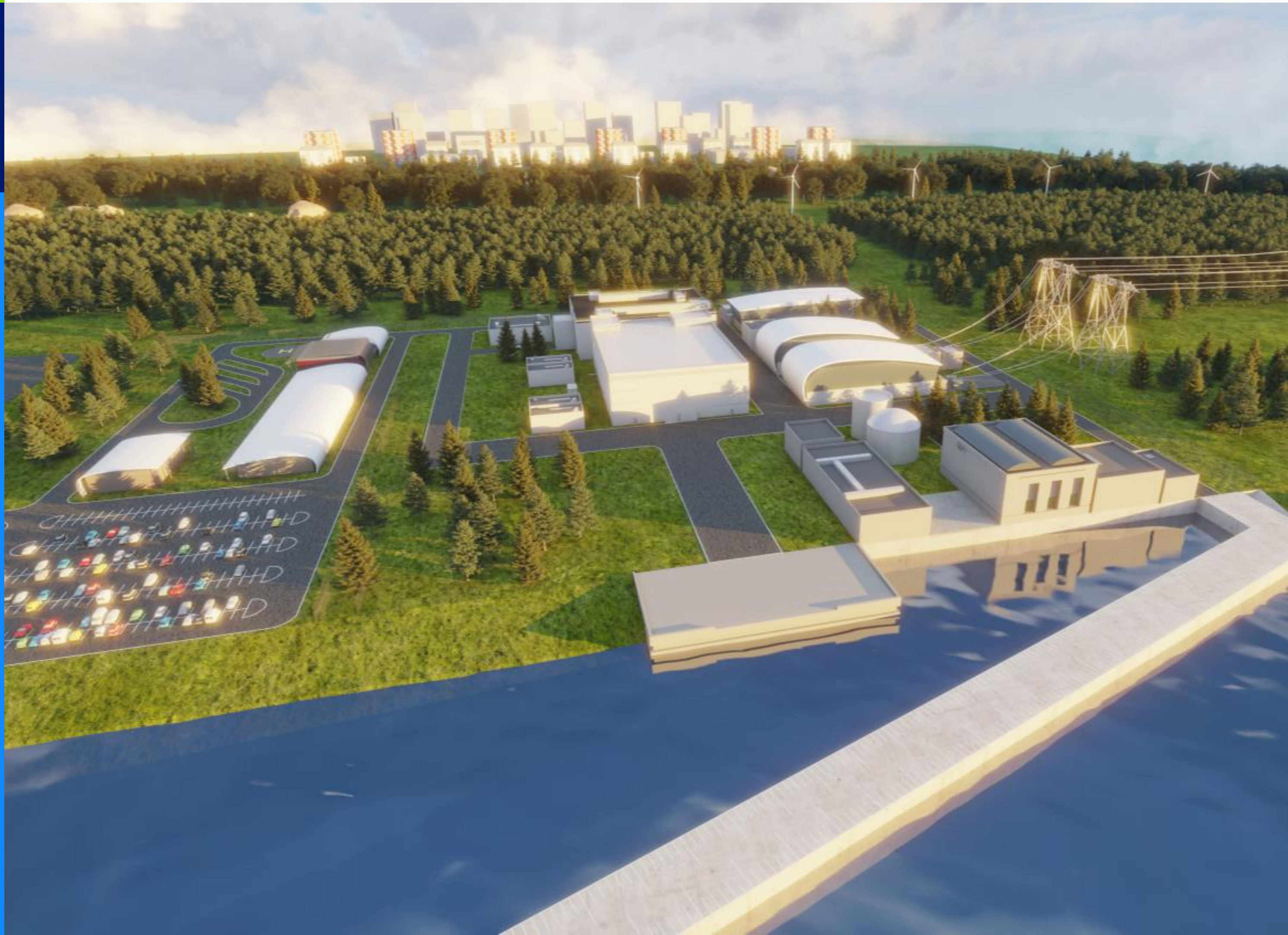
NUWARD™



Eric HANUS

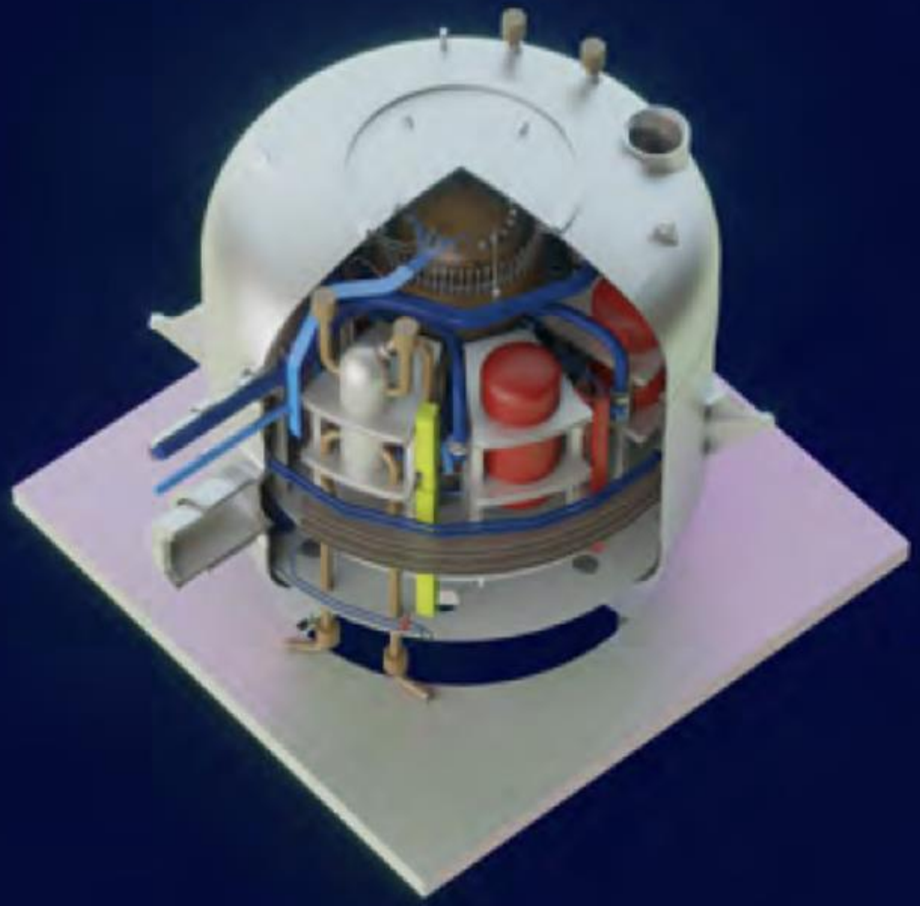
ELSMOR summer school

July 6th, 2022

NUWARD™
Experience Based Technology

Topics

- Target Applications
- Development Roadmap and Design Stages
- European and international approach
- Main Design Features and Key Technical Parameters
- Key Technical Innovations including main Safety Features
- Construction and Modularity

