Status Report - NUWARD™ (France)

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1. Overview

- ☐ **In Operation**
- ☐ **Under Construction**
- ☐ **Described in**

Link to PRIS	--

- ☑ **New Concept**

Number of Units	--
Year	--

Reference Plant

Name of Site	--
Link to PRIS	--
Net Power Output (MWe)	170
Gross Power Output (MWe)	185

1.1 Introduction

NUWARD™ is an integrated PWR design to generate 340 MWe from two independent reactor units, offering flexible operation. The design incorporates the main components of the Nuclear Steam Supply System (NSSS) including Control Rod Drive Mechanism (CRDM), Compact plate Steam Generators (CSGs) and pressuriser, all contained within the Reactor Pressure Vessel (RPV). The RPV is then installed within a further layer of steel containment and this structure is immersed in a pool filled with water (the reactor pool). The NUWARD™ design includes the capability to cope with Design Basis Conditions (DBC) using passive systems without the need for any external electrical power supply. The reactor is self-reliant, connected to an internal ultimate heat sink (the reactor pool) which offers a coping time of more than 3 days without the need for intervention.

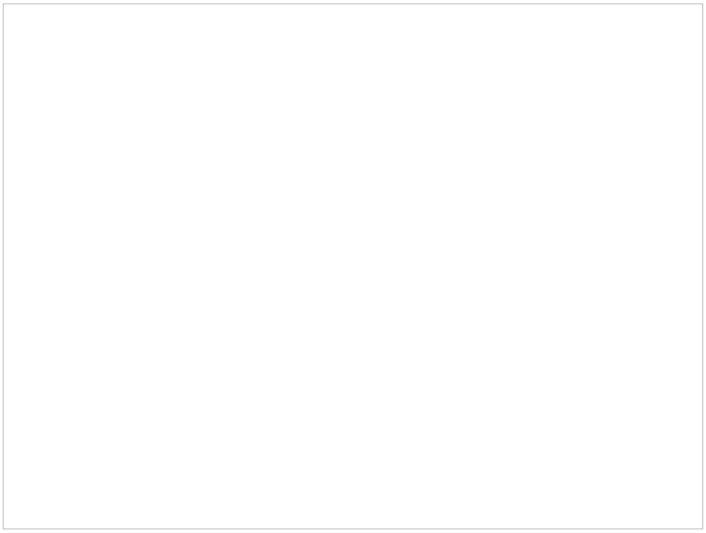


Figure 1. NUWARD™ schematic

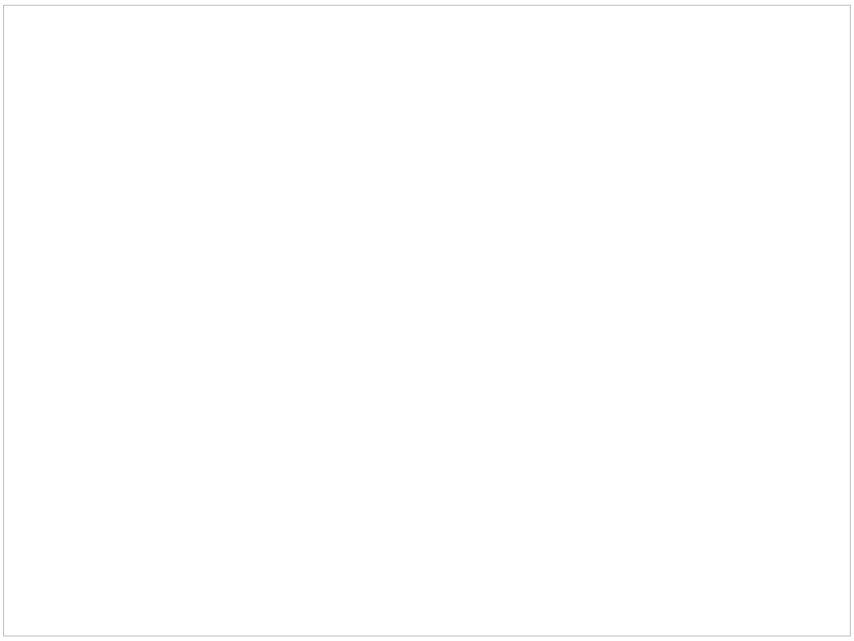


Figure 2. Cut view of NUWARD™

The NUWARD™ technology is being developed to replace fossil-fired power plants in the 300-400 MWe range; to supply power to remote municipalities and energy-intensive industrial sites; and to power grids with limited capacity. By design, it is a multipurpose SMR that can be used for cogeneration of heat and electricity, hydrogen production, district heating, and water desalination. The design offers baseload and load-following capability to enable integration with renewable energy sources.

