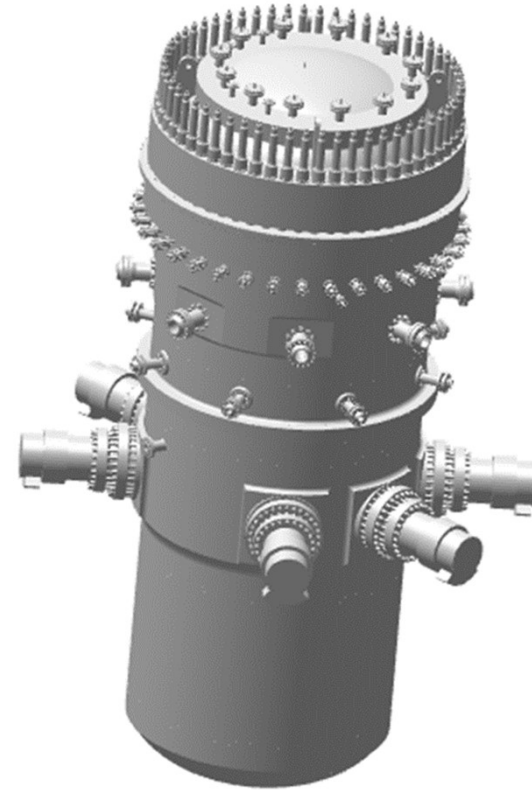


SMR Technology The French approach

Jacques Chénais CEA

IAEA TWG SMR Vienna April 23-26 2018



COMBINING SKILLS OF PARTNERS FOR SMR DEVELOPMENT

Atomic Energy and Alternative Energies Commission (CEA)

- French public research institution in low-carbon energies (nuclear and renewable energies), defense and global security, information and health technologies
- A key player in research and innovation with 16,000 scientists, engineers, and support staff in 10 research centers

- Core designer,
- Involved in the reactor design,
- Thermohydraulic codes, expertise and test facilities



EDF Group

- Designs, builds and operates nuclear plants in France and abroad
- Architect Engineer for new build projects
- The World's largest nuclear operator
- Produces around 22% of the European Union's electricity, primarily from nuclear power

- NPP Architect Engineer
- Safety demonstration
- Operation & maintenance



NAVAL
GROUP



COMBINING SKILLS OF PARTNERS FOR SMR DEVELOPMENT



An European leader in naval defence and a major player in marine renewable energies:

- designs, builds and supports submarines and surface ships.
- supplies services to shipyards and naval bases
- offers a wide range of marine renewable energy solutions.

•Steam conversion system,
•Modular concept,
•Steel containment



- Specialized in the design, construction, operation and maintenance of compact nuclear reactors
- For more than 45 years, offering nuclear engineering expertise on reactors, fuel and related facilities
- Proposes solutions and products that meet the highest safety and availability standards
- About 1,500 people and operates for naval propulsion, research, nuclear medicine and energy.

•SMR reactor designer
•New technologies developer



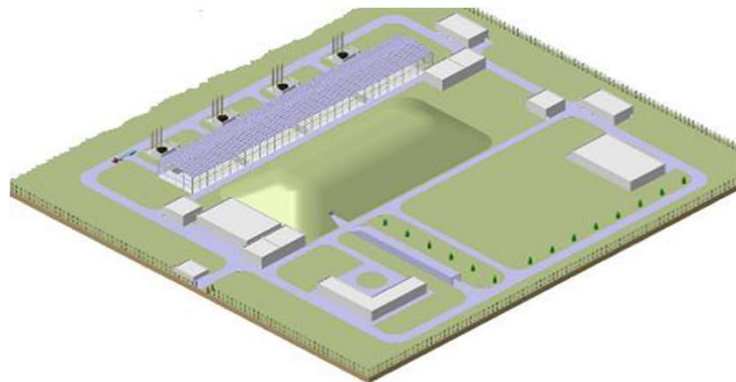
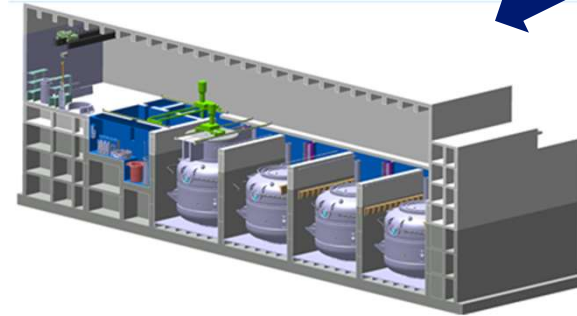
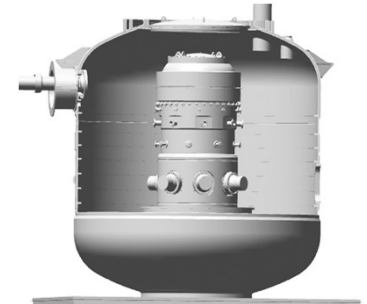
SMR INTERESTS & EXPECTED BENEFITS OF MULTI-REACTORS

