HEXANA: design and development of a sodium-cooled fast modular reactor to decarbonize industry

Nicolas ZWEIBAUM – Deputy CTO

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PRT-HXN-25-0640 rev. **A**

Company overview

- Founded in 2023 – Spin-off from **CEA**
- Laureate of the Innovative Nuclear Reactors initiative under the **France 2030 program**
- **€27M secured** in funding (€17M in equity)
- 60 employees based in Aix-en-Provence, Paris & Brussels

Current industrial challenge

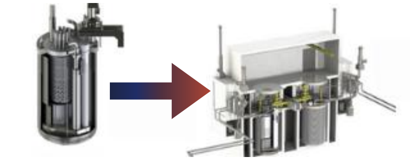
- Heat represents **75% of global industrial energy needs,** of which 75% is above 150°C (IEA)
- **90%** of this heat is **fossil fuel-based**

HEXANA's energy platform

- **2 sodium-cooled fast neutron reactors (SFR):**
  - **Capacity**: 800 MWth output (excluding heat storage capacity), equivalent to 335 MWe
  - **Maturity**: **440 years of operation** worldwide, 120 years in Europe, 6 reactors operated
  - **Dual-reactor strategy:** no downtime during maintenance or refueling, continuous, uninterrupted power supply
  - **A high-temperature heat storage system**

Products & services

- **High-temperature heat** (up to 465°C)
- **Ultra-low-carbon power** generation ($2\ gCO_{2eq}/kWh$)
- **Reliable & highly-flexible** energy system



