DE LA RECHERCHE À L'INDUSTRIE

cea den

OECD/NEA

Workshop on Innovations in water-cooled reactor technologies

Session II-2

Research organisation perspectives

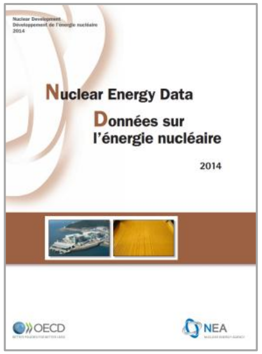
-

Main results and lessons of the 10 years innovation research program dedicated to LWR

Caroline THEVENOT, Guy-Marie GAUTIER, Philippe MARSAULT & Jean-François PIGNATEL

11-12 FEBRUARY 2015

Global picture



- **Nuclear Power Plant** connected to the grids:
  - Mainly LWR: 211 PWR & 76 BWR in OECD countries + 53 VVER*
  - Global distribution: North America (102 LWR out of 121 NPP), West Europe (118 LWR out of 133 NPP), Asia (67 LWR out of 71 NPP)
  - France: 1 manufacturer, 1 utility, exclusively PWR (58) + EPR under construction
- **Increasing nuclear power capacity** with over 60 reactors under construction in 13 countries
- Plant life **extension program** + future **renewed nuclear reactor fleet** notably in U.S or in France (coordinated with GEN IV technologies deployment) taking into account constraints in terms of safety requirement, investment cost, construction time, manufacturing capacities, etc.
- New **realities in the energy global market** and evolving **political context**:
  - Global level: rising global demand for energy, competitiveness (energy cost), financial crisis, Fukushima, security of supply issues, public acceptance
  - EU level: EC Energy Roadmap 2050, 2030 Framework for Climate & Energy
  - National levels: e.g. France "*Loi sur la transition énergétique*"

LA TRANSITION ÉNERGÉTIQUE pour la CROISSANCE VERTE

Research and Innovation for cost competitive, high performance, safe and clean technologies

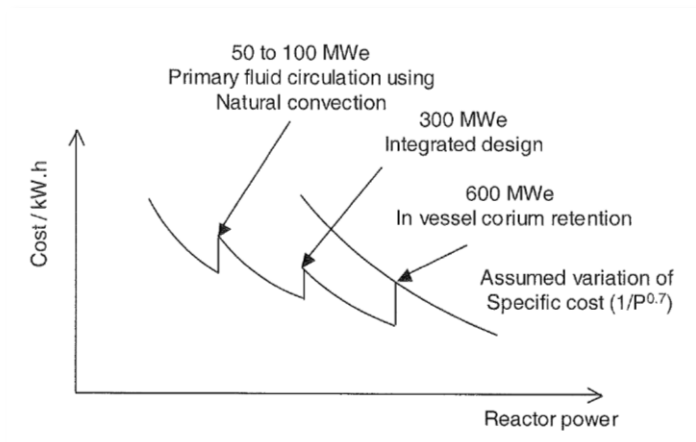
Research perspective

- **Objective of the session**: Discussion on long term developments that could lead to **innovations** for future advanced water-cooled reactors and their fuel cycle

Innovation in LWR

breakthrough vs **incremental** part of a seamless innovation chain

- **Technological breakthrough** may bring **significant economic/safety benefits** by reconsidering parts of (or all) the components of a reactor concept
- For LWR, significant progress might be expected: e.g. innovative temperature-resistant metal fuel or ceramic cladding, a new tight-lattice fuel assembly to optimise uranium resources, modification of the operating point for reactor design simplifications



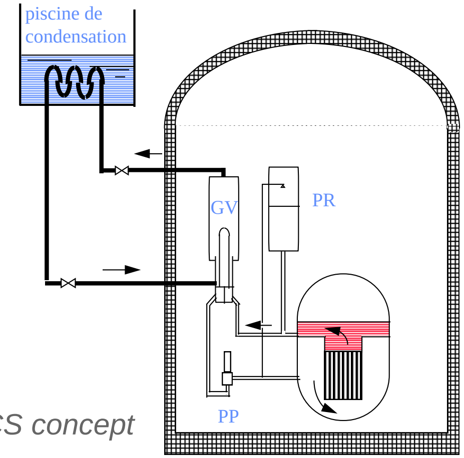
Threshold effects and breakthrough

Illustration with the past CEA Programmes

- **CEA Innovation Programme**: > 10 years of Research and Innovation programs to develop innovative solutions for existing and future LWRs
- **Overall objectives**: Cost reduction, increased safety, high performance core & fuel
- **Various technical fields covered**:
  - <u>Core and fuel</u>: high conversion PWR, innovative fuel (e.g. composite CERCER/CERMET, annular fuel pellet), innovative cladding (e.g. coating, SiC/SiC, burnable poisons), etc.
  - <u>Materials</u>: new alloys for vessel internal structure, coating (e.g. valve, control rod ratchet mechanism), component manufacturing based on densification of metal power, etc.
  - <u>Innovative systems</u>: passive safety systems (e.g. Secondary Condensing System), severe accident management facilities (e.g. innovative containment, core catcher) and other innovative safety systems (e.g. steam injector)
  - <u>Reactor design</u>: simplification (e.g. boron-free PWR, low pressure PWR), breakthrough (e.g. SCOR) etc.
  - <u>Technical economical studies</u>: qualitative comparison between concepts and systems
- **Supported by methodologies, tools/code development and experimental programs**

