FINAL REPORT

ENCO-FR-(22)70 REV 5

ANALYSIS OF SMALL MODULAR REACTORS CONCEPTS (SMR) - STATUS 2022; CONTRACT REF.: 2022-0.492.653

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Bundesministerium
Klimaschutz, Umwelt,
Energie, Mobilität,
Innovation und Technologie

TABLE OF CONTENTS

FIGURES

ABBREVIATIONS

ABWR	Advanced boiling water reactor
AC	Alternate current
ADS	Automatic depressurization system
AGR	Advanced gas reactor
APR	Advanced pressurized water reactor
ASN	French nuclear regulator
BMK	Bundesministerium für Umwelt, Energie, Mobilität, Innovation und Technologie
BWR	Boiling Water Reactor
CAD	Canadian dollar
CCF	Common Cause Failure
CCS	Carbon capture and storage
CDF	Core damage frequency
CEZ	Czech nuclear operator
CFPP	Carbon Free Power Project
CNNC	China National Nuclear Corporation
CNSC	Canadian nuclear regulator
CNV	Cylindrical containment vessel
COL	Combined licence application
CRD	Control rod drive
CRDM	Control rod drive mechanism
DBA	Design basis accident
DBC	Design Basis Conditions
DC	Direct current
DCA	Design certification application
DCS	distributed control system
DEC	Design extension conditions
DHR	Decay heat removal
DSRP	Design specific review plan
DOE	US department of energy
DSRS	Design specific review standard
ECCS	Emergency core cooling system
EDF	Électricité de France
ENSTO-e	European network of transmission system operators for electricity
EPR	European power reactor
EPRI	Electric Power Research Institute
EPZ	Emergency planning zone
ESBWR	Economic Simplified Boiling Water Reactor
EU	European Union
FOAK	First of a kind
FSAR	Final safety analysis report
GDA	Generic design approval
GenII	Second generation of reactors
Generation III/GenIII	New generation reactors like EPR, AP1000
GW	Gigawatt
GWTS	Gaseous Waste Treatment System
HTGR	High temperature gas reactor
HTR-PM	High-temperature gas-cooled reactor- pebble-bed module
IAEA	International atomic energy agency
ICS	Isolation condenser system
I&C	Instrumentation and control
IMSR	Integral Molten Salt Reactor
kW	Kilowatt
LCOE	Levelized cost of electricity
LCOE*	Levelized cost of electricity including system cost
LERF	Large early release frequency

LOCA	Loss of coolant accident
LWTS	Liquid Waste Treatment System
LWR	Light water reactor
MCR	Main control room
MoU	Memorandum of Understanding
MOX	Mixed oxide nuclear fuel
MS	Member State
MW	Megawatt
MWe	Megawatt electric
MWh	Megawatt hour
NEA	Nuclear energy agency
NHSI	Nuclear Harmonization and Standardization Initiative
NRHR	Normal Residual Heat Removal
NNSA	National Nuclear Safety Administration (Nuclear Regulator of China)
NOAK	Nth of a kind
NPM	Nuclear power module
NPP	Nuclear power plant
NSSS	Nuclear steam supply system
O&M	Operation and maintenance
ONR	UK nuclear regulator
PAR	Passive autocatalytic recombiner
PDHR	Primary decay heat removal system
PCCS	Passive containment cooling system
PCMWS	Passive core make-up water system
PLC	Programmable logic controller
PGA	Peak ground acceleration
PNNL	Pacific Northwest National Laboratory
PSA	Probabilistic Safety Assessment
PSAR	Preliminary safety analysis report
PBMR	Pebble bed modular reactor
RCS	Reactor coolant system
RR	Research reactor
PWR	Pressurised Water Reactor
RAW	Radioactive waste
RCS	Reactor coolant system
RPC	Reactor protection system
RPW	Reactor Pressure Vessel
RVI	Reactor Vessel Internals
RWB	Radioactive Waste Building
SAF	Synthetic Aviation Fuel
SAR	Safety analysis report
SDHR	Secondary decay heat removal system
SG	Steam generator
SLIS	Small Leak Injection System
SMR	Small modular reactors
SNF	Spent nuclear fuel
SRP	Standard review plan
SSE	Safe shutdown earthquake
STUK	Finnish nuclear regulator
SUJB	Czech nuclear regulator
SWTS	Solid Waste Treatment System
UAMPS	Utah associated municipal power systems
UK	United Kingdom
URD	Utility requirements document
USD	United states dollar
USNRC	US Nuclear Regulatory Commission
VDR	Vendor design review
WTS	Waste Treatment Systems

1 INTRODUCTION

Unlike previously, the policy focus of interest to develop nuclear programmes is now not only on standard size nuclear power plants, but also on Small Modular Reactors (SMR). Those are, as the name says, significantly smaller (SMRs are, in the IAEA terminology, reactors up to 300 MW electric power) and of modular design, which would allow for a "factory based" manufacturing and limited assembly at a site. Furthermore, SMRs developers promise on-time and on-budget construction, thus offering a solution for the two big challenges related with large nuclear power plant projects. The deployment of SMRs would imply a change from the "project-based" model, where each large nuclear power plant (NPP) was constructed as a unit, to a "product-based" model, where SMRs would be factory produced and assembled at practically any site available, including at the sites of existing nuclear or thermal power plants. While some SMRs offer new and/or refined concepts, others build on and improve or modernise the technologies that have been around since the early nuclear era, including light water, gas and liquid metal cooled, but also molten salt and other reactor concepts. The SMRs are being designed for a range of different uses, from those focused on producing electricity only, over those combining electricity and (industrial, process) heat, to specific concepts for hydrogen production, desalinisation and heat-only SMRs.