1 reactor module

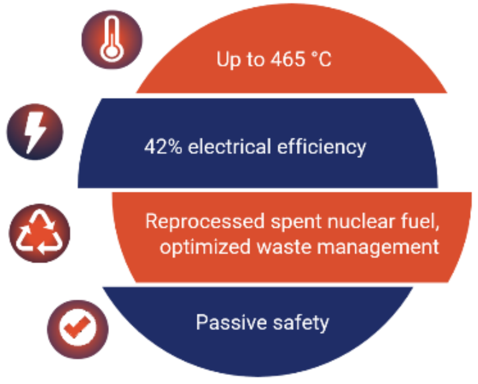
Reactor Building
2x400MWth

End customers: energy intensive industries

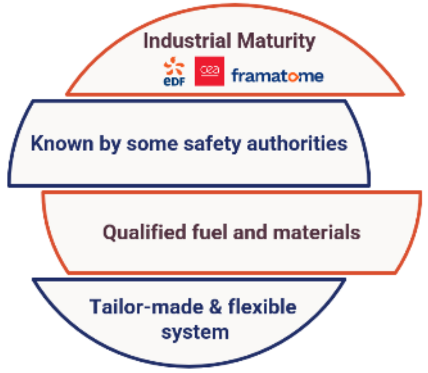
upcycling nuclear
for climate

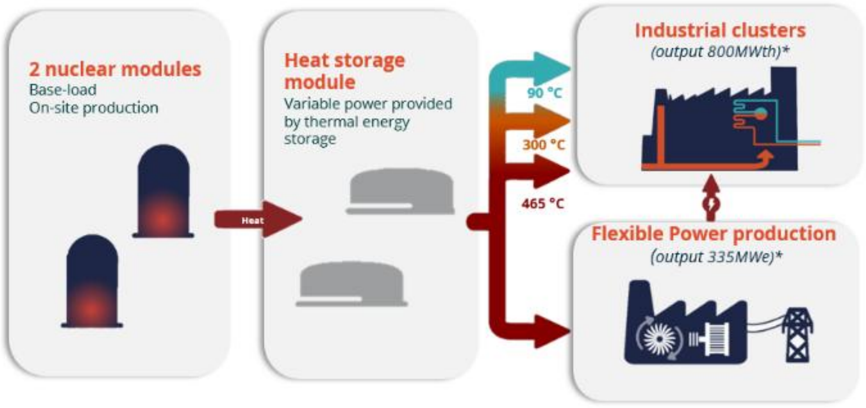
Our added value

Favorable technical specifications to match industry needs



The most mature technology from GEN4 reactors

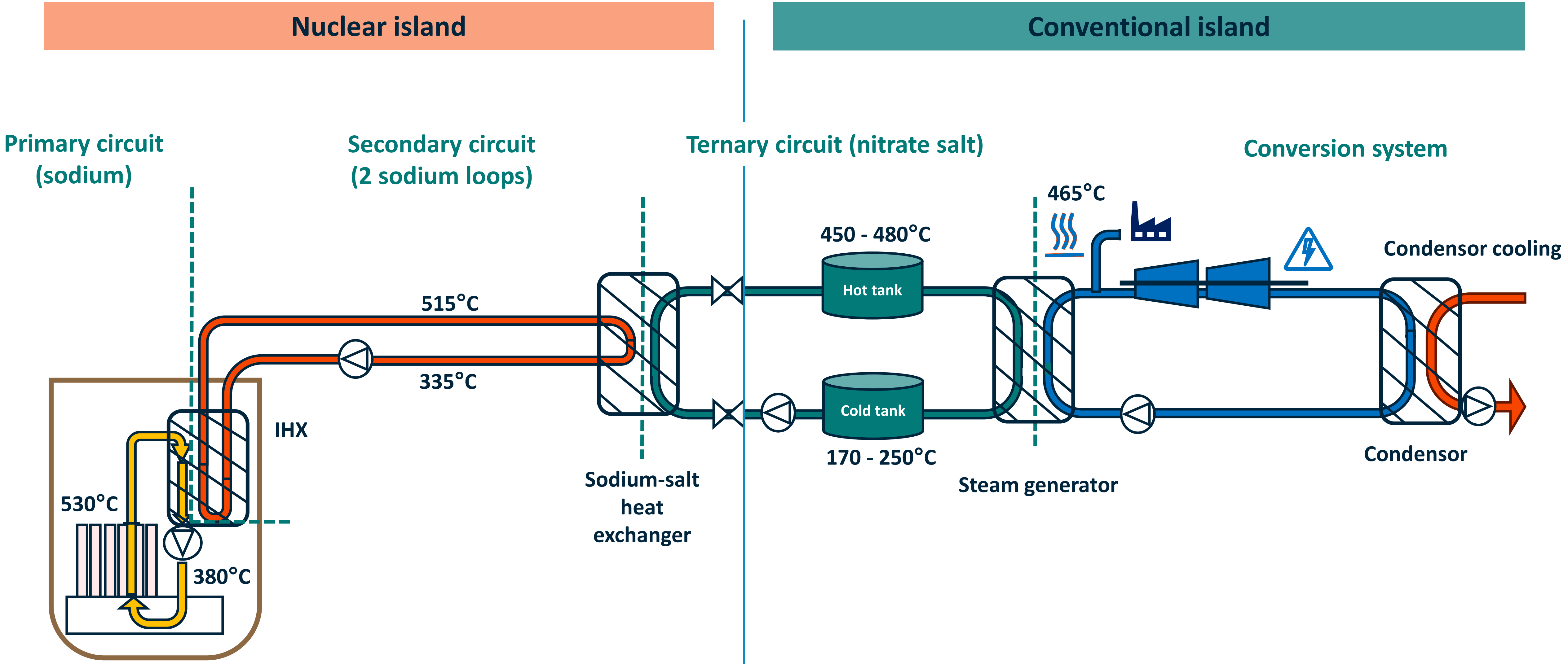




*Capacity of 2 reactors only (excludes additional capacity from thermal storage)

Technology

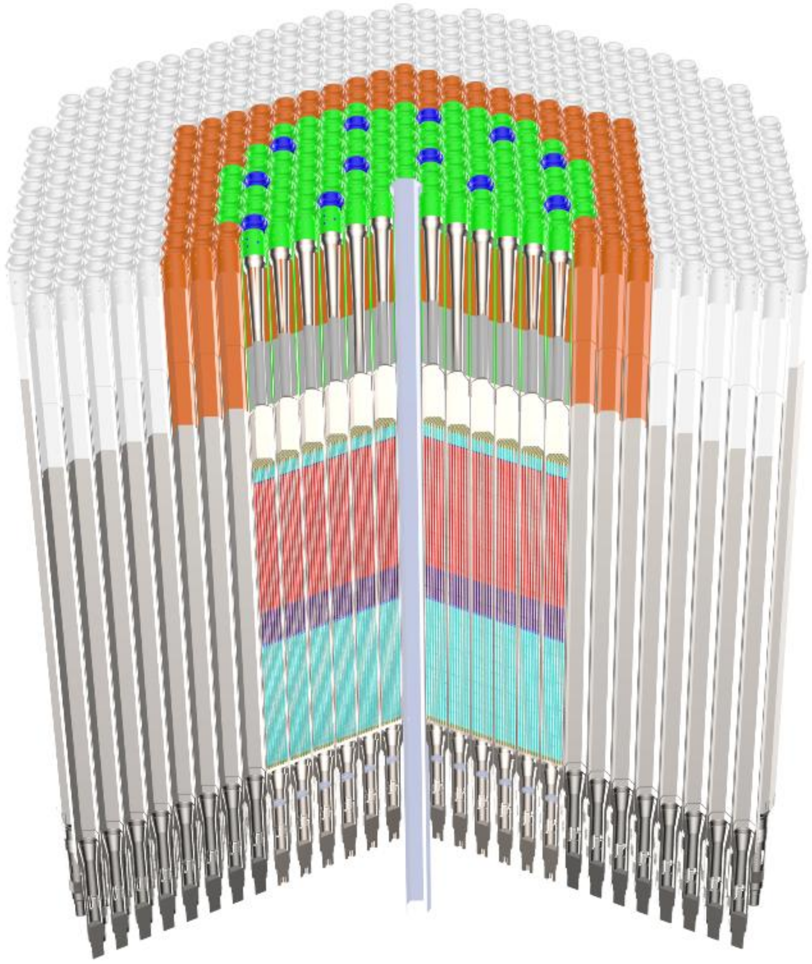
How it works: main fluid circuits



Core characteristics

Core data (FOAK)

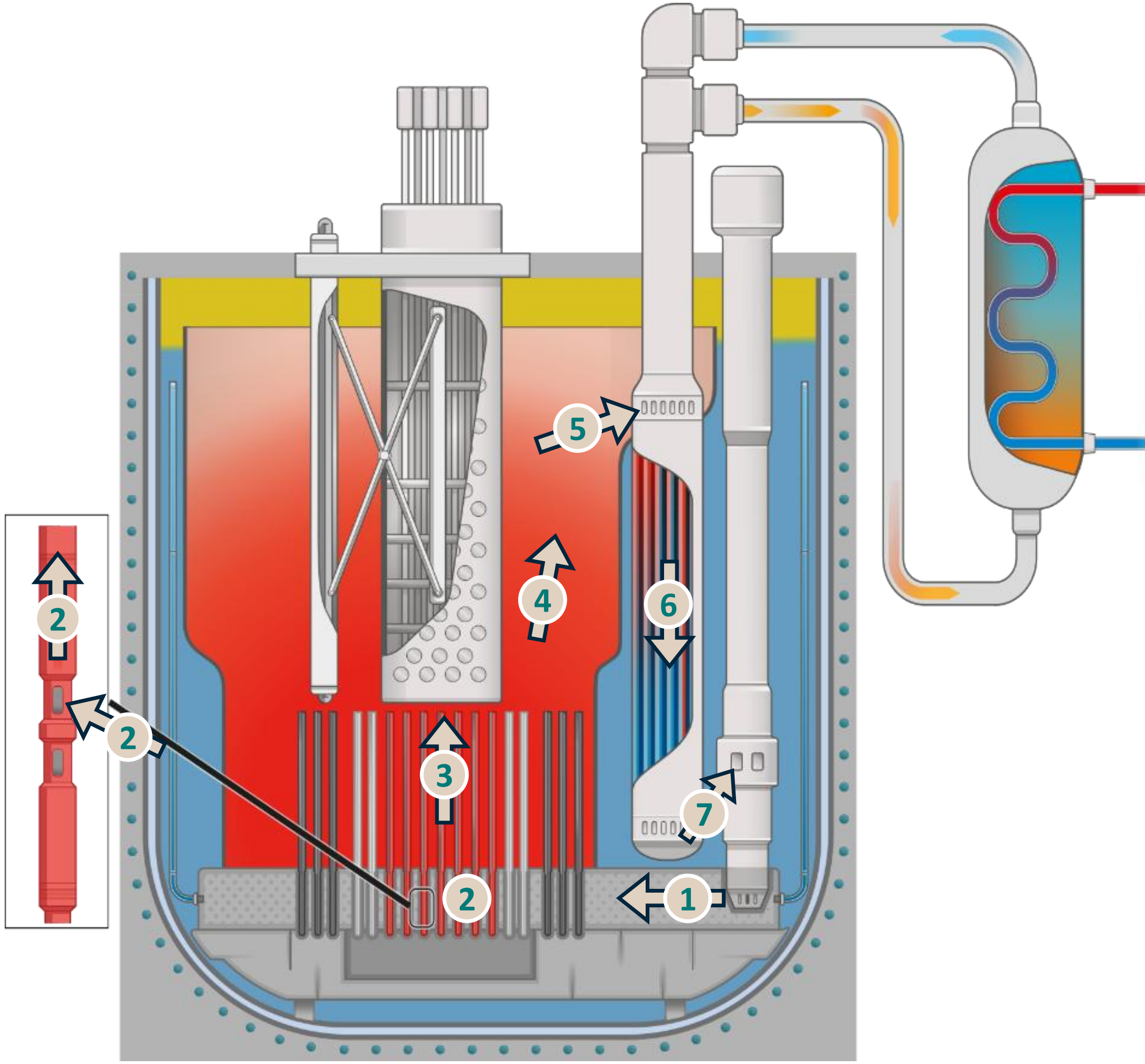
- **Fuel type:** MOX (UO_2, PuO_2)
- **Fuel assembly geometry:** same as Superphenix
- **Core inlet/outlet temperature:** 380°C/530°C
- **Number of fuel assemblies:** 132
- **Fuel cycle:** 12-18 months
- **Reloading scheme:** 1/3 of core