1.2 Development Milestones

2016	Preliminary studies and technological innovation (using previously developed patents).

2019	Pre-conceptual design phase and technology validation
2022	Conceptual Design Phase (and preparation for pre-licensing)
2023-2026	Basic Design Phase
06.2024	EDF Group has decided to shift its SMR product strategy towards the development of a design based on proven technology bricks only.

1.3 Design organization or vendor company

1.4 Links to designer/vendor website

1.5 Design Description

NUWARD™ design is based on the proven PWR-technology that incorporates significant experience acquired in the fields of medium and high-power generation, alongside several key technological innovations, to achieve the following design objectives:

1. Acceptability: robustness of the design will maximise safety and minimise environmental impact;
2. Simplicity: simple architecture, enhanced manufacturability; and
3. Schedule optimisation and constructability.

1.6 Licensing Application Support Documents

1.7 Reactor Unit in PRIS

2. Category Fields

Table 1: ARIS Category Fields

ARIS Category	Value	Units of Examples
Current/Intended Purpose	Commercial – Electric/Non-Electric	e.g. Commercial – Electric/Non-electric, Prototype/FOAK, Demonstration, Experimental
Main Intended Application (once commercial)	Baseload, Non-electric (Cogeneration of heat and electricity, hydrogen production, district heating, water desalination)	e.g. Baseload, Dispatchable, Off-grid/Remote, Mobile/Propulsion, Non-electric (specify)
Reference Location	Inland	e.g. On Coast, Inland, Below-Ground, Floating-Fixed, Marine-Mobile, Submerged-Fixed (Other-specify)

Reference Site Design (reactor units per site)	Multiple Units (3 units)	e.g. Single Unit, Dual Unit, Multiple Unit (# units)
Core Coolant	H2O	H2O, D2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Reactor Core Size (1 core)	30 MWth <= Thermal power < 1000 MWth	e.g. Thermal Power < 30 MWth, 30 MWth ≤ Thermal power < 1000 MWth, 1000 MWth ≤ Thermal power ≤ 3000 MWth, Thermal power > 3000 MWth
Reactor Type	PWR	e.g. PWR, BWR, HWR, SCWR, GCR, GFR, SFR, LFR, MSR, ADS
Reactor Size	SMR	e.g. PWR, SMR
Neutron Moderator	H2O	e.g. H2O, D2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
NSSS Layout	Integral	e.g. Loop-type (# loops), Direct-cycle, Semi-integral, Integral, Pool-type
Primary Circulation	Forced	e.g. Forced (# pumps), Natural
Thermodynamic Cycle	Rankine	e.g. Rankine, Brayton, Combined-Cycle (direct/indirect)
Secondary Side Fluid	H2O	e.g. H2O, He, CO2, Na, Pb, PbBi, Molten Salts, (Other-specify)
Fuel Form	Fuel Assembly/Bundle	e.g. Fuel Assembly/Bundle, Coated Sphere, Plate, Prismatic, Contained Liquid, Liquid Fuel/Coolant
Fuel Lattice Shape	Square	e.g. Square, Hexagonal, Triangular, Cylindrical, Spherical, Other, n/a
Rods/Pins per Fuel Assembly/Bundle	17x17	e.g. #, n/a
Fuel Material Type	Oxide	e.g. Oxide, Nitride, Carbide, Metal, Molten Salt, (Other-specify)
Design Status	Conceptual Design	e.g. Conceptual, Detailed, Final (with secure suppliers)

Licensing Status		e.g. DCR, GDR, PSAR, FSAR, Design Licensed (in Country), Under Construction (# units), In Operation (# units)
Neutron Spectrum	Thermal	e.g. Fast, Thermal