The IAEA report "Advances in Small Modular Reactor Technology Developments" [3] issued in 2022 catalogued 83 individual SMR models under development, ranging from micro and very small reactors - to be used for heating or for isolated small grids/facilities, to fairly large ones, e.g., the UK company Rolls Royce 470 MWe plant.

Perceived affordability and short construction periods, promise of high safely level (many SMRs are said to be "all passive", as their small size is expected to allow for removal of decay heat without any electrical power) lead to growing interest in SMRs. While there is only one SMR under construction (Chinese ACP-100) and few in operation (KLT- 40S in Russian Federation and HTR-PM in China), there are numerous initiatives including signing of agreements to cooperate on development or even deployment of SMRs in many countries worldwide, including up to 10 Euratom Members states.

While there is lots of excitement, there are legitimate concerns that the SMRs designs and their developers might be over-promising. There are concerns of over-optimistic cost estimates, limits related to the industrial production concept (which require significant upstream investment to start manufacturing), challenges with licensing approvals and with the generation of radioactive waste, as well as lack possible of qualified human resources to support large scale deployment. As long as only one western SMR concept (NuScale) has received the final design approval from a major western nuclear regulator (USNRC), and none of the western models started manufacturing and construction – even the prefabrication of plants, those challenges remain to be addressed.

As the SMRs might be expected to be constructed in Euratom Member States in the foreseeable future and some of Austria's neighbouring countries are considering those, it is in BMK's interest to consolidate the level of its knowledge and information. This report analyses SMR concepts that have higher prospects of deployment and undertakes a critical analysis of a series of relevant issues including the design principles (e.g. safety, security and safeguards), licensability, economic parameters and co-generation with other sources, and other parameters including generation of radioactive waste.

The report establishes a snapshot of the status as of the end 2022 and prospects for the 6 selected SMRs, and expands on 16 specific themes that are of specific relevance for SMRs. The collection of information encompasses a variety of public sources including the SMR developers. The information collected was subject to a critical analysis undertaken by the authors of the report.

2 THE SELECTION OF SMRS FOR ANALYSIS

The IAEA publication "Advances in Small Modular Reactor Technology Developments"version 2022 [3] lists eighty-three different models of SMRs being proposed or in development worldwide. Those are ranging from micro and very small reactors to SMRs with rated power of almost 500 MWe (which is already above the IAEA definition of a "SMR being less than 300 MWe"), and cover a variety of technologies, some more traditional and others being novel. The level of completion of the development also varies, from SMRs that are ready for construction (or indeed ACP100 under construction in China) to others that are in an early design stage.

It is obvious that the analysis within this project cannot cover all or even many of the SMRs listed in the Ref [3], and therefore a selection needs to be made. This selection could be made on a variety of criteria, e.g. from the maturity of design to the capacity to be a novel technology. Given the aim of this project and the interest of BMK to be informed and be able to interact with countries that might be considering SMRs in the near to mid future, the main criterion is which of the SMRs are technically most developed and might be of interest to the Euratom MS and, in particular, in Austria's neighbouring countries.

Reflecting the objectives of the project, the selection of SMRs for the analysis is based on the following criteria:

- Credibility of the technology for deployment in short/mid-term;
- The maturity of the design (preliminary design completed);
- Plausibility of construction in and/or interest expressed by, Euratom MS;
- Likelihood of obtaining a construction licence in Euratom MS with specific Euratom MS nuclear regulations and standards;
- SMRs with focus on electricity (i.e., heat-only SMRs not to be considered).

Availability of funding are not in focus of this report.

When considering the criteria of short or mid-term deployment, e.g., the decision on construction by about 2032 and operation by 2035, limits the choice of SMRs to several that are either further developments of a previous model (e.g. a BWRX) or a new development that has been ongoing for some time. In this category are primarily the light water reactors (LWRs), but also some of the gas cooled reactors, which are a further development of the technology that was initially introduced in Germany in the 1970ies.

The LWR and, in particular, the pressurized water reactor (PWR) plants are the most common and widely used nuclear technology in the EU and internationally. This technology is used for land based NPPs, but also for marine vessel propulsion (which are closer in size to SMRs). Many elements of technology (e.g., core design, fuel, materials, etc.) are well developed and are referred to be used in SMRs. All of the most developed, most ready for the market SMRs are the LWRs. The LWR SMRs are generally at a higher degree of technology readiness and likely pose fewer challenges as compared with other designs.

While gas cooled reactors and, in particular, the high-temperature ones are of interest for the industry (as high temperature could be used in industrial processes, including e.g., more efficient generation of hydrogen), it is hard to see those being licensed and deployed in the medium term. This limits the list to the LWRs.