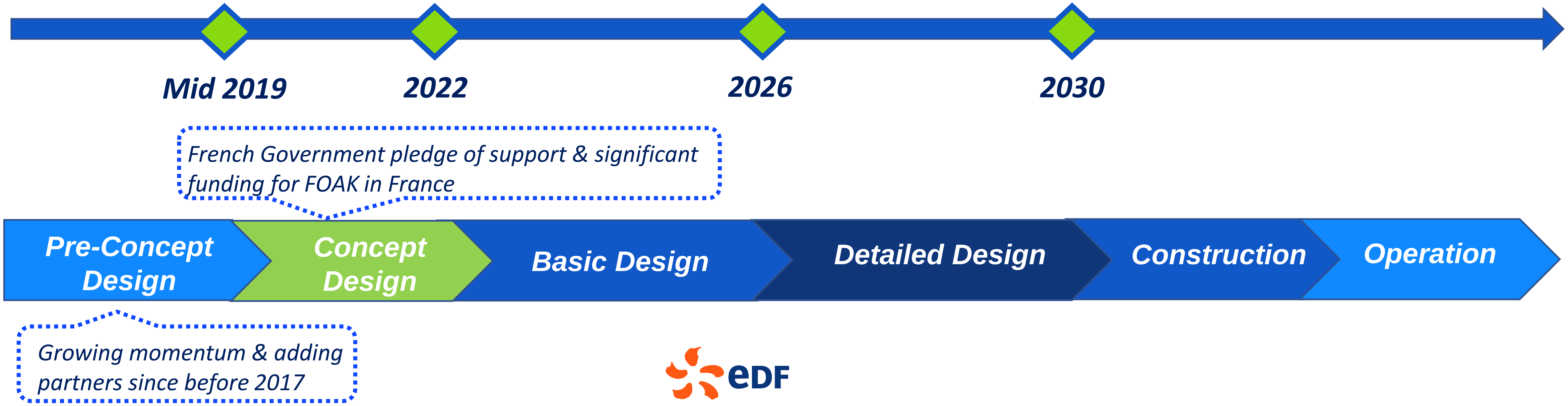


NUWARD™: Designed for a Carbon-free World

- **Three main market segments**:
  - Replacing coal-fired power plants in the 300-400 MWe range,
  - Supplying remote municipalities and energy-intensive industrial sites,
  - Powering grids with limited capacity for large power plants.

- **Multipurpose by design**:
  - Hydrogen production for transport, heat & electricity cogeneration, district heating, water desalination.

NUWARD™ Timeline



NUWARD™ - Experience Based Technology

CEA: Technological research, development and innovation expert in low carbon energies

Naval Group: International experts in Naval Defence and owner of the French naval knowledge base, designer and developer of innovative solutions to meet the needs of Naval fleets and other advanced technology industries

TechnicAtome: Specialised in design, construction, commissioning and operational maintenance of compact nuclear reactors

framatome: International leader on the nuclear worldwide market, designer and supplier of nuclear steam supply systems and nuclear equipment, services and fuel delivering the highest levels of safety and performance

TRACTEBEL ENGIE: Architect engineer and responsible designer for the Belgian nuclear fleet since the 1960's, civil engineering partner of EDF's French operating fleet and international engineering consultancy

NUWARD™: French Government Support

- ***September 2020:* €50m** have been earmarked to NUWARD™ as part of the French Recovery Plan.
- ***December 2020***: French President Macron reiterated the importance of nuclear energy to achieve carbon neutrality and his willingness to **position France as a key player within the SMR** market.
- ***May 2021***: EDF took an important step towards consolidating the design of NUWARD™ with the launch of a **series of technical exchanges with the French Safety Authority ASN and IRSN (technical support organisation)**, with the aim to consolidate the NUWARD™ safety options report, in order to proceed with a full assessment by ASN.
- ***October 2021***: French President Macron announced an investment of **one billion euros** in nuclear energy in the "France 2030" plan, to "develop innovative small-scale nuclear reactors in France by 2030 with better waste management".
- ***February 2022:*** French President Macron announced grating of **€500 million for NUWARD™** as part of the €1 billion call for projects supported by France 2030. This will support the whole design development phase (including innovation, testing and full licensing of the plant) until 2030. The French President also announced that construction of a **reference plant in France will be launched by 2030**.

The unique knowledge and experience of a diverse and robust international industrial team:

NUWARD™ International Outreach

A European core:

- Promoting a **“domestic” European SMR program.**
- Supporting the **European nuclear industry.**
- Initiating cooperation with **EU safety authorities** with the support of the French ASN

A worldwide market ambition:

- Initiating **cooperation with customers** (countries/industry/utilities) willing to develop SMR projects.
- Accelerating the **development and commercialisation** of the product notably through the International NUWARD™ Advisory Board (**INAB)**

International Cooperation:

- **Fostering regulatory harmonisation** for licensing and design standardisation.
- **Promoting policies** to support creation and development of an SMR sustainable market.

International NUWARD™ Advisory Board (INAB)

Bringing together experts and highly experienced senior representatives from leading industry and research organisations, to provide valuable insights and inputs to the NUWARD™ development.