3. Parameter Fields

Table 2: ARIS Parameter Fields

ARIS Parameter	Value	Units of Examples
Plant Infrastructure		
Design Life	60	Years
Lifetime Capacity Factor		%, defined as Lifetime MWe-yrs delivered / (MWe capacity * Design Life), incl. outages
Major Planned Outages		# days every # months (specify purpose, including refuelling)
Operation / Maintenance Human Resources		# Staff in Operation / Maintenance Crew during Normal Operation
Reference Site Design		n Units/Modules
Capacity to Electric Grid	170	MWe (net to grid)
Non-electric Capacity		e.g. MW(th) heat at x °C, m3/day desalinated water, kg/day hydrogen, etc.
In-House Plant Consumption		MWe
Plant Footprint	3500, nuclear island including fuel storage building	m2 (rectangular building envelope)
Site Footprint		m2 (fenced area)
Emergency Planning Zone		km (radius)
Releases during Normal Operation		TBq/yr (Noble Gases / Tritium Gas / Liquids)
Load Following Range and Speed		x – 100%, % per minute
Seismic Design (SSE)	0.3	g (Safe-Shutdown Earthquake)

NSSS Operating Pressure (primary side)	15	MPa(abs), i.e. MPa(g)+0.1, at core outlet
NSSS Operating Pressure (secondary side)	4.5	MPa(abs), i.e. MPa(g)+0.1, at secondary side outlet
Primary Coolant Inventory (incl. pressurizer)		kg
Nominal Coolant Flow Rate (primary)		kg/s
Nominal Coolant Flow Rate (secondary)		kg/s
Core Inlet Coolant Temperature	280	ºC
Core Outlet Coolant Temperature	307	ºC
Available Tempeature as Process Heat Source		ºC
NSSS Largest Component	RPV	e.g. RPV (empty), SG, Core Module (empty/fuelled), etc.
- NSSS Largest Component Length	15000	mm
- NSSS Largest Component Diameter	5000	mm
- NSSS Largest Component Thickness		mm
- NSSS Largest Component Weight	310	tonne
Reactor Vessel Material		e.g. SS304, SS316, SA508, 800H, Hastelloy N
Steam Generator Design		e.g. Vertical/Horizontal, U-Tube/ Straight/Helical, cross/counter flow
Secondary Coolant Inventory		kg
Pressurizer Design		e.g. separate vessel, integral, steam or gas pressurised, etc.
Pressurizer Volume		m3 / m3 (total / liquid)
Containment Type		Dry (single/double), Dry/Wet Well, Inerted, etc.
Containment Volume		m3

Spent Fuel Pool Capacity and Total Volume		Years of full-power operation / m3
Non Electric Application		-
Core Delta Temperature	27	ºC
Fuel/Core		
Single Core Thermal Power	540	MW(th)
Refuelling Cycle	24	months or “continuous”
Fuel Material	UO2	e.g. UO2, MOX, UF4, UCO
Enrichment (avg./max.)	<5	%
Average Neutron Energy		eV
Fuel Cladding Material		e.g. Zr-4, SS, TRISO, E-110, none
Number of Fuel “Units”		Specify as Assembly, Bundle, Plate, Sphere, or n/a
Weight of one Fuel Unit		kg
Total Fissile Loading (initial)		kg fissile material (specify isotopic and chemical composition)
% of fuel outside core during normal operation		Applicable to online refuelling and molten salt reactors
Fraction of fresh-fuel fissile material used up at discharge		%
Core Discharge Burnup		MWd/kgHM (heavy metal, eg U, Pu, Th)
Pin Burnup (max.)		MWd/kgHM
Breeding/Conversion Ratio		Fraction of fissile material bred in-situ over one fuel cycle or at equilibrium core
Reprocessing		e.g. None, Batch, Continuous (FP polishing/actinide removal), etc.
Main Reactivity Control	Control rods and solid burnable poisons	e.g. Rods, Boron Solution, Fuel Load, Temperature, Flow Rate, Reflectors
Solid Burnable Absorber		e.g. Gd2O3
Core Volume (active)		m3 (used to calculate power density)