There are lots of activities regarding SMR deployment around the world and in Euratom MS. Many of the SMR developers signed numerous memoranda of understanding, expressions of interest and alike. As an example, a single nuclear operator in an Euratom MS reportedly signed agreements of intent with 7 different SMR developers. Still, from the perspective of plausibility of construction in the short/mid-term, there are few SMR developers for which multiple Euratom MS would likely be interested.

Given the geopolitical considerations at present and in the foreseeable future, it is very difficult to see a Russian designed reactor being considered for deployment in Euratom MS. This is to a certain extent also true for China, although the advances in the Chinese nuclear sector might make the Chinese ACP100 (which is the only advanced SMR in construction today) an interesting alternative. The

Argentinian CAREM, while being under construction is of a small size, unlikely to attract interest for a grid-level power source.

The safety and licensing requirements in Euratom-MS reduced the list further. It is reasonable to assume that the SMRs designed outside Euratom MS would face a rather difficult process of licensing in the Euratom MS. Furthermore economic, financial and policy challenges including technological autonomy, sanction regimes, certificates, warranties and international nuclear liability instruments (including different nuclear liability conventions) are to be considered.

Even the SMRs using "traditional" LWR technologies are deploying various design features that were not employed in traditional (high power – 900- 1600 MWe) NPPs. This include extended number of passive systems and features, submerged containment, etc., but also construction concepts with most work done in factories rather than at a site. Each of these might be a challenge in the licensing process, in particular in the Euratom MS whose regulatory principles are prescriptive. Such criteria might lead to more difficulties and even an exclusion of SMR models that are using non-LWR technologies.

As SMRs could be designed to be small and compact, many consider applications for remote areas, either as a source of heat or localised electricity production or both. Due to population density and a well- developed grid, those are unlikely to be considered in any of the Austria's neighbouring countries.

Being the only larger size SMR under construction justifies adding the Chinese ACP100 to the list, though the likelihood of the ACP100 being licensed and deployed in the Euratom MS in the short to mid-term remains, in the view of the author of this report, small indeed.

The report did not consider other SMRs either because those are in an early development state, sometimes with uncertain prospects, or those that are designed for a special application (e.g. heat and power in remote areas) or those the deployment of which in the EU and neighbouring countries is not expected in the foreseeable future. The low prospect for the deployment might be due to also political reasons (i.e. for Russian reactors).

Out of 18 SMRs in the IAEA publication [3] that passed the initial criteria (technology and the status of design), the choice of SMRs to be assessed in this project would encompass a design from a French led consortium (NUWARD) and a UK design (Rolls Royce) as well as 2 US designs (NuScale, Holtec) and one of a US/Japan cooperation (BWRX-300). The last of the list is the Chinese ACP100, which, as mentioned above, is the only sizable SMR under construction today.

Table 1 – List of LWR SMRs (extract from [3])

WATER COOLED SMALL MODULAR REACTORS					
Design	**Output MW(e)**	**Type**	**Designer**	**Country**	**Status**
CAREM	30	Integral PWR	CNEA	Argentina	Under construction
ACP100	125	Integral PWR	CNNC/NPIC	China	Under construction
CAP200	> 200	PWR	SPIC/SNERDI	China	Basic Design
DHR400	400 MW(t)	PWR (pool type)	CNNC	China	Basic Design
HAPPY200	200 MW(t)	PWR	SPIC	China	Detailed Design
NHR200-II	200 MW(t)	Integral PWR	Tsinghua University and CGN	China	Basic Design
TEPLATOR™	< 150 MW(t)	HWR	UWB Pilsen & CIIRC CTU	Czech Republic	Conceptual Design
NUWARD™	2 × 170	Integral PWR	EDF	France	Basic Design
IMR	350	PWR	MHI	Japan	Conceptual Design Completed
i-SMR	170	Integral PWR	KHNP and KAERI	Republic of Korea	Conceptual design
SMART	107	Integral PWR	KAERI and K.A.CARE	Republic of Korea and Saudi Arabia	Detailed Design
RITM-200N	55	Integral PWR	JSC Afrikantov. OKBM, Rosatom	Russian Federation	Detailed Design Completed
VK-300	250	BWR	NIKIET	Russian Federation	Detailed Design
KARAT-45	45 – 50	BWR	NIKIET	Russian Federation	Conceptual Design

WATER COOLED SMALL MODULAR REACTORS					
Design	**Output MW(e)**	**Type**	**Designer**	**Country**	**Status**
KARAT-100	100	BWR	NIKIET	Russian Federation	Conceptual Design
RUTA-70	70 MW(t)	PWR (pool type)	NIKIET	Russian Federation	Conceptual Design
STAR	10	LWR (pressure tube)	STAR ENERGY SA	Switzerland	Basic design
Rolls-Royce SMR	470	PWR	Rolls-Royce SMR Ltd.	UK	Detailed Design
NuScale VOYGR	4/6/12 × 77	Integral PWR	NuScale Power	USA	Equipment Manufacturing in progress
BWRX-300	270 - 290	BWR	GE-Hitachi	USA and Japan	Detailed Design
SMR-160	160	PWR	Holtec International	USA	Preliminary Design Completed
Westinghouse SMR	> 225	Integral PWR	Westinghouse Electric Company LLC	USA	Conceptual Design Completed
mPower	2 × 195	Integral PWR	BWX Technologies, Inc	USA	Conceptual Design
OPEN20	22	PWR	Last Energy Inc.	USA	Detailed Design

As an outcome of the selection process 6 SMRs were selected for further review. Compliance of those with selection criteria is presented in Table 2.