Primary circuit

Sodium flow in the reactor vessel

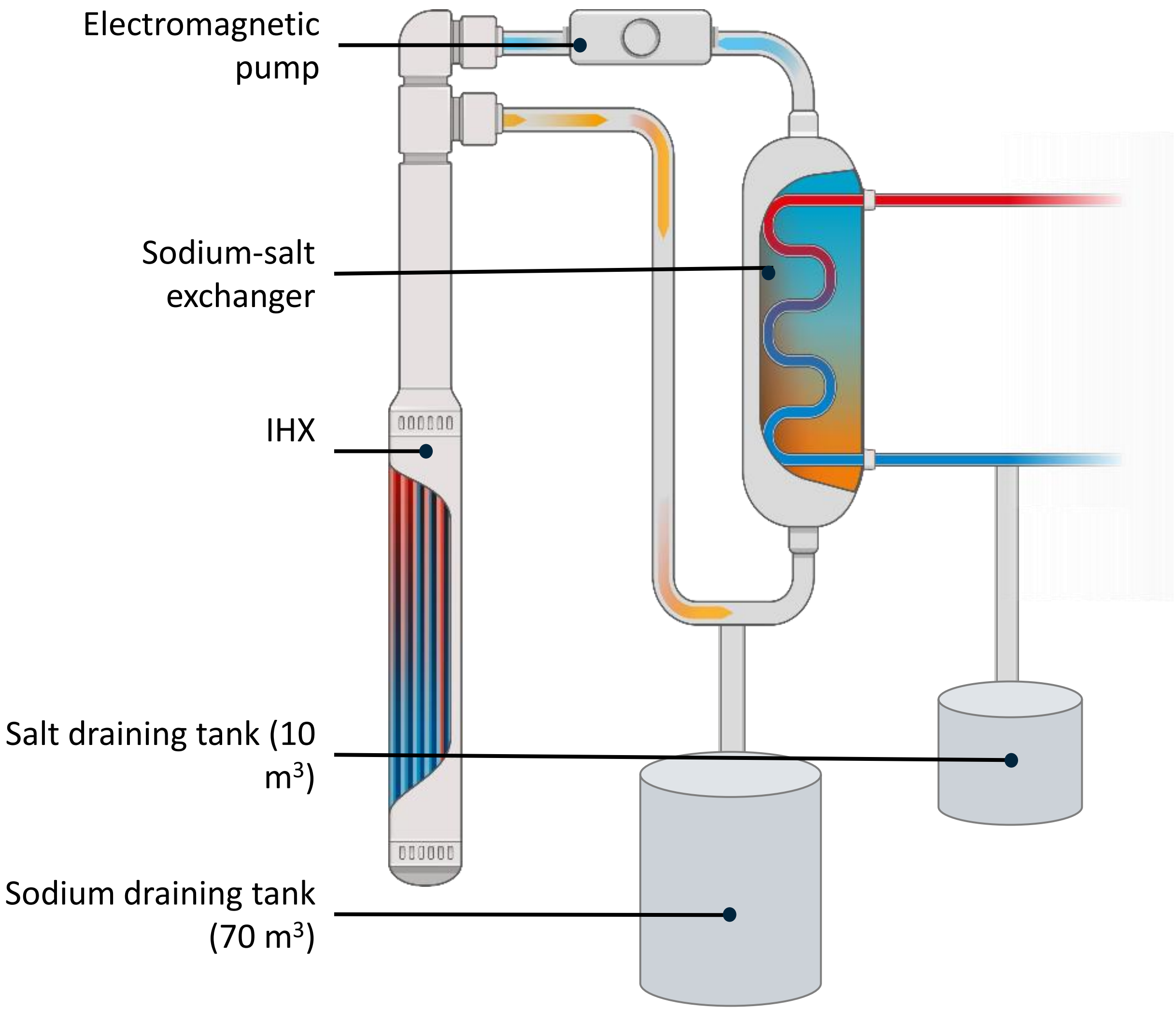
1. **Forced circulation** of cold sodium: 2 primary pumps
2. **Injection of cold sodium (380°C)** at the bottom of the fuel assemblies (93% of primary flow rate, 5 bar relative pressure)
3. **Sodium heated** by convection along fuel pins, exiting core at 530°C
4. **Mixing and transfer** of sodium into a hot collector
5. **Hot sodium** enters 2 intermediate heat exchangers
6. **Primary sodium cooled** along intermediate heat exchanger tubes (heat transferred to secondary sodium)
7. **Cold primary sodium** exits at the bottom of the exchanger into a cold collector and is drawn by the primary pumps