Fast Neutron Flux at Core Pressure Boundary		n/(cm²*s)
Max. Fast Neutron Flux		n/(cm²*s)
Core Control Rod Absorber		-
Core Soluble Neutron Absorber		-
Safety Systems		
Number of Safety Trains	Active / Passive	% capacity of each train to fulfil safety function
- reactor shutdown	Passive	- / - / -
- core injection	Passive	- / - / -
- decay heat removal	Passive	- /- / -
- containment isolation and cooling	N/A	- / - / -
- emergency AC supply (e.g. diesels)	N/A	- / - / -
DC Power Capacity (e.g. batteries)		Hours
Events in which Immediate Operator Action is required		e.g. any internal/external initiating events, none
Limiting (shortest) Subsequent Operator Action Time		Hours (that are assumed when following EOPs)
Severe Accident Core Provisions		e.g. no core melt, IVMR, Core Catcher, Core Dump Tank, MCCI
Core Damage Frequency (CDF)		x/reactor-year (based on reference site and location)
Severe Accident Containment Provisions		e.g., H2 ignitors, PARs, filtered venting etc.
Large Release Frequency (LRF)		x/reactor-year (based on reference site and location)
Overall Build Project Costs Estimate or Range (excluding Licensing, based on the Reference Design Site and Location)		
Construction Time (nth of a kind)		Months from first concrete to criticality
Design, Project Mgmt. and Procurement Effort		Person-years (PY) [DP&P]

Construction and Commissioning Effort		PY [C&C]
Material and Equipment Overnight Capital Cost		Million US$(2015) [M&E], if built in USA
Cost Breakdown	%[C&C]/%[M&E]	
- Site Development before first concrete		(e.g. 25/10) (30/40) (20/25) (20/10) (5/15) (----------) (to add up to 100/100)
- Nuclear Island (NSSS)		
- Conventional Island (Turbine and Cooling)		
- Balance of Plant (BOP)		
- Commissioning and First Fuel Loading		
Factory / On-Site split in [C&C] effort		%/% of total [C&C] effort in PY (e.g., 60/40)
Nuclear System		
System Steam Flow Rate		kg/s
System Steam Pressure		MPa
System Steam Temperature		ºC
System Feedwater Flow Rate		kg/s
System Feedwater Temperature		ºC
Reactor Core		
Active Core Height		m
Equivalent Core Diameter		m
Average Linear Heat Rate		kW/m
Average Fuel Power Density		kW/kgU
Average Core Power Density		MW/m3
Outer Diameter Of Fuel Rods		mm

4. Plant Layout, Site Environment and Grid Integration

SUMMARY FOR BOOKLET

The Nuclear Island (NI) building is located below ground (semi-buried) for protection against external hazards and certain malicious acts; and increased ease of construction. The NI houses the 2 independent units and shared fuel storage pool. NUWARD™ plants are suitable for sea/lake-onshore and/or river-side sites, with open-loop conventional condenser cooling, as well as inland sites with aero condensers. The basic grid interface will be compliant with ENTSO-E and EUR requirements (typically 225kV/400kV and 50Hz).

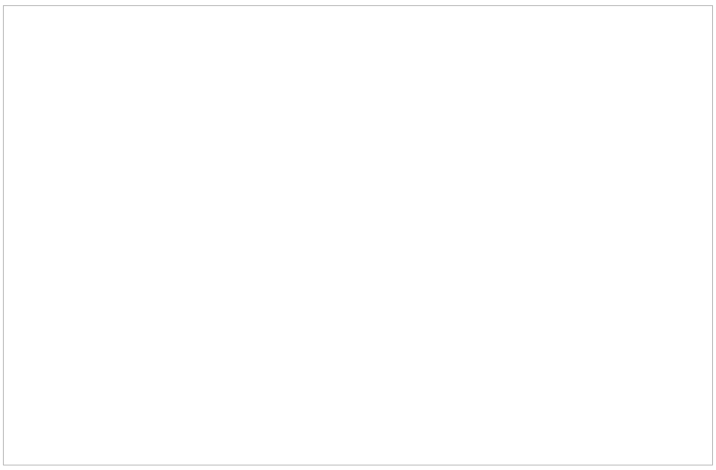


Figure 3. NUWARD expample plant layout

4.1 Site Requirements during Construction
4.2 Site Considerations during Operation
4.3 Grid Integration

5. Technical NSSS/Power Conversion System Designn

SUMMARY FOR BOOKLET

Nuclear Steam Supply System

The NUWARD™ reactor is a fully integrated PWR reactor, housing a single unique vessel containing all the main reactor coolant system components, including the CSGs, the pressuriser and the CRDM.