- **Low power enabling simplified design with high level of safety**

- Simplified and compact architecture, limiting the accident initiators and scenarios
- Low level of residual heat, simplified and passive safety systems

- **Modular reactor, for simplified construction**

- Limited number of modules, manufactured in factories
- Reduction of risks related to construction on site
- Reduction of the construction duration on site



- **Affordable nuclear for power generation**

- Reduced investment per unit
- Reduced Capital cost before generation of first MWh
- Multi-unit financing scheme: first units financing the next units

- **Integration in the power network**

- Single to multi-SMRs solutions, according to power needs
- Flexible operation compatible with base and intermittent sources

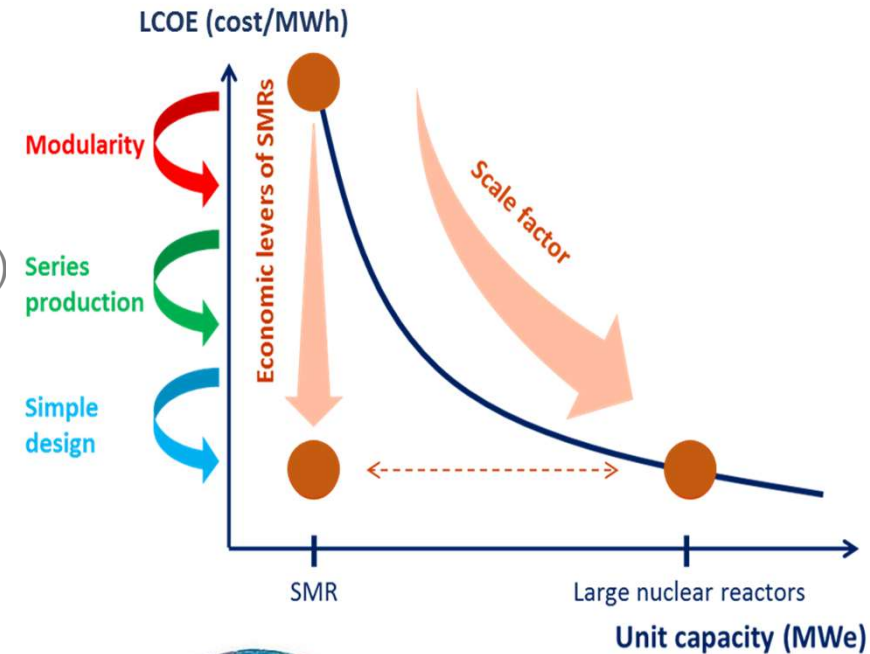
SPECIFIC BREAKTHROUGHS TO CONSIDER

- **Economic levers vs Scale effect**

- **Modular design** and manufacturing (construction cost decrease, shortened construction duration)
- **Series effect** (In series production of components, standardisation...)
- **Simplification of design** (architecture, components, regular civil structure, easy and quick to build)

- **Standard design and international licensing for worldwide deployment**

- Adapted regulatory requirements
- In factory certification
- Passive systems qualification
- Mutualisation of systems and control room



DISRUPTIVE SOLUTIONS RELYING ON FRENCH EXPERIENCE

▪ PWR Technology

- The most mature, spread and near term technology
- Relying on existing capacities (supply chain, fuel cycle industries)

