR 1500, EFR, etc.)
  - **Studies underway to evaluate if a lower power level could provide benefit in terms of robustness, with reasonable impact on the economic competitiveness**
  - **Twinning of two reactors envisioned for lower power level**
- **Other parameters**

Core inlet / outlet temperatures	**395°C / 545°C**
Core pressure drop	**~ 3,5 bars**
Secondary loop inlet / outlet temperatures	**525°C / 340°C**
Water / Steam temperatures	**240°C / 490°C @ 185 bars steam pressure**
Design life	**60 years**

Core and fuel

- Major objective is to obtain a high performance core configuration resulting in low energy release in case of severe accident
- Current design based on a break even core with improved safety characteristics (sodium void-coefficient, Doppler worth, rod worth, etc.)
- Fuel S/A design based on a “fat pin and a small wire” concept, with U/PuO_2 fuel and ODS cladding
- Average burn up of 100GWd/t





Core and fuel

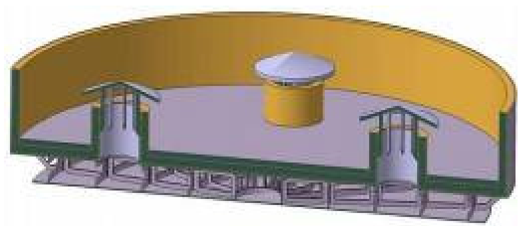
- **Shutdown systems**
  - **Actions under way to implement a third shutdown level**
  - **System like SEPIA (SEntinel for Passive Insertion of Antireactivity) could provide a fully passive and diversified response for short and long term management of unprotected transient**
- **Core configuration**
  - **5 batches scheme (410 EFPD cycles)**
  - **Possibility to substantially increase the cycle length (4 or 3 batches, or even less), with favorable impact on load factor**
- **MA transmutation**
  - **Different options investigated (homogeneous or heterogeneous)**
  - **Objective is to minimize impact on the reactor design and fuel cycle**

High performance, safety enhanced core with long cycle durations

Optimizations still underway to improve the robustness of safety demonstrations and economics at the same time

Robust Safety Demonstration

- **Prevention and mitigation of severe accidents**
  - **Extensive use of the lines of defense approach**
    - focusing on the design of a core with favorable reactivity coefficients
    - minimizing risks associated with sodium
    - diversifying and enhancing reliability of safety systems
  - **Provisions against energetic criticality sequences resulting from core melt down**
  - **Provisions for core degradation safe management (core catcher, decay heat removal)**

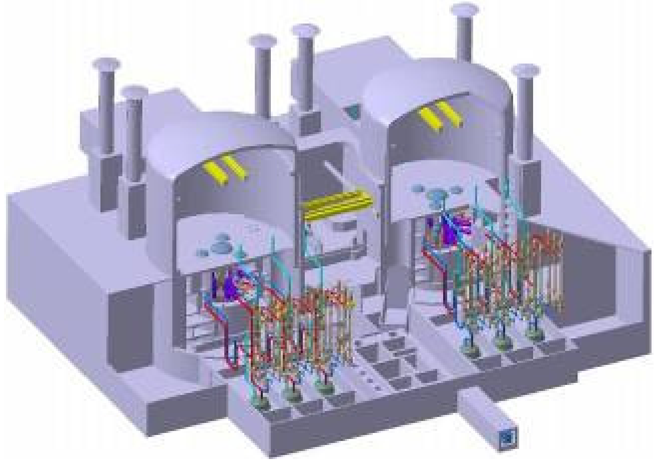


Core catcher study

Significant R&D program launched to improve lines of defense robustness, and to prevent/mitigate core fusion accidents. Objective is a safety level consistent with EPR™.

Robust Safety Demonstration

- **Provisions against external hazards**
  - **Robust containment against commercial aircraft crash**
  - **Seismic isolation for the Nuclear Island**



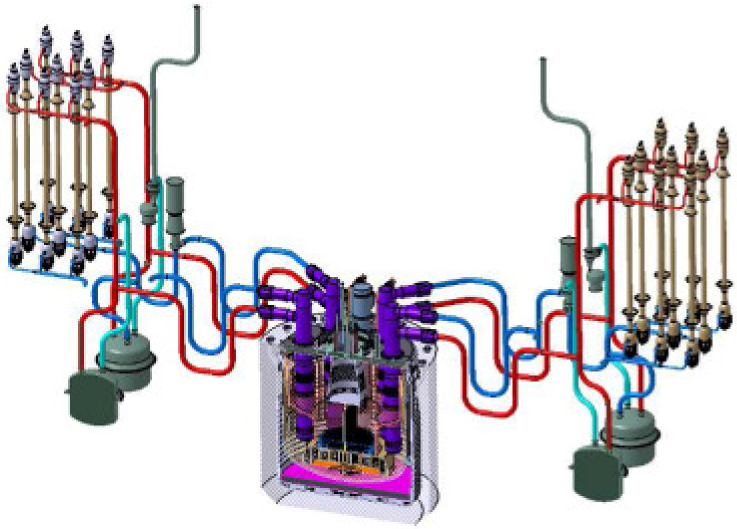
Robust containment study

Safety may lead to design options not prone to cost reduction but necessary to minimize licensing and financial risks