Table 2 – List of selected SMRs

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
Credibility of Technology	PWR	BWR	PWR	PWR	PWR	PWR
Maturity of the design	Equipment Manufacturing in progress	Detailed Design	Basic Design	Detailed Design	Preliminary Design Completed	Under construction
Plausibility of construction in EU	Yes	Yes	Yes	Yes	Yes	Limited
Rated power (MWe)	77 per module	300	2*170	470	160	125
Likelihood of obtaining EU licence	Advanced	High	High	High	Reasonable	Questionable
SMR producing grid level electricity	Yes	Yes	Yes	Yes	Yes	Yes

3 THE CHALLENGES FOR SMRS IN GENERAL

Even though there are examples of SMRs in operation (e.g. Russian barge mounted KLT 40S, several small heat-producing integral reactors in different countries), the majority of SMRs on the IAEA list are at the level of the development of being a concept or at intermediate phases of the design. Several SMR models are approaching the end of the design phase and some are in or about to enter the licensing stage. While some SMRs largely rely on previously used technologies, various new features and concepts – in particular passive systems and features, – are considered more broadly. As SMRs are different in some features than traditional reactors (e.g., multiple modules, single control room for multiple units, more extensive operation in load-following mode, etc. but also newly designed components and manufacturing methods), regulators internationally are supposed to put the designs under thorough scrutiny before issuing the construction and operating licences.

In terms of the licensing, apart from the ACP100 that was approved for construction by Chinese regulator NNSA, the only SMR that obtained an approval from USNRC, based on US regulatory requirements, is the NuScale VOYGR design of which received the final regulatory design approval in January 2023.

Considering 6 SMR types preselected for this report, there are sites where, from todays' perspective, such SMRs are likely to be built in the mid-term future. The most advanced ones include the Carbon Free Power Project (CAPP) in Idaho in the US (NuScale), Darlington NPP in Canada (BRWX-300) and likely the Doicești site in Romania (NuScale). The latter is planned to be constructed at the site of a shut-down coal plant, and may house 6 NuScale modules (462 MWe). For that site, the IAEA completed its first ever safety review of a site allocated to SMR. Furthermore there are more SMR projects being considered globally, but that is beyond the focus of this report.

Any deployment of the SMRs in Euratom MS and internationally still require numerous conditions to be met. Those include:

- Technological innovation: Even when relying on the physical processes (reactor design) that are well known, many SMRs add innovations in design, materials and manufacturing. Those need to be thoroughly analysed, their safety level verified and accepted by regulators. The technological issues are likely not expected to be a significant challenge, at least for the LWR SMRs (6 assessed in this report). Nevertheless, lack of or unfinished detailed design and engineering on (likely) all of the SMRs may lead to challenges;
- Licensing: The licensing process is still a pretty steep challenge for SMRs. Regulators in countries where the SMRs might be deployed are likely to put those to increased scrutiny, possibly adding specific safety or other requirements. Different safety or operational requirements from one country to the other might severely undermine the concept of "product based model" of SMRs. Currently international harmonized type licensing approaches are not established in nuclear power industries and prospective of full scale harmonisation is rather low;
- Safeguards, radioactive waste and other issues: the SMRs, as other nuclear facilities need to comply with safeguards requirements, as well as other nuclear related regulation and conditions. Some developers claimed that SMRs would produce less radioactive waste, which is appears not to be correct. Some researchers even believe that SMRs would produce more spent nuclear fuel (SNF) and possibly more radioactive waste. SMRs would need radioactive waste processing facilities, spent nuclear fuel storages and decommissioning arrangements to be a part of the business (and safety) case.
- Standardisation: The key to success for SMRs is in a large number of identical modules being produced, constructed and operated. There are many SMR designs (at least 10 viable ones) that will be competing on the market. This would lead to a higher number of unit types, effectively undermining the standardisation;
- Supply chain: For a large SMR deployment to materialise, a robust industrial supply chain

needs to be put in place. It is not just for manufacturing the modules, but for erection, fuel supply, as well as specialised services. It is very likely that the supply chain will remain a hindrance for large deployment for some time, also as it requires significant upstream overnight investment even before construction of serial SMRs can start, as well as availability of qualified human resources for construction and operation of the plants needs to be ensured;

- FOAK and NOAK: Many developers are promising a rapid reduction of the price from FOAK (first of a kind) to NOAK (N-th of a kind). While modular construction and serial production of modules would certainly lead to a price reduction, achieving the targets remains a (big) challenge and requires a large total investment. The same applies for the production and construction periods, where the optimisation achieved in NOAK are the key in achieving these targets;
- Operations: SMRs are conceptually (claimed to be) designed for up to 0-100% load follow operation (EPRI URD requirements for SMR is the 24-hour load cycle: 100% → 20% → 100%), where low loads could be achieved quickly by turbine bypass or by shutting down individual modules (NuScale). Continuous load variations are challenging for the reactor core and other systems, as thermal cycles might impact fuel and cause thermal stresses in main equipment;
- Operators: SMRs might be built by non-utility users, adding the challenge of needed nuclear experience, qualified staff, etc. This is sometimes overlooked, and will be an added challenge as the regulators would insist on robust arrangements, as for current NPPs;
- Economics: The SMRs would need to prove their promises regarding the construction schedule and the price. When used only to supply the electricity to the grid in a case of a need, SMRs would likely have rather limited energy production in case of reduced power operation, resulting in a high levelized cost of electricity (LCOE). Alternative uses, like industrial heat or desalination would increase the operating hours, but would not be of use in every SMR location. To achieve the promised economics, SMRs need to rely on a large number of deployed units.