▪ NSSS integrated design

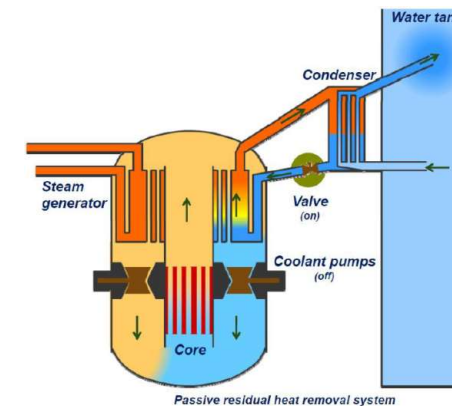
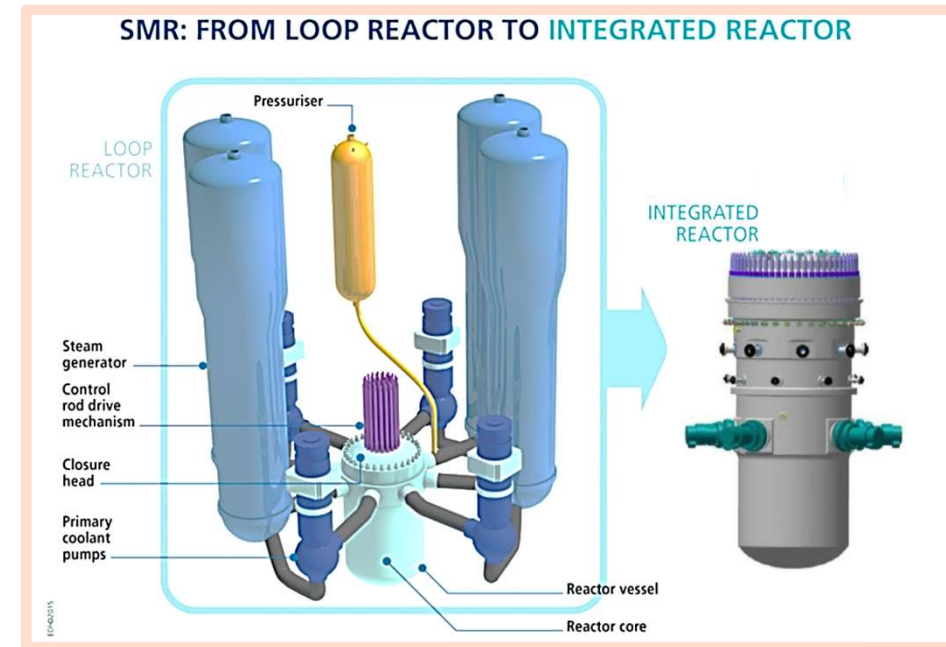
- Compact primary components located inside the pressure vessel