Government of India
Department of Atomic Energy
Bhabha Atomic Research Centre

ONTARIO POWER GENERATION

UJV Group
TECHNOLOGY I INNOVATION I PEOPLE

fortum

TVO

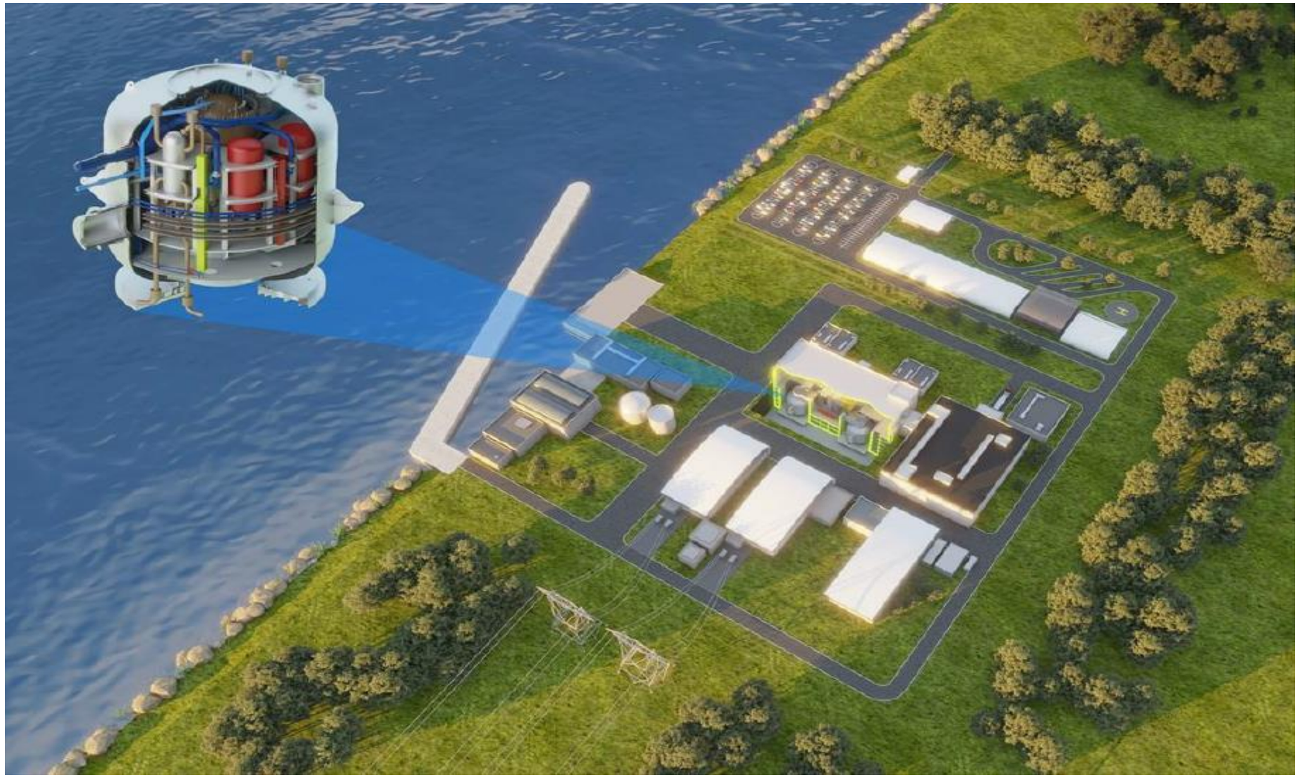
cea

POLITECNICO MILANO 1863

NUWARD™ Helping create the conditions for SMR international licensing

- Fostering transnational communication on safety and licensing
- Encouraging collaboration on international licensing conditions
- Early insights on design and safety options for EU market
- Joint early review of design

NUWARD™ Technology



A nominal power of **340 MWe** from 2 integrated reactors of 170 MWe each

>90% availability; compatible with ENTSO-E network requirements; **60 years** of operation

Safety objectives that meet the best international standards

Modular approach and **simple competitive design** targeting **40-month** construction duration

Improved **landscape** integration

Multipurpose by design (H2, district heating, desalination, heat & electricity cogeneration, CO2 capture)

Designed for export, allowing adaptation to multiple markets without significant re-design

First Nuclear Concrete in France in 2030 and construction internationally thereafter

NUWARD™ Technology
General Objectives

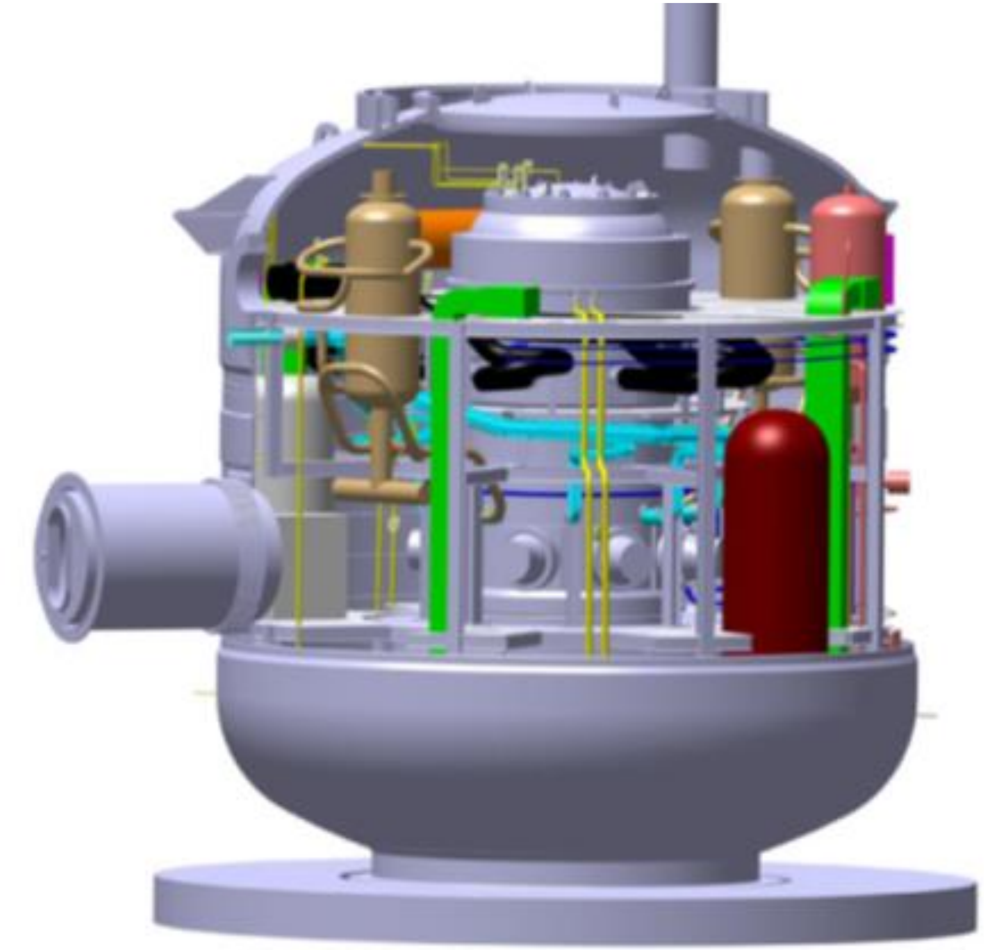
A PWR model based on the wide experience acquirec the fields of medium and high power.