4 CRITICAL ANALYSIS OF SELECTED SMR MODELS

This chapter provided a narrative summary of the critical analysis of selected SMR models, for each of 15 different issues that are relevant to present the state of the development and future expectation for SMRs. This critical analysis is further supported by factsheets presented in the ANNEX 1: FACTSHEETS OF 6 SELECTED SMRS and by the comparative analysis related with each technical item as provided in the ANNEX 2: COMPARISON OF SIX SMRS ON DIFFERENT PARAMETERS.

Brief description and main challenges that need to be addressed for each of the 6 SMRs under review are presented in the below table:

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NUSCALE		
	PRO	**CONTRA**
Technology – PWR VOYGR -12 - 924 MWe (12 NPM) VOYGR-6 - 462 MWe (6 NPM) VOYGR-4 – 308 MWe (4 NPM) Natural circulation Design life 60 years	Proven PWR/LWR technology	Low secondary side parameters reduce efficiency
	Modular design and size/rated power eliminate on-site modules assembling	Each power generation module is equipped with own turbine and the balance of plant systems, thus likely substantially increasing maintenance activities
	Concept of passive safety systems eliminates active elements and improves reliability	Novel integrated design and concept of passive safety systems have not been proved by operation
	Small size EPZ (plant fence) approved by the USNRC	Small size EPZ is unlikely to be accepted in the EU countries where population density is higher than in many US locations.
	Low CDF and LERF values due to specific of the design (i.e. submerged containment and passive safety systems)	Currently claimed low CDF and LERF values are related to internal events only and therefore could substantially increase due to site specific external factors
		Potential for Common Cause Failure (CCF) of MCR e.g. due to fire affecting multiple modules
		Reference US NuScale design has very limited capacity of the on-site RAW management facilities
		The initial licencing process did not address: (1) the shielding wall design in certain areas of the plant; (2) the potential for containment leakage from the combustible gas monitoring system, and (3) the ability of the steam generator tubes to maintain structural and leakage integrity during density wave oscillations in the secondary fluid system

BWRX 300		
	PRO	**CONTRA**
Technology – BWR Single module 300 MWe Natural circulation Design life 60 years	Proven BWR/LWR technology	
	Natural circulation of the coolant eliminates active elements and has a positive impact of plant's reliability	Module design with rather high rated power would likely require more extensive on-site module assembling works
	Inerting containment with nitrogen	Hydrogen accumulation risk in case of accidents is not yet demonstrated (subject to specific PSAR analysis)

	Extended use of passive systems	While BWRX-300 claims use of passive safety systems and no necessity of the AC power, the operation of the ICS for RPV depressurization and decay heat removal requires one-time automatic actuation using onsite Class 1E battery-backed DC power (subject for additional review during application process) PCCS design is not finalized yet (2022 Licensing Topical Report) Concept of passive safety systems is not proved by operation

NUWARD		
	PRO	**CONTRA**
Technology - PWR Dual module - 2*170 MWe Forced circulation (6 pumps) Design life 60 years	Proven PWR technology	Low secondary side parameters reduce efficiency
	Innovative integrated reactor design	Novel integrated design has not been proven by operation
	Boron-free design reduces amount of effluents	Boron free design has not been proven by operation
	Forced circulation improves heat removal from the reactor core	Forced circulation requires active elements and that has some negative impact of plant's reliability
	Use of passive safety systems	Concept of passive safety systems is not proved by operation

ROLLS ROYCE SMR		
	PRO	**CONTRA**
Technology - PWR Single module - 470 MWe Forced circulation (3 pumps) Design life 60 years	Proven PWR technology	
	Forced circulation improves heat removal from the reactor core	Forced circulation requires active elements and that has some negative impact of plant's reliability
	Use of passive safety systems	Concept of passive safety systems is not proved by operation
	Boron-free design reduces amount of effluents	Boron free design has not been proven by operation
	Powerful (470 MWe) single module	Module design with rather high rated power would likely require more on-site module assembling works

HOLTEC SMR-160		
	PRO	**CONTRA**
Technology – PWR	Proven PWR technology	Low secondary side parameters reduce efficiency of the plant

Single module - 160 MWe Natural circulation Design life 80 years	Concept of passive cooling with indefinite passive air cooling	Concept of passive safety systems and "black-start" are not proved by operation Indefinite passive cooling concept should be proven by calculations and tests
	Large size of the pressurizer eliminates any need in relief valves	Novel integrated design and safety features have not been proved by operation
	Dry SNF storage foreseen in the design concept	Unloading of the SNF into dry storage facility after second refuelling claimed by HOLTEC is to be further analysed as wet storage time is shorter than in any of known designs
	Design life 80 years	Design life of 80 years as will be first precedent to assign such long lifetime at the design phase, so might cause difficulties during licensing