Reactor Core

The reference core is based on proven 17x17 (76) fuel assemblies used in the operating PWR fleet with a shortened height and UO2 rods (enrichment < 5wt% 235U). Due to the boron-free design, various 235U enrichments and burnable poisons are used. The refuelling interval is 24 months for half the core.

Reactivity Control

The reactivity is controlled by means of control rods and solid burnable poison. The reactor boron-free

reactivity control allows for simplification of auxiliary systems design and operation in both normal conditions and DBCs, as well as a drastic reduction in effluents produced from operation.

Reactor Pressure Vessel and Internals

The RPV and equipment layout are designed to facilitate enhanced in-factory manufacturing. A specific design effort has been made to reduce the number of pipes connected to the RPV with the objective to limit the maximum Loss Of Coolant Accident (LOCA) size to a 30 mm diameter break.

Reactor Coolant System and Steam Generator

The NUWARD™ reactor coolant system adopts an innovative steam generator technology using the plate heat exchanger concept. The CSGs are in direct connection to the reactor thus eliminate the need of external primary loops. This makes the design highly efficient with a high thermal power per volume ratio. The overall size of the reactor coolant system is therefore significantly reduced given the reactor thermal power.

Pressuriser

The NUWARD™ pressuriser is integrated within the RPV head. The large volume of the pressuriser provides margins for the operational transients as well as for normal operation of the reactor.

Primary pumps

Six (6) canned-rotor pumps are horizontally mounted onto the RPV, positioned under the CSGs in the cold leg for efficient hydraulic conditions.



Figure 4. Reactor's cross section view

Instrumentation and Control Systems

The Instrumentation and Control (I&C) system designed for NUWARDTM is based on the defence in depth concept, compliance with the single failure criterion and diversity.

5.1 Primary Circuit
5.2 Reactor Core and Fuel
5.3 Fuel Handling

5.4 Reactor Protection
5.5 Secondary Side
5.6 Containment/Confinement
5.7 Electrical, I&C and Human Interface
5.8 Unique Technical Design Features (if any)

6. Technology Readiness

SUMMARY FOR BOOKLET

Testing Conducted for Design Verification and Validation

Various tests and studies are in progress to validate aspects of the design and its function, particularly around the residual heat removal passive system. Design feedback and evolution as a result of the outcomes from these studies and all other aspects of design and verification will follow. Certain aspects of the design are drawn from operational experience and design experience related to existing medium and high power PWRs.

Design and Licensing Status

NUWARD™ is close to completing its conceptual design phase at the time of writing and is preparing for pre-licensing. A safety options file (Dossier d'Options de Sûreté or DOS) will be completed by the end of the conceptual design to be formally reviewed by the French safety authority (ASN). Following EDF's initiative, NUWARD™ is the case study for an on-going Joint Early Review, led by ASN with the participation of STUK and SUJB, respectively the Finnish and the Czech safety authorities, from which early insights into the design development and safety approach are anticipated. Site permit for First Of A Kind (FOAK) is being pursued. Agreement has been reached with the Government of France that a FOAK NUWARD™ will be built in France. a number of potential sites are being considered for this.

6.1 Deployed Reactors
6.2 Reactors under Licensing Review
6.3 Reactors in the Design Stage

7. Safety Concepts

SUMMARY FOR BOOKLET

Engineered Safety System Approach and Configuration

The NUWARD™ reactor and associated safety systems are designed for:

1. Passive management of DBC scenarios with no need for an external ultimate heat sink or any external electrical power supply (normal and emergency) for more than 3 days;

2. Active management of Design Extension Condition (DEC)-A accidents, with simple diagnosis and implementation of diversified systems;
3. In-Vessel Retention of the corium (IVR) strategy for DEC-B management.