Secondary circuit

Description

- **2 independent secondary loops** per reactor
- **Non-radioactive sodium**
- Direct heat exchange with thermal storage system through **sodium-salt heat exchangers**
- Connected to decay heat removal loops (with passive **sodium-air heat exchangers**)
  - **Air as ultimate heat sink** = infinite cold source in accident scenarios



Conventional Island – Heat storage system

Heat storage technology

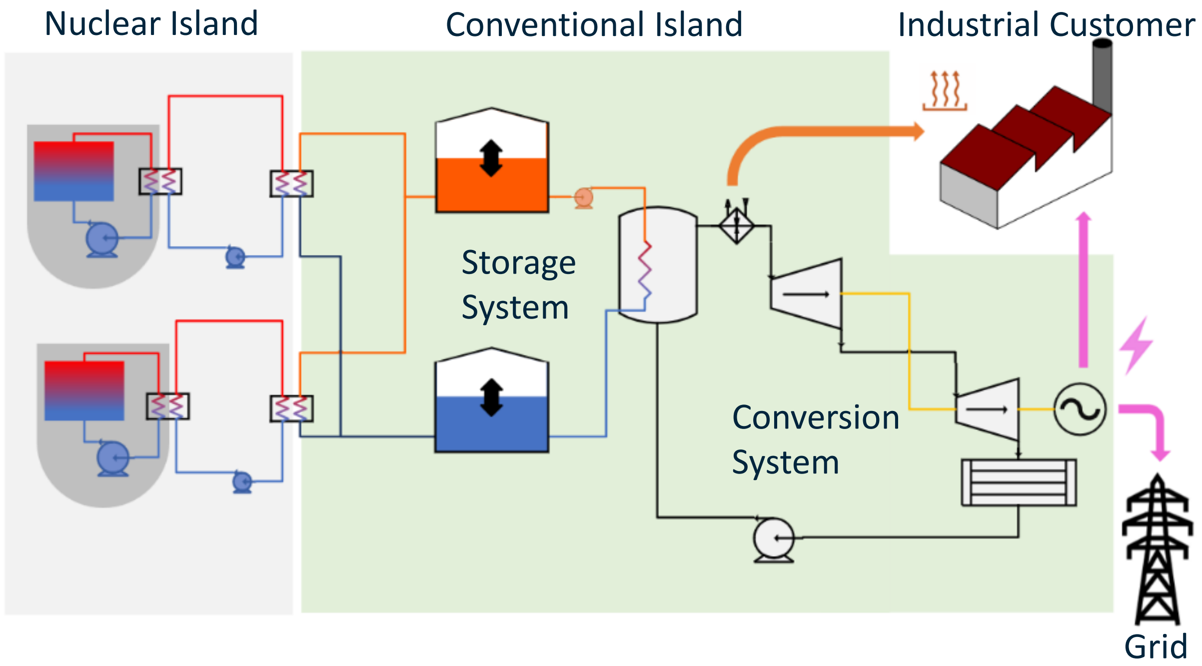
- **Storage medium:** molten nitrate salts
- **Storage architecture:** hot/cold tanks
- **Charging circuit:** sodium-salt heat exchangers
- **Power:** steam generator

Load following strategy

- **Reactor:** 100% power at all times
- **Heat storage:** used for high flexibility

High flexibility

- **Storage capacity:** 300 MWh up to 2.5 GWh



Conventional Island – Energy conversion system

Conversion system

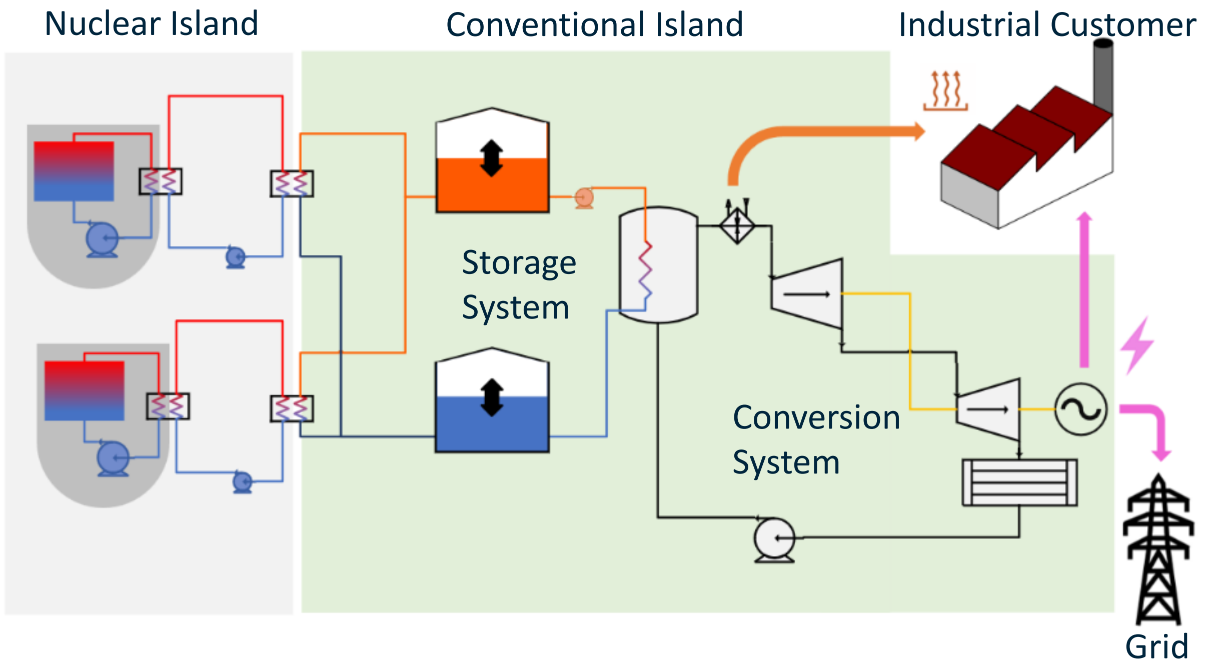
- **Conversion cycle:** Rankine (water/steam)
- **Power:** up to 2 x 400 MWth or 330 MWe
- **Cogeneration:** heat up to 465°C
- **Equipment grade:** non nuclear