ACP100		
	PRO	**CONTRA**
Technology – PWR Single module - 125 MWe Forced circulation (4 pumps) Design life 60 years	Proven PWR technology	Low secondary side parameters reduce efficiency of the plant
	Novel integrated design	Novel integrated design and concept of passive safety systems have not been proved by operation
	Concept of passive core cooling, passive residual heat removal, passive containment cooling improves safety and reliability of the plant	
	No need for operator intervention after accident for 72 hours	Results of safety analysis are not available
		No experience in licensing of the Chinese NPPs/nuclear facilities in the EU Almost no technical information has been made public

4.1 BASIC CONCEPT OF THE SMR

All SMR types selected for the analysis are LWRs, reflecting the historical trends where the LWR (and in fact PWRs) dominate reactor technology. This technology likely offers the best ratio of utilization and complexity, in particular when the focus is on generating electricity (for other applications, as heat production other types might have distinctive advantages). All 6 selected SMRs are standard LWR in terms of reactor physics and basic core, Reactor Coolant System (RCS) design.

In reality, only NuScale is a modular concept, where a client could choose 4, 6 or 12 modules. NUWARD is meant to have two modules in one plant. All others are a single (small) self-sufficient unit (though there might be some shared systems and features like waste processing), which could be built several times on the same site.

The primary focus for all reviewed SMRs is generating electricity, where all claim full flexibility to operate on a grid with renewables over the entire power range.

While this might be possible with the turbine bypass function (which is also envisaged for NuScale, and likely for others), at certain point the operation in the load follow mode might become difficult if not impossible due to the limitations of reactor physics, i.e. nuclear fuel. The same applies to the ramp up or down rate. Some SMR models specifically mention EPRI load follow requirements (100% -> 20%->100% within a day).

All SMRs list intended additional (i.e. to electricity generation) application as production of heat, support generation of hydrogen, and some are used for the desalination. Nevertheless, it is not clear whether there are specific design features that would make those types advantageous for any of additional applications.

4.2 SMR DEVELOPERS AND RECORDS, SET GOALS

The designers of 3 out of 6 SMR models assessed are entities with long or very long experience in designing reactors (NUWARD encompass French NPP, RR SMR has Rolls Royce (military) naval reactor experience, GE and Hitachi are behind BWRX, which is a small model of BWR line;). Being solely devoted to SMR, NuScale had no experience in nuclear power plants' technology and never produced an operating nuclear reactor so far, it was a specially established entity with a goal to create new nuclear reactors. Holtec is a company with long-standing experience in nuclear fuel cycle, mainly fuel and waste/decommissioning. All have a realistic potential to succeed in designing a SMR that would be a viable product, though the authors of this report believe that RR SMR and Holtec's SMR 160 will face more challenges than the other 4, including a less secure financing. RR SMR might be expected to draw on UK government's funding, but this might not be enough if no other partners are found who would be willing to fund the development.

A new reactor design would need to receive multiple customers' commitment/support to be able to proceed to create the industrial basis. This will likely also require a significant public commitment, ensuring investment stability or even direct involvement e.g. by public co-financing.

In term of the development timeline, ACP 100 is under construction. NuScale is very likely being able to deliver detailed design within next couple years, and it is on the way to identify/establishing manufacturing facilities. NuScale construction in USA might be expected to commence within 2-3 years. However the time schedule is under scrutiny and was shifted already several times.

Other SMR models analysed are less advanced in the development of the design, with BWRX being more developed than others. NUWARD might be expected to be able to complete detailed design before 2030. For SMR160 and RR SMR, it is the estimate of the authors of the report that it will all depend on the level of funding and ability to attract the customers.

4.3 DESIGN AND TECHNOLOGY AND ITS MATURITY

All of the analysed SMRs are at their core LWRs, utilizing known traditional technologies of the reactor and the RCS, so their design could be seen as evolutionary rather than revolutionary.

All SMRs selected deploy a concept that residual heat could be removed by passive systems, which leads to a claim that those are safer than traditional NPPs that need active system for heat removal. Passive systems are at the same time an advantage and a potential problem, because passive systems do have challenges on their own, e.g. powered only by physical forces, having potentially weak points, etc. (passive system concept testing and approval are among licensing challenges). While the design details are not available for most of SMRs, all are claiming to be using advanced technologies and rely on passive features.

In term of challenges, and reflecting the information available (which is not enough for thorough analysis) it is not expected that there will be too many challenges with the materials used. There might be some challenges related with the design, mainly related with assuring that the design as proposed is complying with the requirements- which are set very high.

The challenges might be expected in the manufacturing of the equipment as well as in the construction/commissioning for any First-Of-A-Kind SMRs under the review, in particular in terms of achieving envisaged quality, schedule and costs. ACP100 might be expected to have resolved those, although lack of available information precludes an assessment whether there are issues with manufacturing.

It needs to be stressed that constructing a prototype or a FOAK still does not mean that the manufacturing challenges related with a series of SMR units would not occur.