▪ Safety features

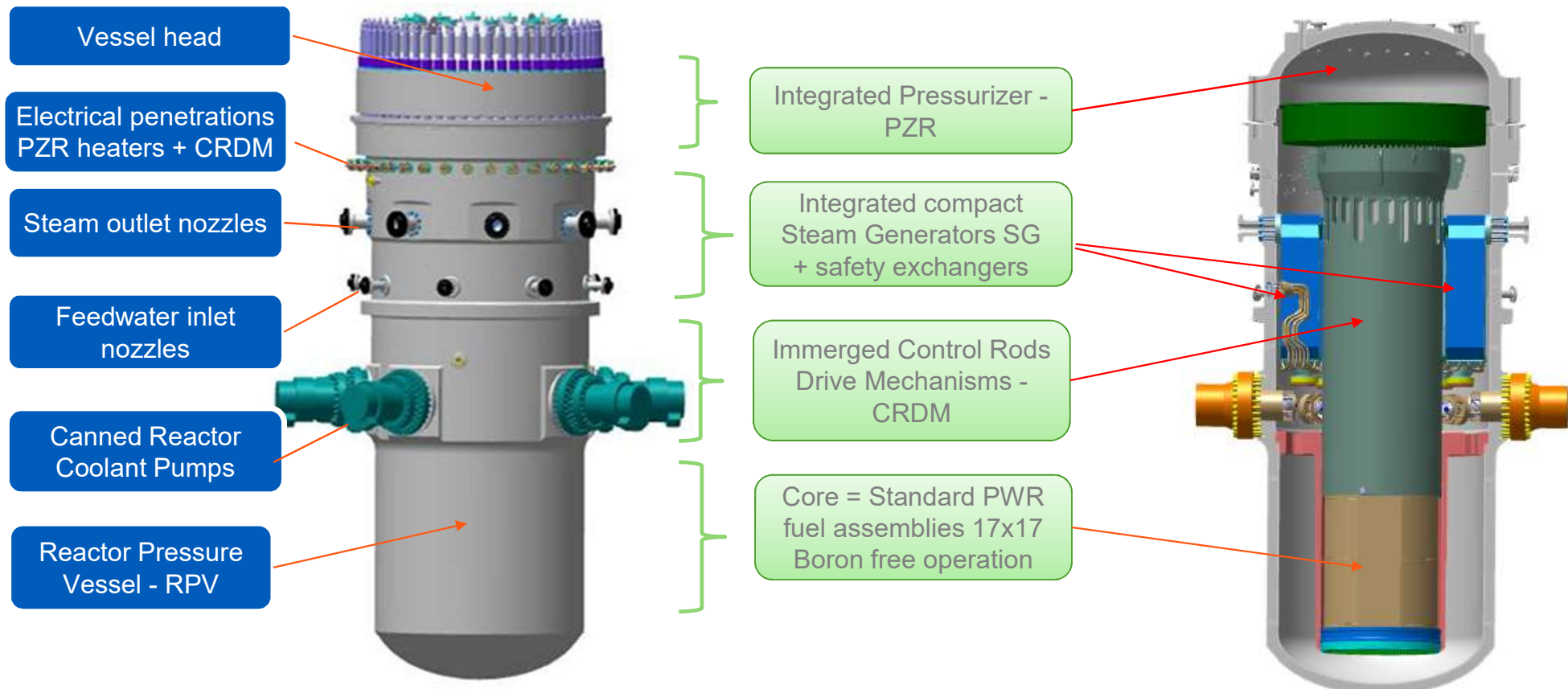
- GEN III+, post FKS requirements
- Resistance to hazards
- Passive systems with large grace period
- Severe accident management

▪ Flexible and versatile

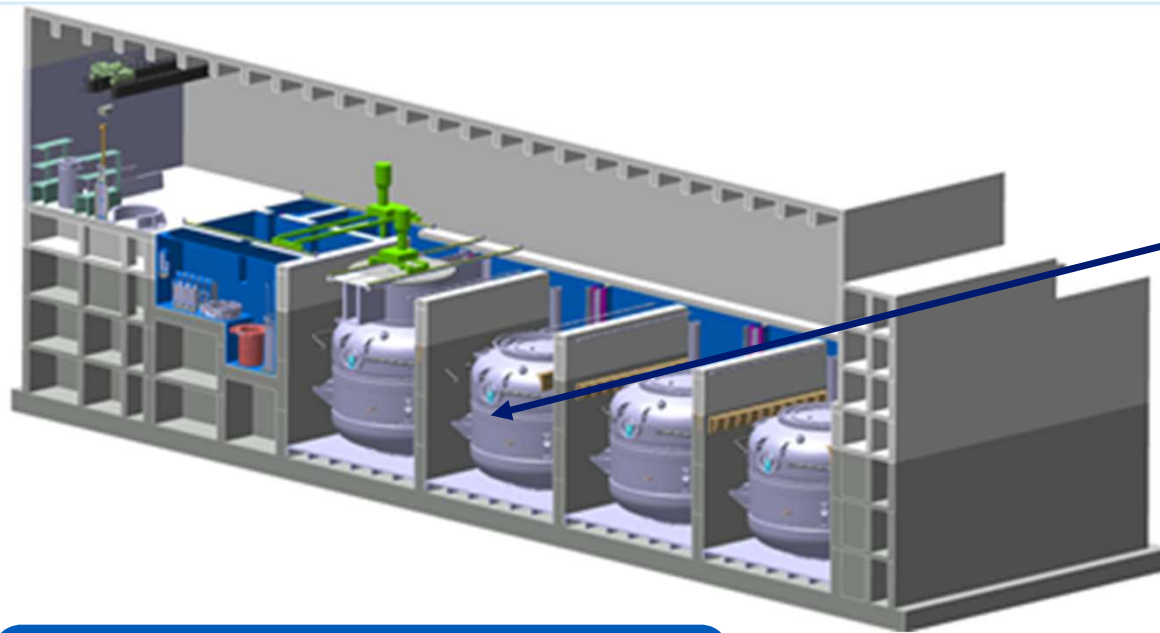
- Flexible operation for power generation
- Single to multi-SMRs facilities