Incorporates technological innovations for a simple a safe design:

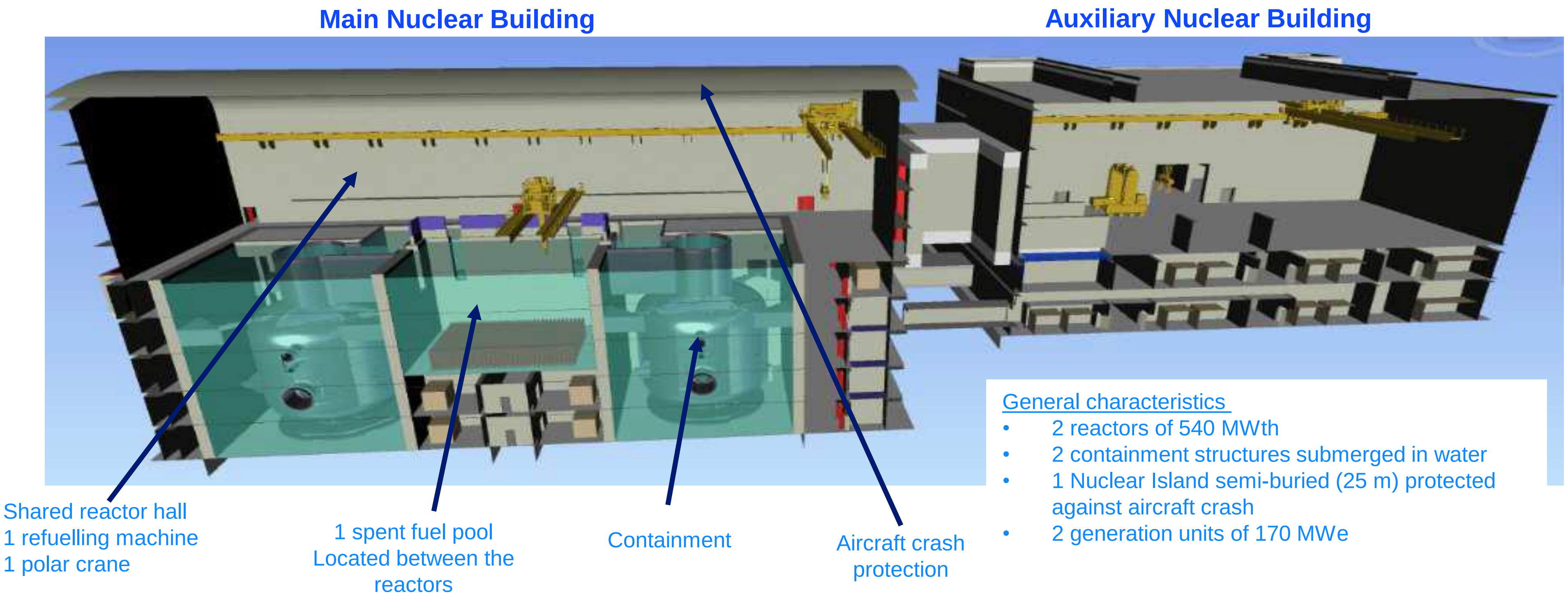
– Integrated Reactor Pressure Vessel (RPV);
– Wide deployment of passive systems;
– Boron free operation.

Corresponds to the highest safety standards in the world:

– Meeting post-Fukushima requirements;
– Passive removal of residual heat with a high level of autonomy;
– Severe accidents taken into account with ambitious radiological objectives.



NUWARD™ Technology - Overview of Key Design Features



General characteristics

- 2 reactors of 540 MWth
- 2 containment structures submerged in water
- 1 Nuclear Island semi-buried (25 m) protected against aircraft crash
- 2 generation units of 170 MWe

Reactor Type: Integral Pressurised Water Reactor (PWR)

Coolant/ moderator: Light Water

Thermal / electrical capacity: 2x540 MWth / 2x170 MWe

Primary circuit operating pressure: 15 MPa

Secondary circuit operating pressure: 4.5 MPa

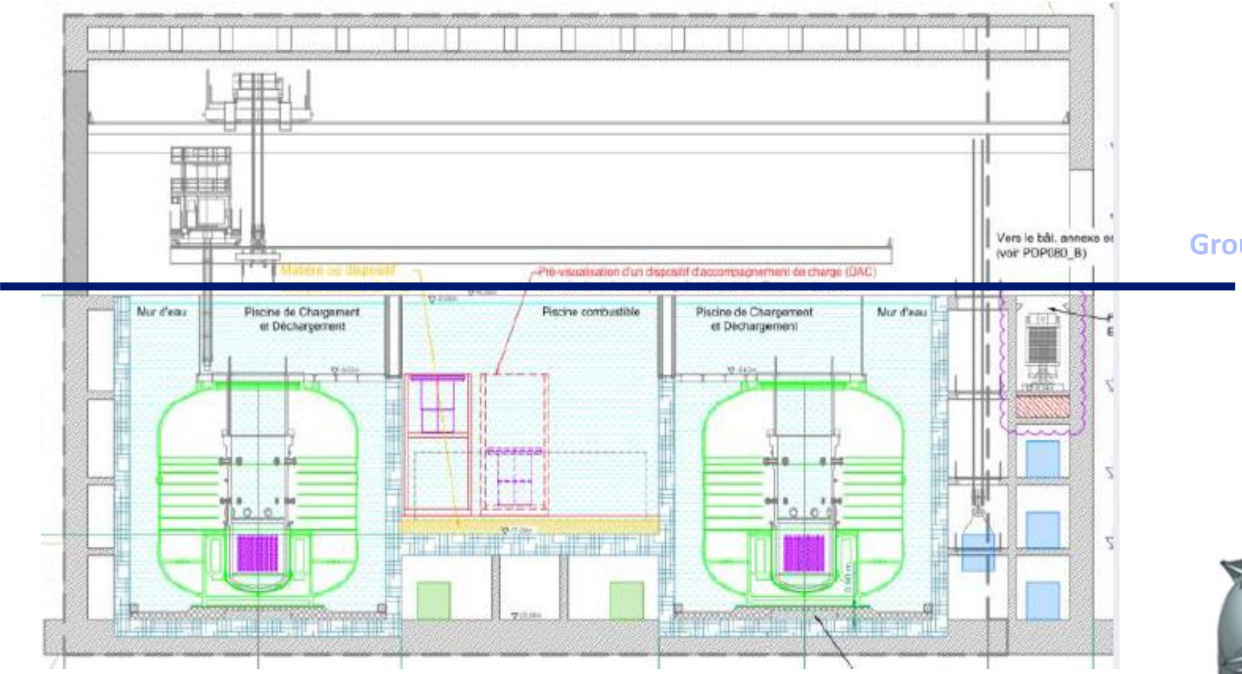
Fuel type: Uranium Dioxide (UO_2) enrichment less than 5%