4.4 LICENSING

Licensing is the challenge for the construction of traditional NPPs and it is expected to be a significant one for the construction of SMR. So far, the ACP100 has been licensed and is under construction, while NuScale SMR obtained the design approval from the USNRC. BWRX and SMR 160 submitted the pre-application for licensing to the USNRC. BWRX is under an active licensing review by the Canadian nuclear regulator. RR SMR submitted the application for the generic design review to the UK regulator, and NUWARD submitted an equivalent to the French ASN. Noteworthy is an agreement between ASN, SUJB and STUK to undertake a joint regulatory review of the NUWARD design.

The standards and criteria against which the ACP 100 has been licensed are not publicly available, though those are expected to be comparable to large NPPs that are under construction in China. For NuScale, USNRC recognized that specific design solutions would not qualify under the requirements of the “Standard review plan” for large NPPs, and thus developed the Design specific review standard (DSRS), which redefines the requirements in some of the areas. It might be expected that modified licensing requirements would be needed for most other SMRs.

On international level, the EU SMR pre-partnership has a Work-stream on the licensing, which is discussing some of the challenges. The IAEA via its Nuclear Harmonization and Standardization Initiative (NHSI) established the SMR Regulator’s forum for discussing the licensing on the international level.

Licensing may be expected to remain a challenge for SMRs in the Euratom MS, as some novel design solution, material and manufacturing may/would require changes in the acceptance criteria. While at present some preliminary licensing reviews are being undertaken (while the detailed design is being developed), the real challenge will arise as one or another SMR model applies for a construction license. Among challenges that are likely to be faced are passive system, different design concept of the containment, shared system and/or MCR among modules/units, some specific design features (e.g. lack of boron injection), as well as the manufacturing and construction processes, quality control during manufacturing, etc. The licensing challenges that might be expected are also related to the qualification of operators, as well as of the operating organization.

There is a lot of discussions about harmonizing the requirements and in particular mutual recognition of the regulatory reviews. Such is likely essential for the SMRs to be rolled out in high numbers internationally, but in the view of the author of this report this remains a relatively long term goal that would not be easily reached. It is rather expected that the initial licensing of the SMRs will be undertaken by national regulators and against national regulations in each country.

4.5 CONSTRUCTION AND DEPLOYMENT

The concept of SMR is that those are modular and are to be built in large number of modules that are (to a larger extent) industrially manufactured and then assembled on site. Such a concept has advantages, from the shorter scheduling to the quality, as the quality and the time needed for the production could be much better controlled when multiple similar modules are industrially produced. It is nevertheless not clear to which extent, especially larger SMR, would fit within such a concept. NuScale modules are expected to be more or less transportable, but NUWARD’s “vessel” containing RCS will have to be built on site.

All of the SMRs expect the duration of the site construction to be reduced to couple of years, significantly less that for traditional NPPs, mainly due to the fact that those would be factory-built and tested, and only assembled on a site. While large NPPs are also increasingly using pre-fabricated modules to accelerate plant erection, those, however, still require site assembly.

In the view of the authors of this report, the construction schedule challenge remains a challenge, in particular for the larger SMRs. Only when the experience is gained from construction of multiple SMR units, the actually-needed time for the construction could be reliably estimated.

A stepwise adding of “SMR modules” on a site would likely not be meaningful for large SMRs like RR SMR or

BWRX, because these are in reality self-contained units, rather than modules. It is different for NuScale, where reactor modules are contained in one enclosure, so number of modules is to be fixed before the construction starts.

4.6 COMPLEMENTARITY OF OPERATION WITH RENEWABLES

All of the SMR developers offer, as one of the important features, the operation in tandem with renewables. This is based on the ability for a fast ramp up and down of power as well as also (continuous or extended) operation on a wide range of power levels. Some SMR quote their ability to (continuously) operate at any power level from 20% full power to 100% full power. Furthermore, NuScale specifically stresses its modularity (i.e. up to 12 modules, each having 77 MWe) as well as availability of turbine bypass, supporting the claim that it could operate at any power output level (i.e. 0 to 100% power).

Ability of operate at very low power level, e.g. 20 % is, in comparison with traditional power plants, an improvement that would make SMRs a better complement to renewables. In designs with numerous small modules (e.g. NuScale) those could be individually operated or shut down. A full capacity turbine bypass makes a broad-range load following even more achievable.

While the smaller reactor core is an advantage for variable loads, physical limitations of a LWR core would, in the view of the authors of this report, still limit the possibility for stop/go operation as well as the ramping up and down rate. It is also likely that the design parameters and material properties might add some limitations in terms of number of transients a facility could be subject to (though likely that would be much higher than for large plants that are primarily designed for continuous full power operation). Prolonged operation at low power level might negatively impact the core and the fuel utilisation, both increasing the costs and needs for management of SNF and radioactive waste.