High flexibility

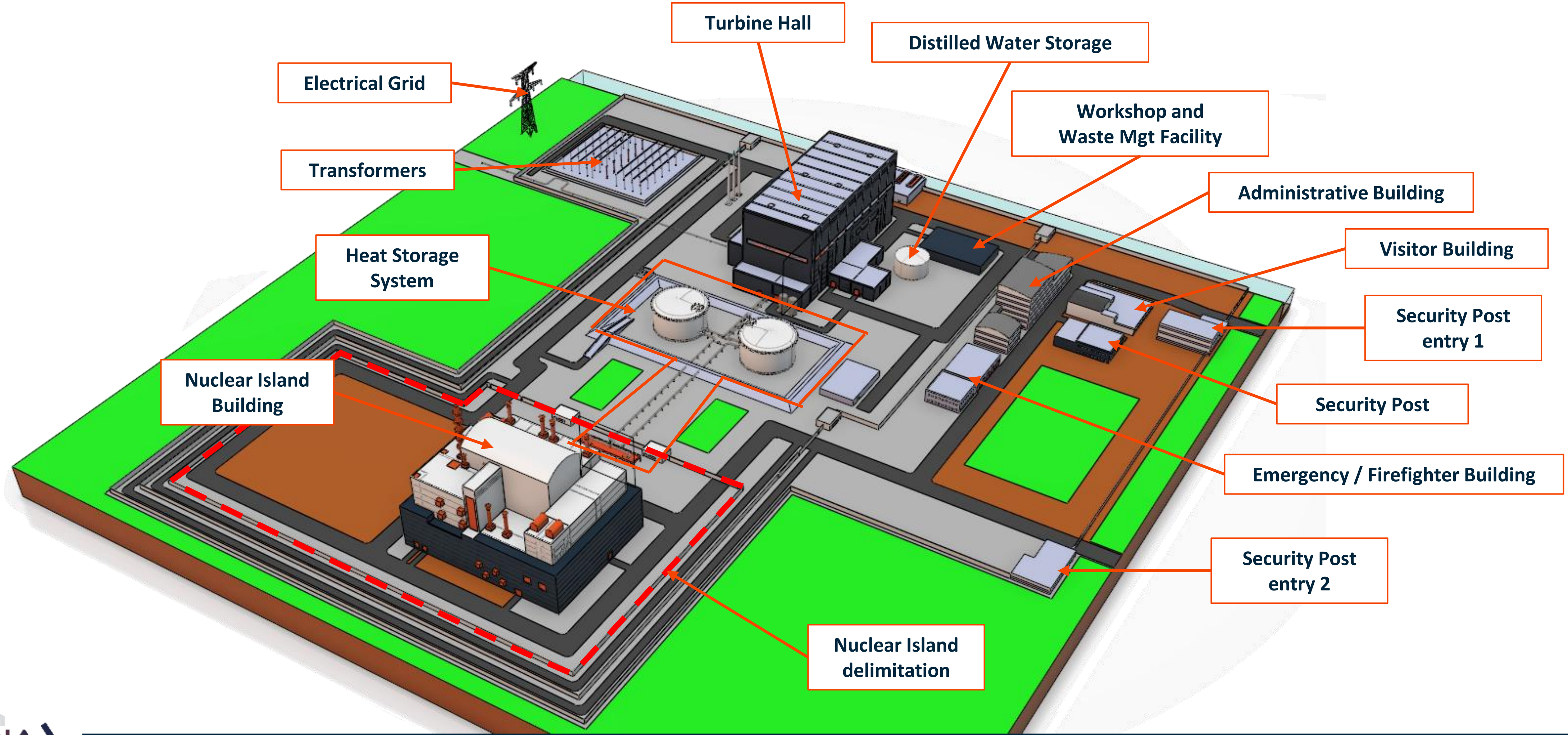
- **Power ramp:** 20% NP/min
- **Main limitations:** Thermal dilation issues

Cold source and thermal pollution

- **Heat sink:** ocean/sea or river
- **Thermal pollution:** high efficiency (high temperature) → less thermal pollution than LWRs