Assembly array: 17 by 17 square pitch, 76 fuel assemblies in the core

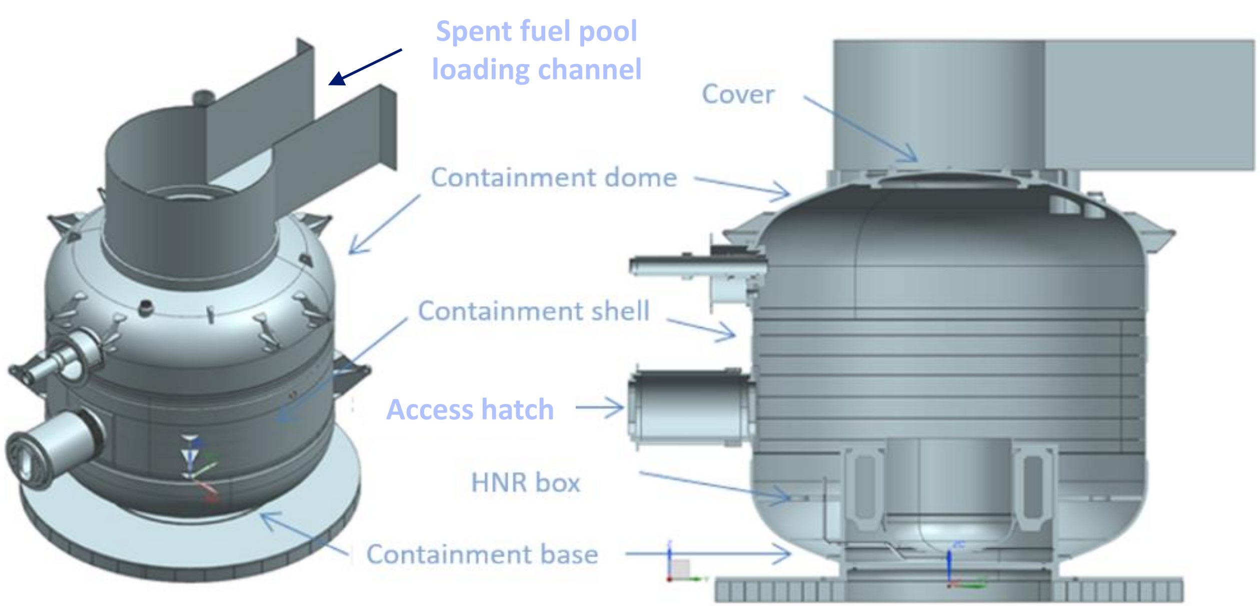
Refuel cycle: 24 months

Reactivity control: Control Rod Drive Mechanism (CRDM) integrated in RPV

NUWARD^{TM} Technology
Summary of Key Technical Innovations



Submerged steel containment structure



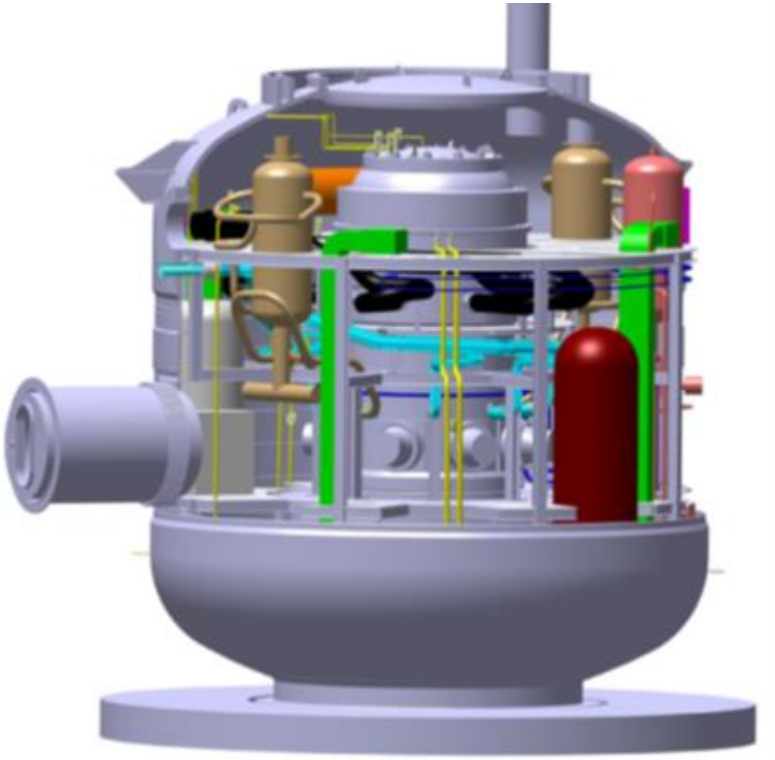
Containment: approximately ø15m x h17.5 m

Pool: approximately 20m x 20m x 20m

NUWARD™ Technology Overview

An integrated reactor...

...incorporated into a metal containment submerged in a water pool



Design life: 60 years

Reactor Pressure Vessel (RPV) height: 15m (approx.)

RPV diameter: 5m

Seismic design withstand: up to 0.3g with margin

NUWARD™ Technology
Summary of Key Technical Innovations

Integrated RPV

- one sole component incorporating the Compact plate Steam Generators (CSGs) and CRDM.
- a simpler and easier to assemble reactor design with:
  - integration of all primary components within the RPV
  - one primary component (the reactor vessel) under pressure, no primary loops and fewer welds.
- for NOAK shorter construction period and quicker delivery.