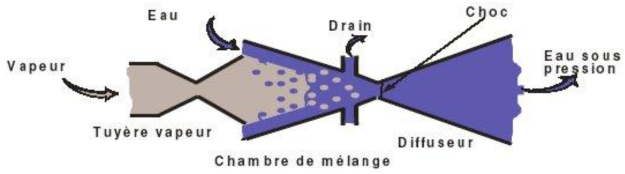
Examples – Innovative safety systems

- **Rational**
  - **Many systems for various functions** (e.g. reactivity control, residual power removal, corium recovery system) usually **complex and/or expensive**
    - ➔ technological breakthrough to bring **economic/safety benefits**
- **Examples**
  - Secondary Condensing System:
    - Passive residual heat removal system in natural circulation connected to the steam generator
    - Promising results notably in terms of safety improvement (e.g. steam generator tube rupture)



SCS concept

  - Steam Injector:
    - Replace/complement safety pump injection (passive system)
    - Possible applications into the primary or secondary with steam sources coming from pressurizer, steam generator
    - Example: provide the steam generator with water when the normal supply fails



Steam Injector concept

Examples – Innovative reactor design (1/2)

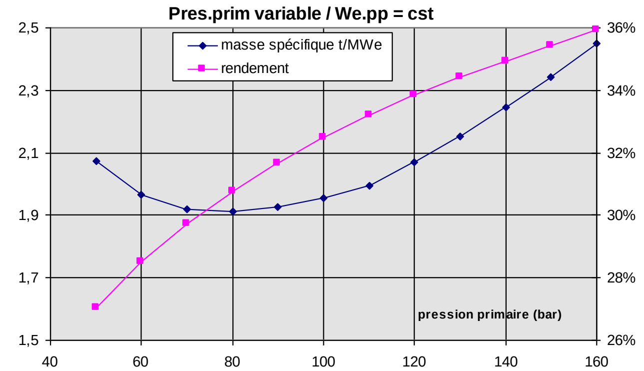
- **Rational:** simplification of standard PWR design (Ref. 900 MWe French PWR)
- **Examples:**

Soluble boron-free PWR

- **simplification** of plant operation/management (deboration) and **improved safety** (reactivity accident through heterogeneous boron dilution) + *regulation / legislation and acceptability aspects*
- feasibility studies of the reactivity control only through control rods and burnable poisons while maintaining performances and safety criteria – different levels of boron removal
- **encouraging results**: with an adequate assembly design, core reactivity adjusted with burnable poisons + an optimised control rod system for core shutdown
- to be considered: residual penalties of the burnable poison + redundancy of control means + complex load following

Low pressure PWR

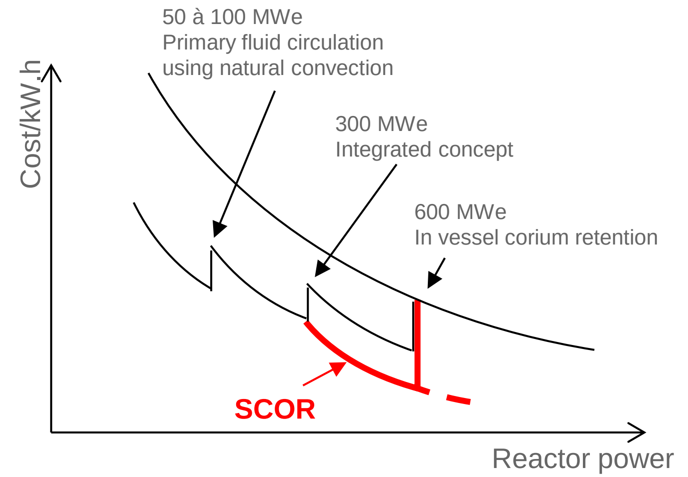
- **cost reduction** for components (e.g. vessel, steam generator), possible high burn up and **safety systems simplification**
- study of an adequate operating point by reducing the pressure
- **complete file** covering: core (neutronic and thermal hydraulic), fuel, thermal hydraulic systems, technical economic evaluation



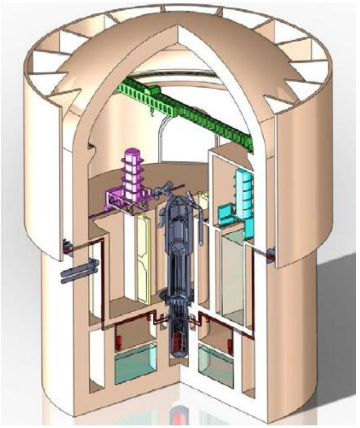
Parametric study on LP-PWR

Examples – Innovative reactor design (2/2)