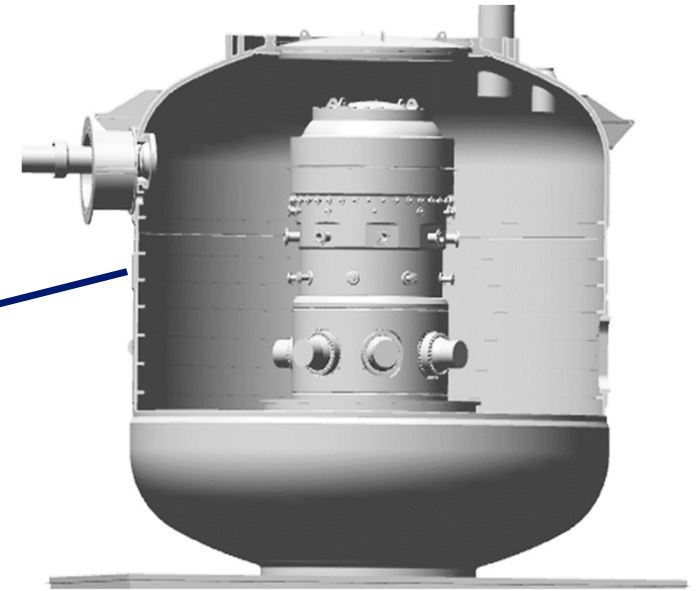
FRENCH SMR DESIGN – INTEGRATED ARCHITECTURE – 170MWe



FRENCH SMR DESIGN / CONTAINMENT AND NUCLEAR ISLAND



Nuclear Island for 4 units (2 or more possible)
Partially buried/partially covered architecture



Integrated reactor located in a metallic
containment shell ($\varnothing$ 15m),
Containment immersed in a water basin

FRENCH SMR DESIGNED FOR HIGH % IN-FACTORY MANUFACTURING

All critical interfaces are metal/metal factory-made interfaces

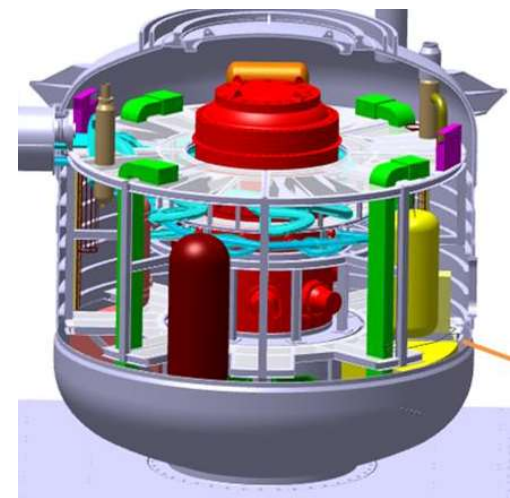
- Compactness of the reactor block and its metallic containment allows innovative in-containment prefab.
- Pre-fabricated and pre-tested functional circuit modules (including local I&C) on skids or cradles, for inside and outside containment assembly

Components designed and selected for large series

- Simplified manufacturing process for newly designed components (e.g Plate SG v/s tube SG and/or Motor-driven CRDM v/s magnetic jack)
- Low pressure/Low diameter pipe components (except main steam pipes)
- Almost undrilled vessel head