Compact plate steam generators (CSGs)

- in direct connection to the reactor thus without the need of external primary loops.
- highly efficient with high thermal power/ volume ratio.

Control Rod Drive Mechanism (CRDM)

- elimination of rod cluster ejection risk.
- vessel head can be manufactured without a penetration.

Passive safety cooling system (residual heat removal RRP)

- autonomous system with extended grace period and high reliability targeted.
- simplification of support system architecture and operation.

Core located immersed in fresh water

- reduction of effluent releases, simplified reactivity control, elimination of the risk of dilution accidents.
- boron free reactivity control.

Submerged steel containment structure

- as 3rd containment barrier, passive cooling via the water pool.

Nuclear Island building located below ground (semi-buried)

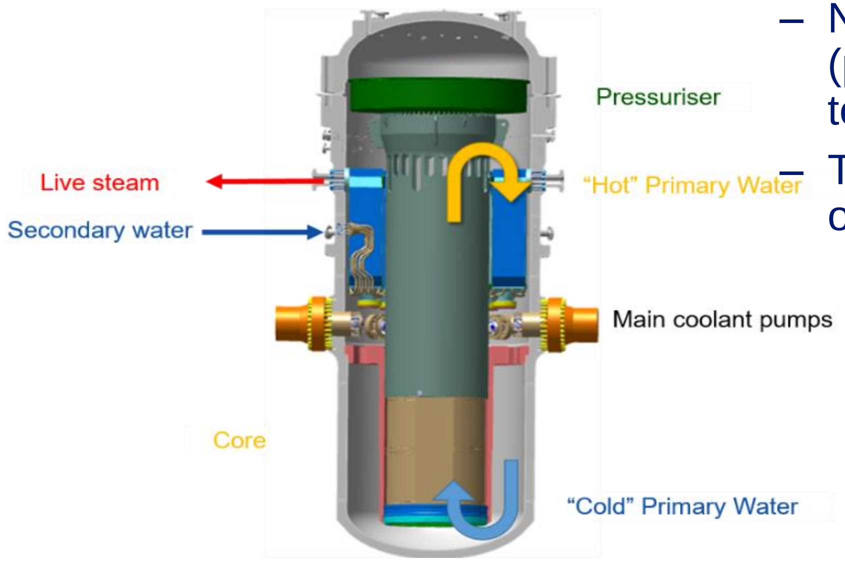
- protection against external hazards and certain malicious acts.
- increased ease of construction, assembly of large equipment by sliding across on rails therefore not requiring large crane lifts.

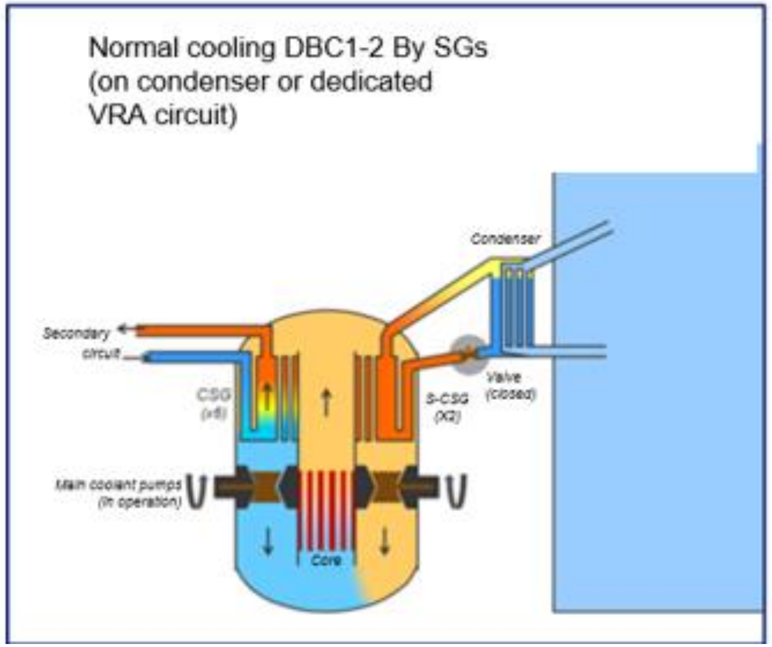
NUWARD^{TM} Technology
Summary of Key Technical Innovations

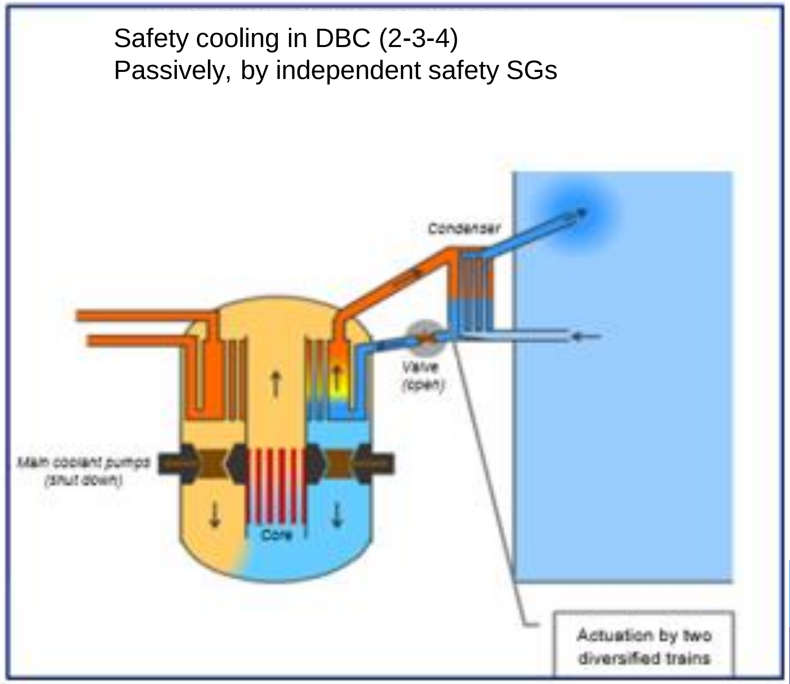
Passive safety cooling system (residual heat removal RRP)