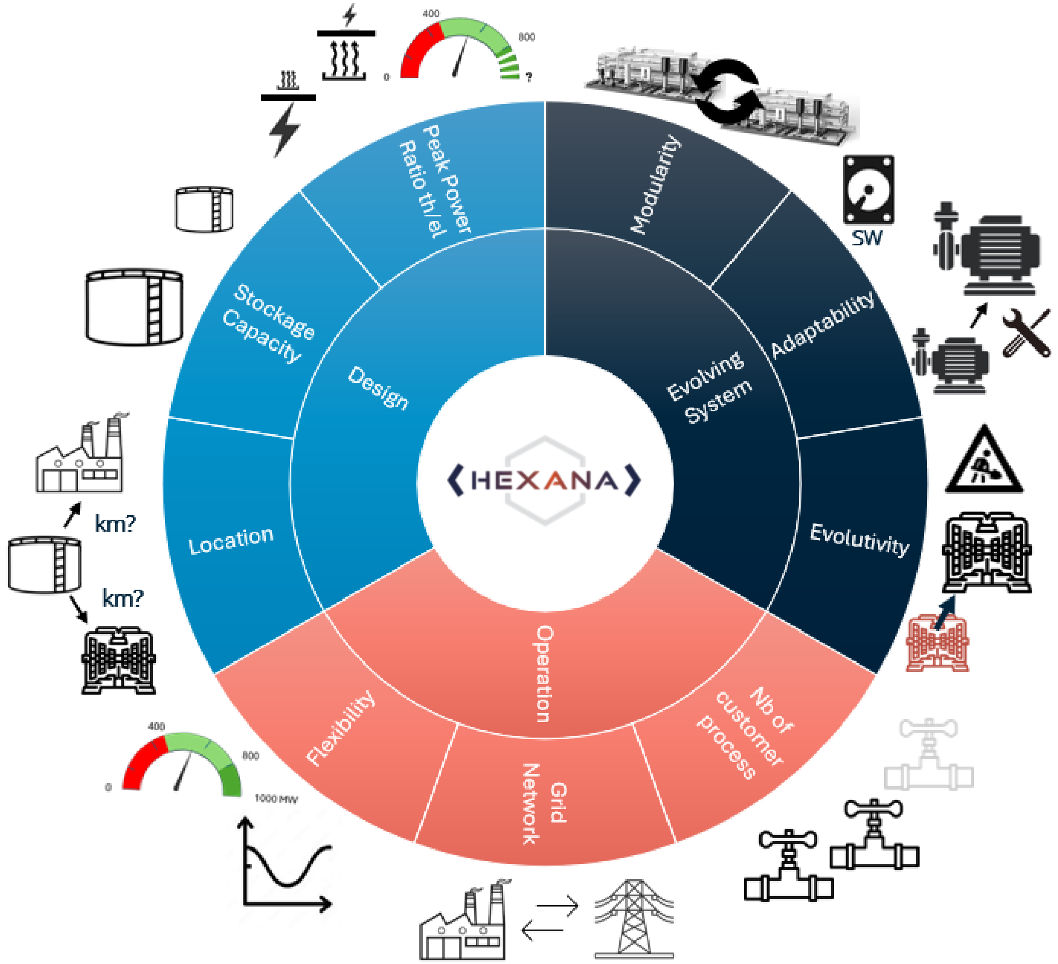
Typical site layout



HEXANA: a highly flexible energy platform

▪ Three levels of flexibility:

- **Design flexibility**
  - Peak & power range limits
  - CHP ratio (thermal/electric)
  - Storage capacity
  - Distance between Nuclear Island, storage and conversion
- **Operational flexibility**
  - Power variation (baseline: 20%/min)
  - Power dispatch (heat vs. electric, industrial customer vs. grid)
  - Number and temperatures of steam supplies
- **Evolutive flexibility**
  - Modularity: swap or add modules
  - Adaptability: software, minor hardware changes
  - Evolutivity: major change (turbine change, storage upgrade)



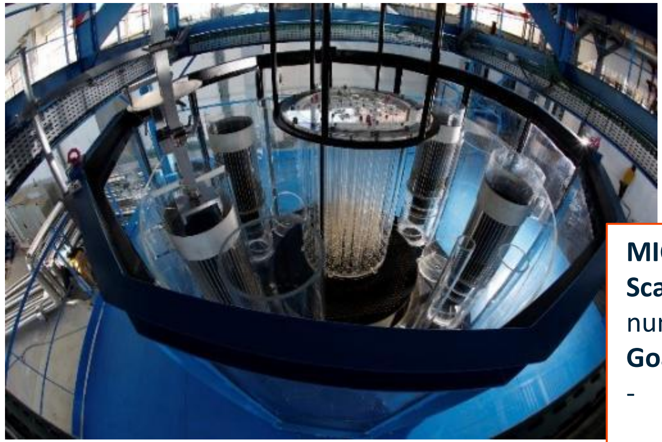
R&D needs

Technical innovation: challenges and opportunities

	Challenges	Opportunities
Modular layout	Rethinking of system interfaces	Optimized assembly and commissioning sequence
Compact reactor vessel	Constraints around component "packaging" and in-vessel flow distribution	Transportable design
Fuel and reactor internals handling system	Mechanical qualification required	Reduced maintenance duration (hence increased system availability)
Salt-based thermal storage system	Development and qualification of new sodium-salt heat exchangers required	Better system flexibility + eliminates sodium-water interaction risk in historic SFRs

Existing and planned collaborations with CEA (France)

- **Water-based thermal-hydraulic installations**
  - **Validation of the geometric configuration of the HEXANA primary circuit (compact reactor, asymmetrical component positions) with respect to forced convection, natural convection, gas entrainment, vibration**
  - **Validation of thermal-hydraulic codes (CATHARE 3, STAR-CCM+)**

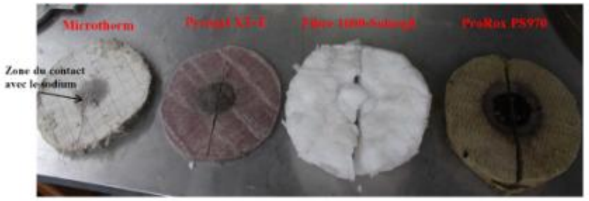


Source: CEA

MICAS – CEA Cadarache (France)
Scale: ~1/6 (matching Froude and Richardson numbers)
Goals:
- Simulate hydraulic flow in the upper plenum of an SFR
- Study gas entrainment
- Provide data to validate numerical models

Existing and planned collaborations with CEA (France)

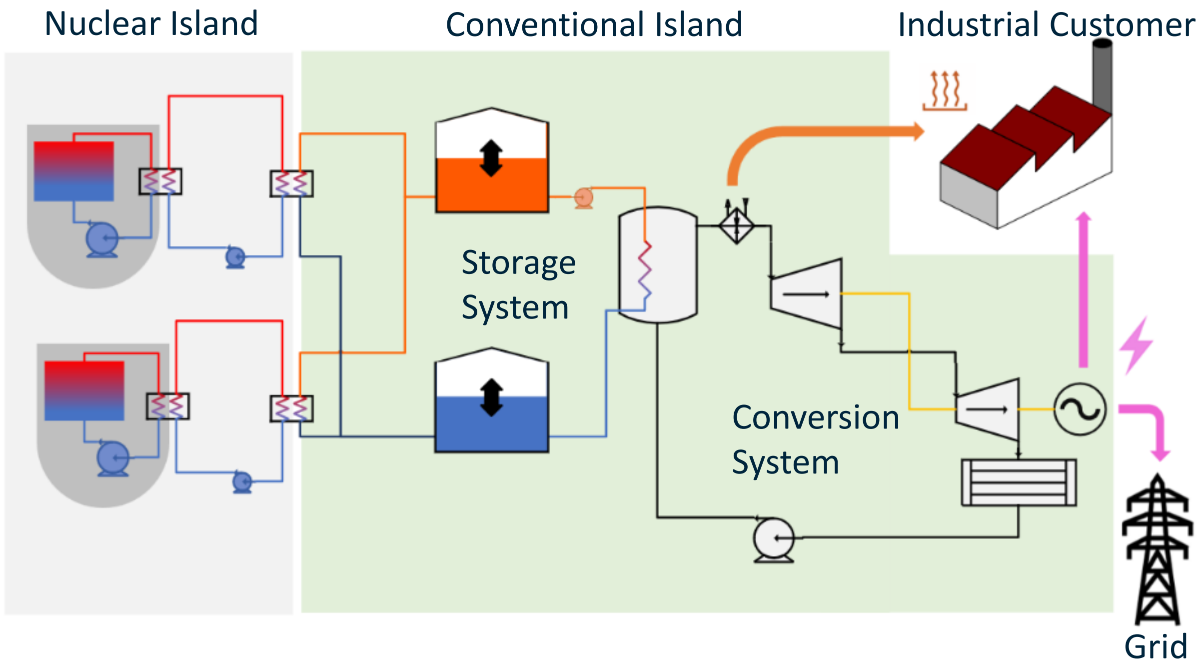
- **Water-based thermal-hydraulic installations**
- **Sodium leak detection and location**
  - **CEA's work on multi-layer insulation + optical fibers**
  - **Interest in pursuing additional tests tailored to HEXANA's design needs (special components such as valves)**