The safety approach for NUWARD™ benefits from the following inherent features of the design to satisfy and maintain a safe state that requires minimum intervention from the operating team:

1. Large reactor coolant inventory (kg/MWth) providing inertia versus power transients;
2. Integrated reactor coolant system architecture reducing the maximum LOCA break size thus providing more coping time in the event of the design basis LOCA;
3. Internal CRDMs preventing rod-ejection accidents;
4. Boron-free in normal operation (including all DBCs) providing large and constant moderator counter-reaction and preventing boron dilution;
5. A metallic submerged containment providing passive cooling for several days;
6. A relatively small core in a large vessel enabling the efficient implementation of the IVR concept for DEC-B accident scenario.

Safety Approach and Configuration to Manage DBC

NUWARD™ incorporates 2 trains of passive heat removal, via a natural circulation transfer system of the decay heat from the core to the water surrounding the unit containment (the reactor pool), through two dedicated Safety CSGs (S-CSG) independent from the operational or the operational six CSGs. Each train can be actuated by 2 diversified channels (diversified sensors and I&C) and redundant (backup spare) actuators. The water surrounding the unit containment ensures the heat removal function for more than 3 days without the need for an external ultimate heat sink. The passive vessel heat removal system is considered a D-passive system according to IAEA classification. A set of 2 redundant low-pressure safety injection accumulators provide the make-up of reactor coolant water inventory in case of LOCA. NUWARD™ includes safety features to prevent criticality risks. The use of an internal CRDM eliminates the occurrence of a rod ejection accident. Dedicated safety systems to manage DBC are provided for each of the two reactor units.

Safety Approach and Configuration to Manage DEC

DEC-A systems include Low flowrate depressurisation system and active water injection. This system provides for the removal of the decay heat in case of a postulated common mode failure of redundant trains of passive DBC safety systems; high pressure borated water injection is available to cope with Anticipated Transients Without Scram (ATWS) accidents. DEC-B systems include the low flowrate depressurisation system; Flooding of the vessel pit in order to provide IVR of corium; and nitrogen injection to manage the risk of hydrogen combustion.

Containment System

The NUWARD™ design includes steel containment as the 3rd barrier, which is immersed in water. The minimised LOCA break size and the efficient passive heat removal system result in a limited peak pressure inside the steel containment which is passively cooled by the surrounding water. The containment is protected against hydrogen accumulation risk in DBCs by passive recombiners.

Spent Fuel Cooling Safety Approach / System

Located between the 2 units that form the NUWARD™ design, is a shared spent fuel pool. The fuel

assemblies are moved through a transfer chute located at the top of the steel containment; this feature is available on each unit. Along with the shared spent fuel pool is a shared refuelling machine used to achieve the fuel transfer.

Plant Safety and Operational Performances

The design target value for the lifetime capacity factor is above 90%, with the major planned refuelling only outages scheduled for 20 days every 24 months. The reference refuelling strategy is to replace half of a core every 2 years. The plant provides a storage capacity of spent fuel assemblies for 10 years of operation.

7.1 Safety Philosophy and Implementation
7.2 Transient/Accident Behaviour

8. Fuel and Fuel Cycle

SUMMARY FOR BOOKLET

Fuel Cycle Approach

The reference plant refuelling cycle is for half a core every 2 years. The plant provides a storage of spent fuel assembly for 10 years after operation before decommissioning.

Waste Management and Disposal Plan

Options regarding waste disposal are currently under assessment, taking note of industry best practice.

8.1 Fuel Cycle Options
8.2 Resource Use Optimization
8.3 Unique Fuel/Fuel Cycle Design Features

9. Safeguard & Physical Security

SUMMARY FOR BOOKLET

9.1 Safeguards
9.2 Security
9.3 Unique Safeguards and/or Security Features

10. Project Delivery & Economics

SUMMARY FOR BOOKLET

10.1 Project Preparation and Negotiation
10.2 Construction and Commissioning
10.3 Operation and Maintenance