Emergency cooling (RRP):

- 2 independent trains
- Natural circulation in the primary (passive leg by S-CSG), secondary and tertiary
- Thermal hydraulic tests and studies are ongoing







Passive Reactor Cooling or RRP System

NUWARD™ Technology
Summary of Key Technical Innovations

- **Active management of normal operation**

- **Passive management of most DBC2-3-4 situations**
  - Control rods drop
  - Use of passive cooling (RRP system, 2 independent trains)

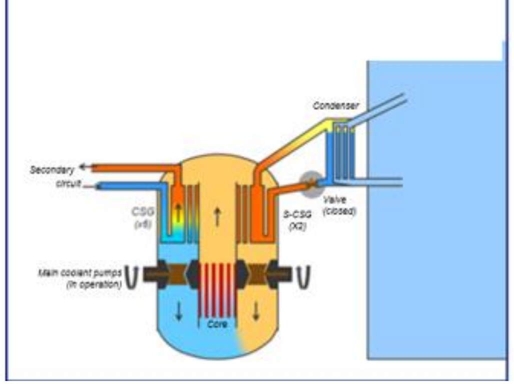
- **Active, diversified management of DEC-A situations**
  - Anticipated Transient Without Scram: Boron injection by a dedicated system
  - Loss of normal cooling + RRP: Deliberate depressurisation and water make-up

---

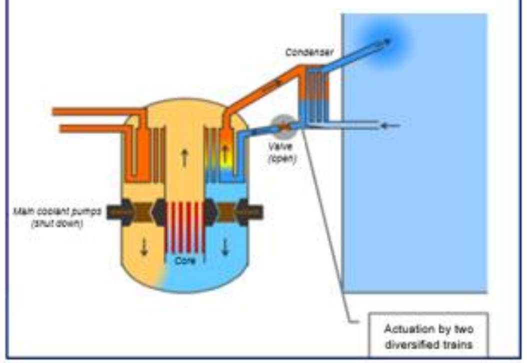
- **Management of DEC-B situations with corium In-Vessel Retention**

Passive Reactor Cooling (RRP System)

Normal cooling by SGs



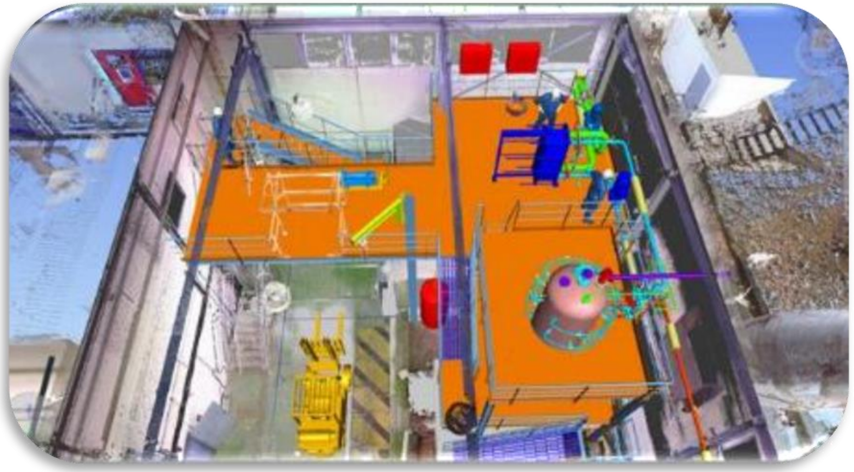
Safety cooling in DBC (2-3-4)
Passively, by independent safety SGs



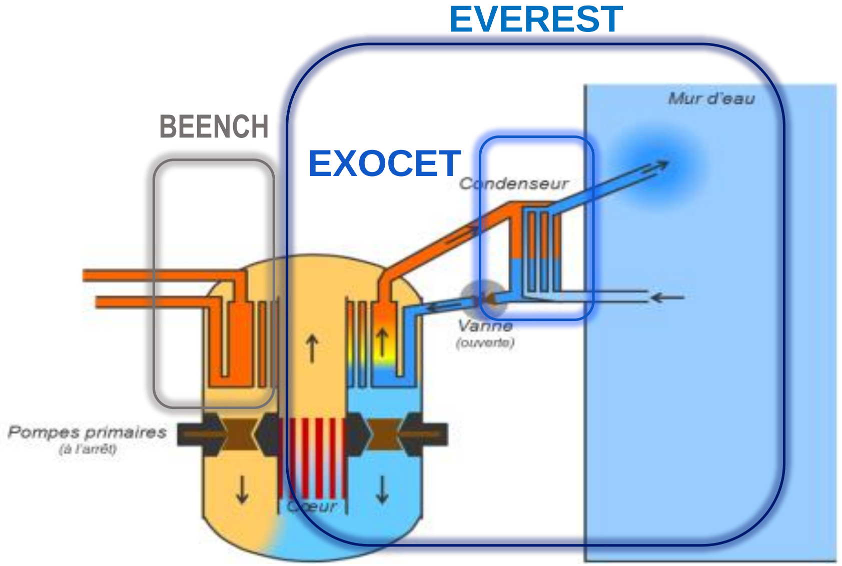
NUWARD™ Design Readiness Studies

Ongoing test program for passive safety cooling system (RRP)