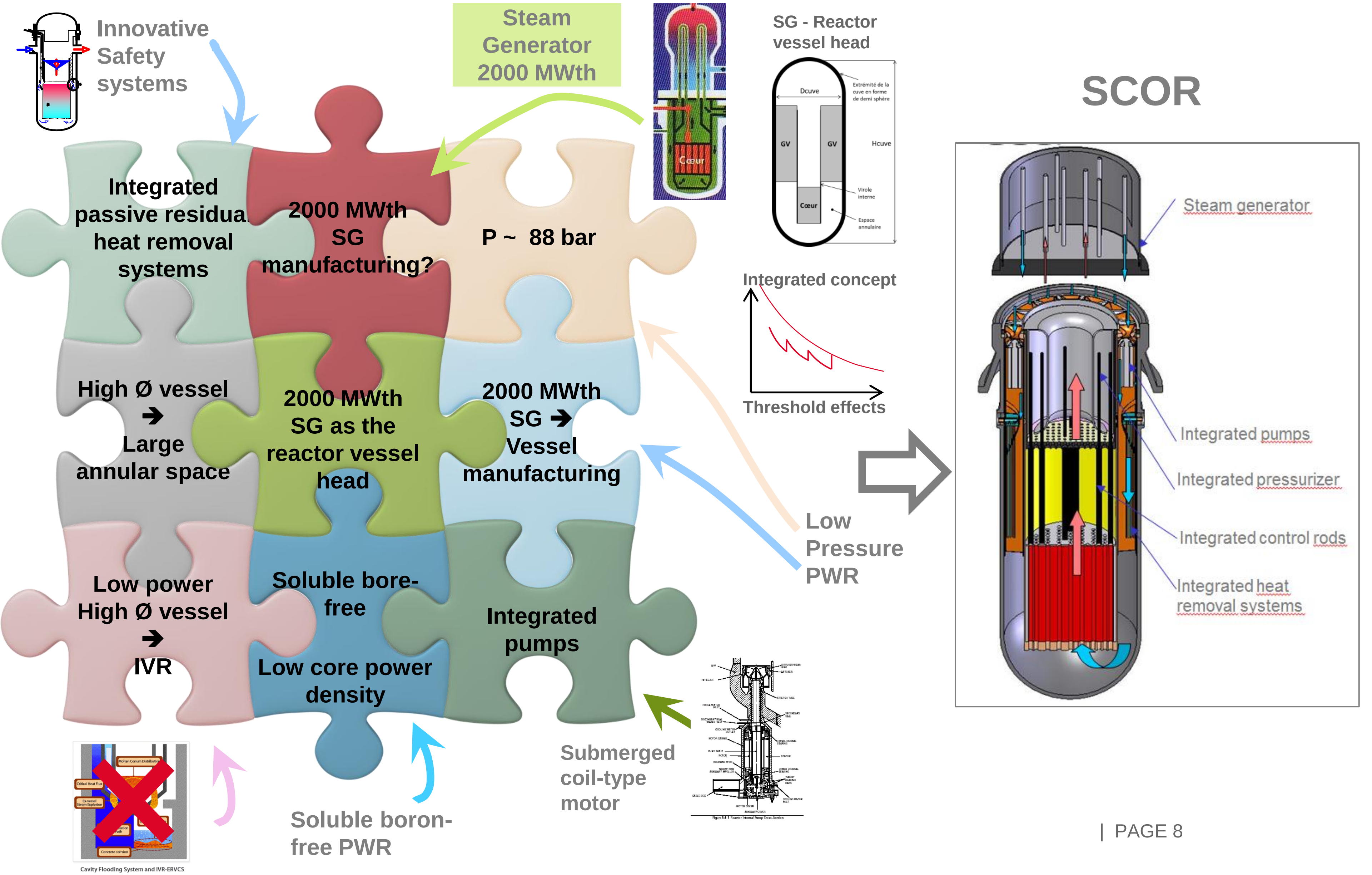
- **Rational:** Propose new conceptual designs integrating several innovative systems to analyse the performance of theses systems and evaluate their interactions and the overall coherence
- **Example**: SCOR - Simple COmpact Reactor
- **Evolving basis** to evaluate innovative systems, new core design or new strategy
  - First version: 600 MWe (threshold effects)
  - Then: variation until 1000 MWe (to evaluate the feasibility & possible economic benefits)
  - Lately: SMR Version 200 / 150 MWe



Threshold effects and breakthrough


SCOR in its containment building

RESEARCH AND INNOVATION IN LWR



CONCLUSION

- **Lessons learned** from this significant innovation program (> 10 years)
  - Many attractive innovative solutions studied
  - But lack of industrial applications

  ➔ need for a reinforced industrial involvement (from the very beginning of the studies to define specifications)

- Innovation depends on the **political context and industrial priorities**, such as:
  - Economics? e.g. Nuclear vs Shale gas, RES
  - Safety? Increased safety demand: e.g. post Fukushima, LTO extension
  - Energy mix? e.g. system integration, reactor flexibility, cogeneration
  - Optimisation of uranium resources? e.g. Gen III and Gen IV strategies

THANK YOU FOR YOUR ATTENTION