Enhanced safety should also contribute to a better public acceptance

Optimized Energy Conversion System

- **Prevention against sodium/water reaction**
  - **Current secondary loop design based on modular Steam Generators**
    - Robust demonstration with regard to sodium/water reaction
    - Design more costly than large monolithic SGs but should provide advantage in terms of maintenance and repair



Example of configuration with modular SGs

  - **Alternatives to sodium or water, but requiring significant R&D**
    - Supercritical CO_2 cycle
    - Alternative fluids (such as Pb-Bi) to replace the secondary sodium

Optimized Energy Conversion System

- **Prevention against sodium fires**
  - **Different solutions under review: sectorization, double pipes, tunnels or inerted rooms**
  - **Production of aerosols will require specific extraction or filtering capabilities**
- **For both sodium/water reaction and sodium fires, leaks have to be detected as early as possible and R&D is underway to improve detection performance and reliability**
- **R&D performed on ferritic-martensitic steels to evaluate possibilities of simplification and cost reduction of SGs**

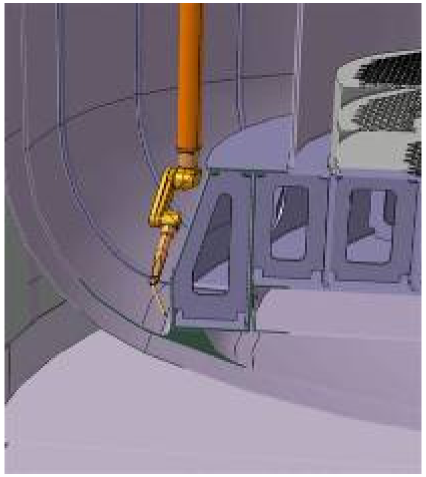
Some design options may be more costly but could be counterbalanced by improved maintenance and repair capabilities with positive impact on plant availability

Improved ISI&R capabilities

- **Need for both continuous monitoring and periodic inspection**
- **Need for "industrial" inspection techniques**
  - **Large effort placed on the development of high temperature sensors (and associated remote handling tools) for ultrasonic NDE and telemetry under sodium**

Sensor for under sodium NDE

Remote handling tools



- **Focus on structures simplification, component removal capability, accessibility, core discharge and primary circuit draining provisions, repair capabilities**

Main objective of ISI&R actions is to improve availability factor and minimize investment write-off risks

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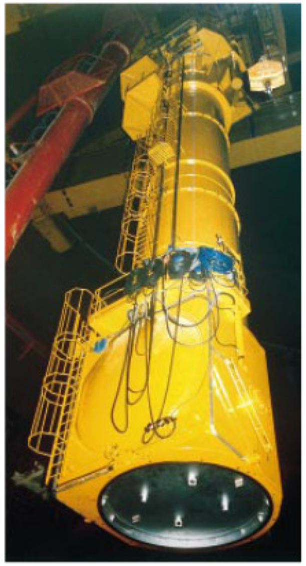
Improved O&M capabilities

- **Systems need to be simplified to facilitate maintenance operations, reduce O&M costs and limit risks associated to human factor**
  - **Reduction in the number and length of piping**
  - **Reduction in the number of auxiliary systems**
  - **Trade-off to be found between prevention of Na issues and ease of access for maintenance operations**
- **Refueling and component handling to be optimized to improve availability factor**
- **Reactor design to be optimized to minimize personnel exposure**
  - **Selection of Co-free materials to facilitate maintenance**
  - **Neutronic protection to be optimized based on maintenance needs**

SPX component handling flask



» **Target is to achieve an availability factor close to that considered for Gen III+ reactors**

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Twinning and Modularity

- **Twinning of reactors is envisioned to reduce costs**
  - **Most significant cost savings obtained with sharing of fuel handling and component handling systems together with associated buildings**
  - **Additional savings result from :**
    - lessons learned and team mobilization effects for the second or multiple units
    - series effect and reduced financial risks for lower power levels
- **Unlikely that cost savings resulting from modularity of smaller reactors (for instance 600 MWe) could balance cost increase due to the size effect (on a per MWe basis)**
- **On the other side, twinning of large power reactors could be a drawback to the SFR deployment**

» **Need to optimize the power level of twinned reactors to find the best balance between market demand, costs and risks (range 750 to 1500 MWe under consideration)**

Conclusions

- France is involved in a significant R&D program to evaluate the industrial prospect of MA transmutation in SFRs
- Decision is expected in 2012 to launch an industrial project, including a demonstration plant
- Economics is one of the aspects considered when studying design alternatives, but trade-off has to be found with safety, ISI&R and O&M capabilities with the objective to
  - Improve the robustness of safety demonstration
  - Reduce financial risks
  - Improve the public acceptance
- Economic competitiveness of SFR is dependent on future Uranium prices. Focus is to ensure competitiveness with Gen III reactors at the deployment date (2040-2050)
- Additional costs of MA burning will be evaluated and compared to the cost of alternative options