Source: CEA

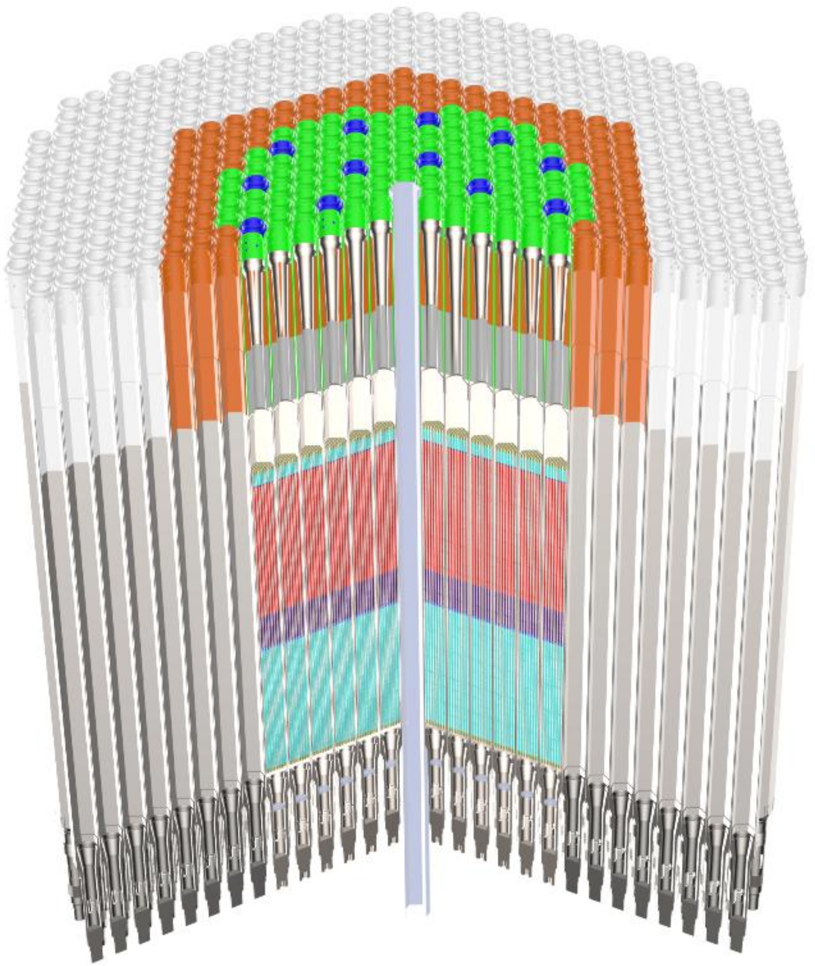
Existing and planned collaborations with CEA (France)

- **Water-based thermal-hydraulic installations**
- **Sodium leak detection and location**
- **Salt-steam loop for thermal storage**
  - **Ongoing collaboration on the CEDALION salt-steam loop**
  - **Qualification of new components (steam generator), new fluid (YARA salt), operations (overall dynamics)**



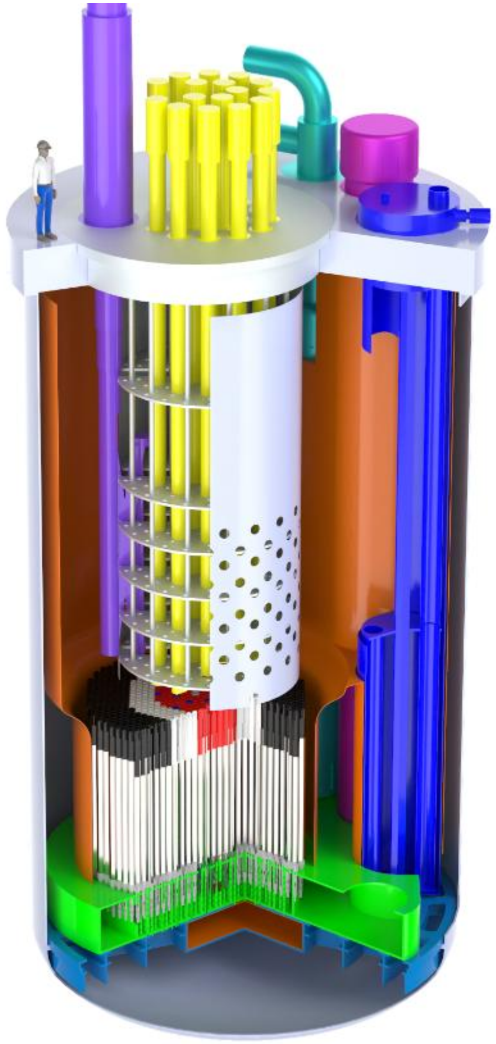
Other R&D needs by subsystem

- **Fuel and other core components**
  - **Supplement existing qualification data for the intended operating range for core materials (B_4C, MgO, borated steel, hafnium for rods and neutron shields)**
  - **Improve irradiation resistance of fuel cladding to extend cycle times**
  - **Mechanical modifications to fuel assemblies to improve CAPEX (non-integrated fissile part, absence of hexagonal tube, etc.)**
  - **Extension of MOX fuel qualification to low linear power and high burn-up**
  - **Study of the automatic drop of shutdown elements into the core upon reaching the melting point of a thermal fuse to improve the diversity and passivity of reactivity control methods**