Easy and quick construction on site

- No need for pre-stressed concrete containment building
- Regular & rectangular shape buildings, with moderate excavation depth (~20m)
- Partially buried/partially covered architecture for efficient APC protection
- No need for heavy crane during site construction
- Disconnect (as far as possible) civil work schedule from electro-mechanical erection



FRENCH SMR DESIGNED FOR FLEXIBILITY & SIMPLICITY

Designed for flexible operation

- No soluble boron, small and stable core (no Xe oscillations) for easy reactivity control by control rods
- No thermomechanical solicitation for the NSSS from ~3% to full power

To simplify daily operation

- No soluble boron management ⑨ easy chemistry and reduced liquid waste management
- Robustness to transients : large primary coolant inventory (m3/Mwe) and large pressurizer volume
- Passive systems, testable during operation
- Simple auxiliaries systems thanks to small and compact components (e.g 400kW sealed reactor coolant pumps), simplified In-core instrumentation,...

To simplify maintenance

- Noria based maintenance for most primary components : CSG or reactor coolant pumps are replaceable components (inspection and maintenance can be performed out of outage schedule)
- Reduced perimeter of 2nd regulatory barrier, few pressure retaining components for NSSS
- Redundant system modules on functional skids

FRENCH SMR DESIGNED FOR SAFETY

Safety design features:

- Simple design, large water core inventory, large operation margins
- Protection against external hazards (buried/under mound)
- Robustness against usual PWR accident initiators (Large break LOCA, spurious boron dilution, rod ejection...)

Passive DBC2-4 management :

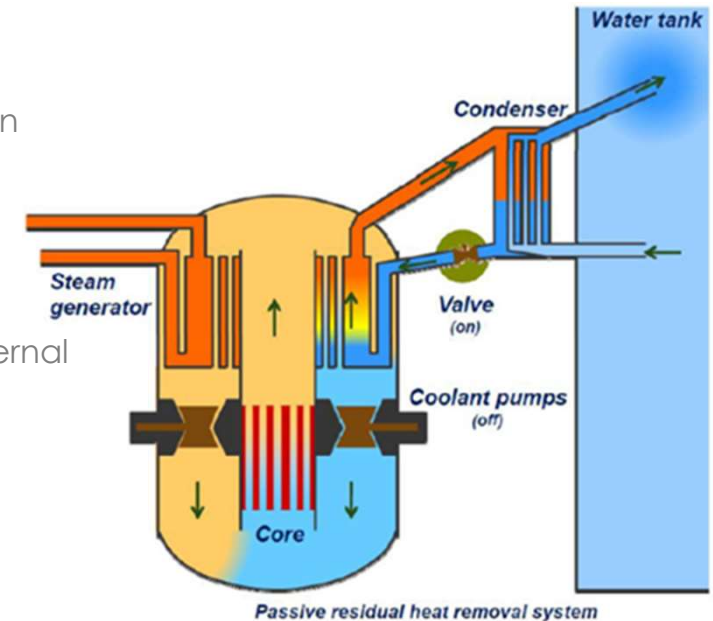
- Usual gravity driven emergency shutdown
- Passive safety architecture to manage DBC3-4 scenarios with large grace period (several days) with no need of human action, safety classified power supply or external heat sink
- Large inventories for reactor coolant, water basin, containment volume
- Passive cooling of the spent fuel pool

Active diversified DEC-A mitigation

- Active high pressure boron injection for ATWS
- Low diameter depressurization + Mid pressure active pump from cooling pool to vessel and/or containment

Passive diversified DEC-B mitigation

- Passive flooding of vessel pit for In-Vessel Retention of corium
- Passive nitrogen injection for H2 risk



SMR : OPPORTUNITY FOR THE FUTURE

A proper response to high expectation

- **A relevant and affordable solution for new nuclear uses**

- New comers in nuclear, carbon free alternative to existing fossil
- Remote sites, isolated network, heat, steam and desalination

- **Compatible and complementary with existing large nuclear**

- Mid merit operation, complementary to large base nuclear and intermittent renewable

As world leaders in nuclear technology and operation, French partners are engaged to develop a valuable and competitive SMR solution and are opened to international cooperations.