An immersed SMR with a new and challenging nuclear paradigm
A few words about NucAdvisor

- Private company founded in 2009, independent from major players of the nuclear industry
- Provides advisory services and expertise, technical and financial assistance, training and engineering services in the nuclear domain. Three business lines:
  - Owner’s engineer services for new nuclear programs
  - High level expertise and advice for nuclear clients
  - Owner’s engineer services for decommissioning, dismantling and waste management
- Advisor to DCNS for the Flexblue project since the beginning
Small and Modular Reactor (SMR) Market analysis

- SMR market is
  - Small grids in fast developing countries
  - Non interconnected grids in large countries
- Reference competition technology is fossil fuel – gaz, diesel, coal, with medium installed power & electricity cost usually over 100$/Mwh
- Market size is estimated to hundreds of SMR over the next 20 years
SMR market assessment
Units (150 MWe @ 100 €/MWh) worldwide: 2040
An innovative approach where the whole system is more important than the nuclear reactor by itself:
Operation Cycle of a Flexblue module

1. Completion of construction and tests (France)
2. Transportation to site (Sea)
3. Installation and tests (Host country)
4. Several years of Operation (Host country)
5. Maintenance and refueling (Host country)
6. Back to site and installation (Host country)

or

5 bis. Transportation to France or regional support base (Sea)
6 bis. Maintenance and refueling
7 bis. Transportation to site (Sea)
8 bis. Installation and tests
An innovative approach where the whole system is more important than the nuclear reactor by itself

- Power: 160 MW Electric
- Length ≈ 146 meters
- Hull Ø ≈ 14 meters
- Displacement ≈ 20 000 tons
- Moored up to a 100 meters depth
- Unmanned Operation, permanent accessibility
An innovative approach where the whole system is more important than the nuclear reactor by itself:
Operation Cycle of a Flexblue module

Transportation and installation ship, five Flexblue modules and ground control center on an electric power production site
Flexblue Innovative Concept
A safer nuclear concept

- No external power
- No operator action
- Indefinite grace period

IMMERSION +
EXTENDED PASSIVITY

- Simple accident management
- Easy maintenance
- Human factor minimized
- Reduced moving parts

ROBUSTNESS – SIMPLICITY

MATURITY
- Qualified or existing technologies (Submarines, terrestrial LWRs, SMRs)
- Test facilities (PANDA, …)
- Factory building

DESIGN REQUIREMENTS
- IAEA
- NRC
- …
Interests and challenges of a fully immersed system for nuclear safety, security and public acceptance

Immersion coupled with passive systems allows an infinite cooling of the core without any need of electricity in case of emergency.
Interests of a system fully manufactured and tested in the country of origin

- Short manufacturing cycle (3 years)
- Possible anticipation of orders: shortening of delays of delivery
- High level of quality control and of replicability
- Among other tests, nuclear tests of the system may be done at significant proportion of full power in the country of origin
- Civil works on site area limited to the control/command center
- The First-of-a – Kind can be everywhere there is a suitable site
Flexblue®: an attractive LCOE when compared to other nuclear and non nuclear power production systems

COMPETITIVE LCOE (FOAK)

● CAPITAL EXPENSES
  • Passive systems - simplicity
  • Modular construction technology in naval shipyard
  • Simple and fully standard design
    › Project risks controlled
    › Project schedule reduced
    › Quality and compliance mastered
  • Reduced site and civil Works
  • Proven and Qualified technologies

● OPERATIONS EXPENSES
  • Long lifecycle
  • Maximum mutualization of maintenance facilities & manpower
  • Easy decommissioning and dismantling
Flexblue®: an attractive LCOE when compared to other nuclear or non-nuclear power production systems

LCOE FLEXBLUE Vs Large Reactor - FOAK

- **LARGE REACTOR FOAK**
- **CONSTRUCTION DURATION (8 to 4 years)**
- **CAPITAL COST DIFFERENTIAL (7.5 Vs 10%)**
- **REACTOR SIZE (160 Vs 1630 Mwe)**
- **LOAD FACTOR (85% Vs 92%)**
- **FUEL BURNUP (40 GWj/T Vs 55 GWj/T)**
- **OPEX / MWh (+35%)**
- **FLEXBLUE FOAK**

Flexblue®: an attractive LCOE when compared to other nuclear or non-nuclear power production systems
A challenging new approach for licensing to be defined
Cycle of Safety Authorities responsibilities (nominal case)
Two families of challenges:

✓ Procedure of licensing and surveillance during transportation to the host country. No Convention, no international Treaty addresses this situation.

✓ Licensing on fixed stations (operation site or maintenance site in France). Taking in charge by Safety Authority after several years break in another country has to be organized.
A challenging new approach for licensing to be defined: Solutions

- Mechanism of continuous cooperation between the French and the Host Country Safety Authorities, validated by a Bilateral Convention, or
- Assistance by an experienced Safety Authority (country of origin) to a springing-up Safety Authority (INSAG 26), or
- Variant: treaty of extra territoriality to be applied to the site area and signed by the two Countries. It may be a solution but would require a significant evolution of the multinational safety issues approach by the international nuclear community.
included in the French national SMR programme,
a partnership under discussion with countries involved or interested in Transportable Nuclear Power Plants
numerous marks of interest from industrial companies to Flexblue,
funding by the French government under study
Basic Design planned to start in 2014
ANNEXES
Flexblue Innovative Concept
A safer nuclear concept

- **Extended** and **passive** safety

- 1st line of defense ensured by active systems
  - PCC-2 (> $10^{-2}$ / reactor.yr) : active systems
  - PCC-3/4, severe accidents : passive systems with extended grace period

![Diagram](image)

**NORMAL ACTIVE SYSTEMS**

**PASSIVE SAFETY SYSTEMS**

- Passive core cooling
- Depressurization + flooding

- Residual heat removal needed
- Safety injection needed
Flexblue Innovative Concept
A safer nuclear concept: emergency core cooling

- Passive Heat Removal Heat Exchangers

- Maximum pool temperature 60 hours after station blackout
  - Conservative assumptions: no SG heat removal, sea temperature 35°C
  - Primary temperature increase < 15 °C

- No circulation of activated fluid outside containment
Flexblue Innovative Concept
A safer nuclear concept: safety injection

- RCS depressurization and compartment flooding

- ADS
- CMTs (HP)
- Accumulators (MP)
- Safety tanks (LP)
- Recirculation screens (LP long term)
Flexblue Innovative Concept
A competitive source of electricity

LCOE < 100 €/MWh (FOAK)

- **CAPEX**
  - Passive systems - simplicity
  - Modular construction technology in naval shipyard
  - Simple and fully standard design
    - Project risks controlled
    - Project schedule reduced
    - Quality and compliance mastered
  - Reduced site and civil Works
  - Proven and Qualified technologies

- **OPEX**
  - Long lifecycle
  - Maximum mutualization of maintenance facilities & manpower
  - Easy decommissioning and dismantling
Flexblue Innovative Concept
Maximal use of modularization

- 80 sub-skids
- 11 skids factory assembled
- Hull & skids shipyard assembled
- Fully completed module shipped on site
- Very limited civil works on site

reactor : 2 skids
Turbine : 5 skids
Aft sect. 2 skids
Fore Sect. 2 skids

Accès principal