EXOCET

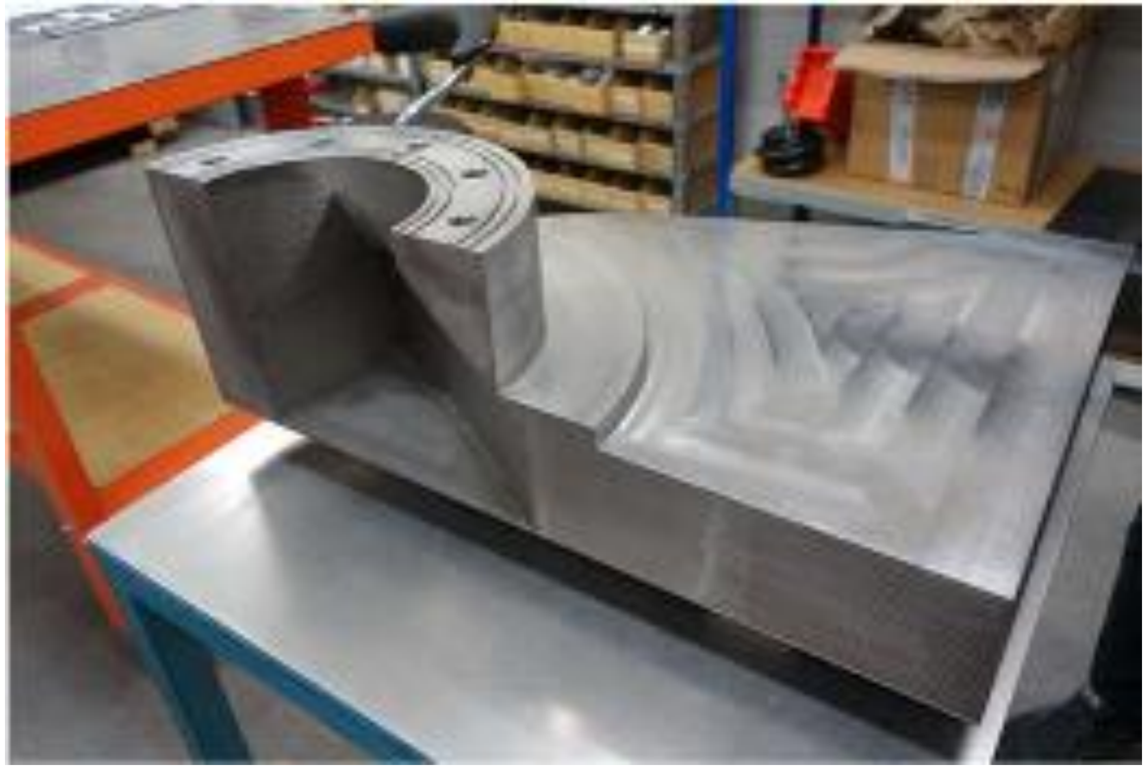


EVEREST



NUWARD™ Key Technical Innovations Development

CSGs and S-CSG



Compact Steam Generator mock-ups to setup the manufacturing process

CSG steam generator performance experimental validation
Temperature & pressure thermohydraulical testing (2019)

NUWARD™ Key Technical Innovations Development

Control Rod Drive Mechanism (CRDM)

CRDM in-vessel motor technologies

In-vessel wiring and vessel penetration

NUWARD™ Construction and Modularity

Modularity to ease all areas of the life cycle of the NPP

- A modular design for easier construction
- A modular design for easier operation and maintenance
- A modular design for easier deconstruction (decommissioning)

That means before Operation :

- Modules must be as far as practicable manufactured and tested in the factory
- Module transportation is, as far as possible, in containers by standard means
- Site assembly facilitated with expected gains in quality and in the implementation schedule
- Model developed from an international perspective: consistency sought in frames of reference and design choices
- Search for standardisation of equipment to benefit from economies of scale

That means during Operation and Maintenance

- Model easily integrated into the electrical grid, with good availability and flexible, “agile” production
- “Plug and play” modules for maintenance
- Capability to add functionality such as cogeneration for hydrogen

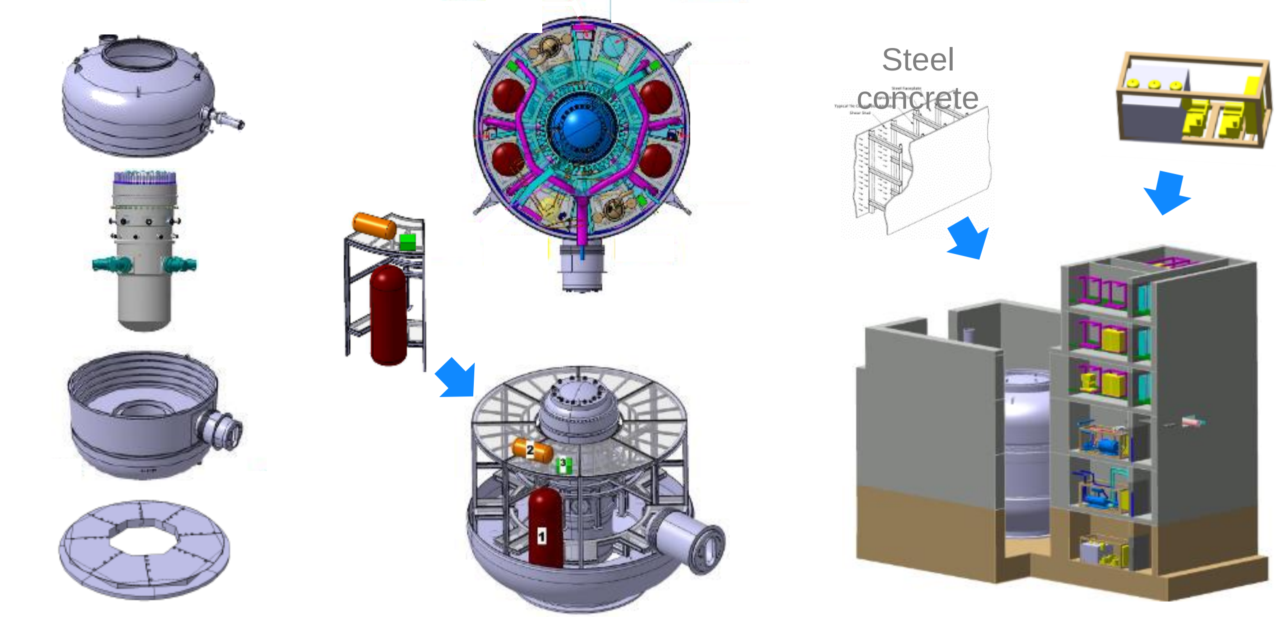
That means for dismantling

- As far as possible the irradiated modules are easy to “unplug” and remove

Modularity to reduce the overall cost of the project: schedule, in factory manufacturing, financial risk management

NUWARD™ Construction and Modularity

Principles of modularity



Not only the in the NSSS

- The objective is to have >80% of the Nuclear Power Plant modularised

With a limited number of modules

- Maximise the size of the modules with respect to transportation capability
- One module cannot be just a single component
- One module represents one unitary function
- It allows in factory testing of functionality
- It increases quality

With a limited number of modules requiring "Non-standard" transport

Containment and reactor vessel

Non-standard transport (abnormal load)

8 containment modules Factory tested

Specialised transport

BNI, CI and BOP modules Factory tested

Standard 20' transport skids

Merci