Other R&D needs by subsystem

- **Fuel and other core components**
- **Reactor**
  - Qualification of a fuel handling system using a pantograph arm in air, then in sodium
  - Qualification of the core fusion mitigation system (retention, cooling, choice of materials)
  - Development and qualification of multifunctional casks for washing, cooling, and transporting core components



Other R&D needs by subsystem

- **Fuel and other core components**
- **Reactor**
- **Reactor pit**
  - Qualification of a new residual heat removal system
  - Qualification of in-service inspection and repair systems

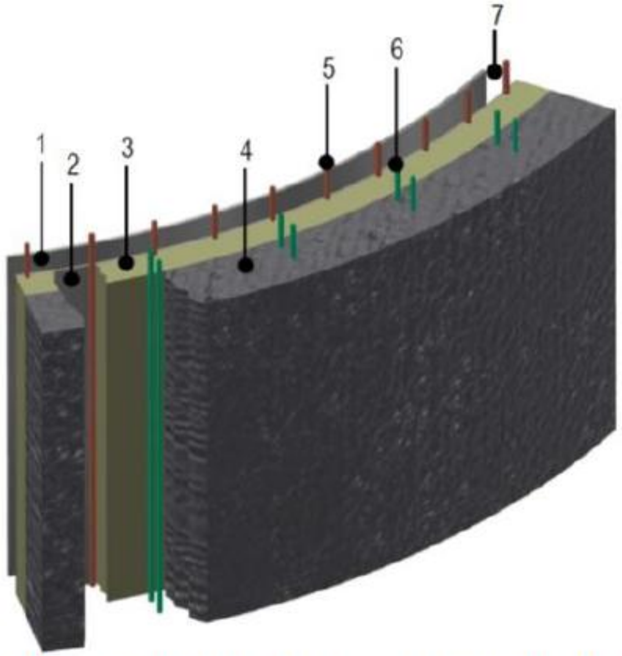


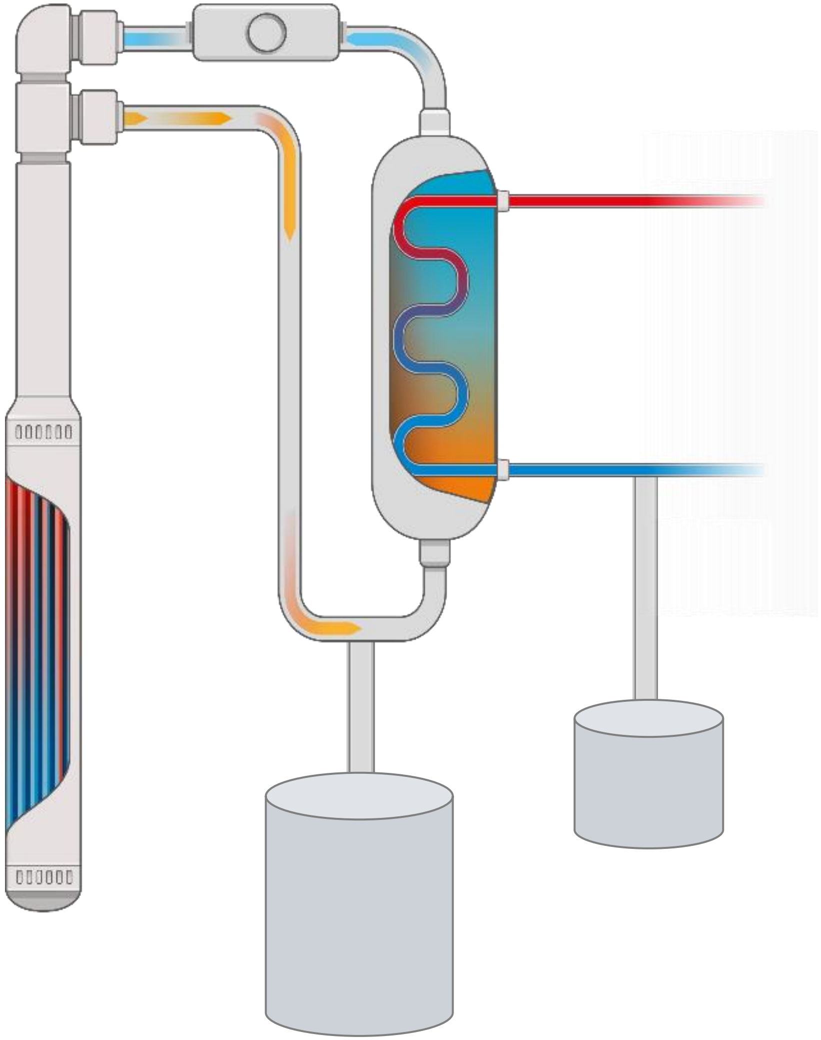
Figure 2: Detail of the reactor pit design

1 – Reactor vessel
2 – Liner
3 – Insulation
4 – Concrete/metal structure
5 – Oil cooling system (DHRS-3.1)
6 – Water cooling system (DHRS-3.2)
7 – Gap

Source: ESFR-Smart

Other R&D needs by subsystem

- **Fuel and other core components**
- **Reactor**
- **Reactor pit**
- **Secondary sodium loop and interfaces**
  - **Qualification of new components (salt/sodium exchanger, expansion bellows, electromagnetic pump, flanges), instrumentation**
  - **Qualification of new processes (unloading, draining, sodium purification, cold traps, blockage indicators)**



Specific needs for qualification of instrumentation

- **Opportunities to continue the work initiated by CEA**
  - **ASTRID project innovations**
    - **Ultrasonic non-destructive testing:** development of piezoelectric and/or electromagnetic multi-element sensors
    - Leak detection: **multi-layer insulation** and/or use of optical fibers
  - **Optical fibers**
    - Adaptation of **coating materials** (or protective sheaths) for use in high-temperature sodium
- **New needs**
  - **Chemistry control**
    - Measurement of cover gas quality by **laser-induced breakdown spectroscopy** for detection of leakage and/or fuel cladding breaks
  - **Detection of fuel cladding breaks**
    - **High count rate gamma spectrometry:** use of the ADONIS gamma spectrometry system, developed by CEA LIST
    - **Detection of delayed neutrons**
  - **Qualification of in-core neutron detectors in a sodium environment**

THANK YOU FOR YOUR ATTENTION