Operation on a turbine bypass is attractive, especially when the whole of the power conversion system is designed for such from the beginning. The turbine bypass adds an advantage of allowing a rapid increase and decrease of power level (i.e. being able of supporting the grid stability) while limiting necessary power oscillation of the reactor. In theory such an operation could likely be sustained for a long time at any power level wished for. However, it comes at the cost, where the reactor operates at a higher power level than needed, the power conversion system is releasing large amount of energy into the environment (through cooling system), rather than that energy being productively used. Such operation clearly increases the costs of the operation of a SMR, resulting in the electricity generated being more expensive than it would be otherwise

4.7 CO-GENERATION – POWER AND HEAT

All 6 SMRs covered in this report highlight the ability to operate in a co-generation mode, either producing heat, supporting the generation of hydrogen, desalinisation or other uses. Some SMR developers are stressing those abilities when talking advantages of SMRs. While the use of either waste heat (i.e. heat available after the turbine, when the steam to generate electricity has been used) or a heat directly from the steam generators does increase overall efficiency of a plant, the LWRs are, due to their relatively low temperature, not really that useful (high temperature heat from gas reactors is much more useful for the industry). Nevertheless the heat could still be used for industrial heating, also like from any thermal plant, though it does not offer any significant advantage in comparison with other industrial heating options or it is likely represent significant income stream for the SMRs.

Apart from mentioning a possibility for co-generation, SMR concepts analysed provide few details or specifics. The ACP100 provide some concrete (design) numbers as either: 125 MWe electricity production; steam and electricity cogeneration (300 t/h steam at 290 degrees C and 62.5 MWe); or alternatively the distilled water and electricity co-generation (100,000 tonnes per day water and 80 MWe).

In term of the co-generation capacities, there is no specific advantage of SMRs as compared to large reactors or thermal plants. It is all driven by the design of the power conversion system.

In terms of supporting the generation of hydrogen, the HTGRs with their higher temperature would have an advantage, as the effectiveness of steam electrolysis improves at high temperatures that those SMR would be capable of generating. In terms of electricity driven electrolyser, there would be no distinctive advantage of a SMR as compared with any other electricity generating facility. In principle, the excess electricity generation that is not needed by the grid would be used in an electrolyser. The efficacy of the process will be directly proportional with available electricity. Operating in an intermittent mode, where a SMR would support the grid when there are no available renewables and support the electrolyser when other electricity is available, would results in intermittent operation and likely relatively few operating hours at full capacity of the electrolyser. While such a coupling is possible, it is likely not very efficient, mainly due to an electrolyser rarely operating at a high capacity.

4.8 FUEL CYCLE RELATED ISSUES

All six reviewed SMR concepts use a fairly standard LWR fuel, in a pretty typical LWR configuration (e.g. 17x17 configuration fuel elements), with burnable absorbers. The enrichment of up to 5% and up to 24 months fuel cycle is comparable to modern standard size NPPs. Due to lower power of the core, SMR fuel elements are typically significantly shorter in dimension. No information is published regarding the use of accident tolerant fuel.

NUWARD envisages use of (Pu-U) MOX and even Thorium containing fuel, while none of the other SMR concepts are expressing their position in this regard. However, given a fairly standard design and geometry of the core, it is reasonable to assume that those could be used (though for the MOX fuel, the reactor control system needs to be capable of supporting the excess reactivity).

Unlike modern large NPPs, some of SMRs analysed (e.g. NuScale, HOLTEC-160) are reporting a somewhat lower burn up, which means that the generation of the SNF will be higher than on a reactor with higher burn up. Apart from that, the fuel and fuel cycle related issues are not significantly different for SMRs than for traditional (high rated power – 900- 1600 MWe) NPPs.

4.9 SAFETY RELATED ISSUES

One of the strong pronouncement of SMR developers is that the safety level is higher than for traditional reactors, even that for GEN III plants. The smaller size of the core means that less heat needs to be removed and dissipated in the environment (ultimate heat sink). This results in all the reviewed SMR models claiming a possibility of a full residual heat removal by passive systems. While passive systems could generally be considered more reliable than active ones (e.g. that there is no need for electricity, etc.), those need to be thoroughly analysed in every operating mode to ascertain that this is really the case.

To the information available, the defence in depth levels are maintained in all analysed SMRs, though at least some of the SMR would not have the containment of the same strength-size as the GEN III plants. As an example, the USNRC when doing the licensing review of NuScale SMR, took exception of the regulation regarding the concrete containment which is otherwise applicable to all nuclear plants in the US.

Apart from NuScale and ACP100, the list of design basis accidents and hazards are not available. All claim seismic design for at least 0,3 g PGA and even 0.5 g for some. It is nevertheless believed that a full spectrum of internal and external events (with possible exception of aircraft crash) would be revealed in the detailed design.

The SAR is available for NuScale and ACP100 and was reviewed as a part of the licensing process, but not the others. PSA studies are not publicly available, though the probabilistic targets in terms of CDF and LERF were found. ACP100 claims to have performed a PSA study for full power and internal events, which has been " verified".

Only for the NuScale the source term for severe accidents has been considered by USNRC (and likely for ACP100 by Chinese regulator). For other SMRs, the source term is not yet available. The core inventory provides the upper limit for the source term, but without the analysis of the accident progression, what would eventually be released off site is not really known. Nevertheless, USNRC in its licensing process accepted a significantly smaller emergency protection zone for the NuScale, which is, for the US, limited to the plant's fence. In the view of the authors of this report, this approach would not be accepted as current Euratom MS nuclear safety regulations and standards do not foresee exceptions or specific provisions reducing EPZ for the SMRs.

4.10 SITING REQUIREMENTS

The siting requirements for the SMR are, at least in the EU, very likely to be similar for the traditional plants, with the standard exclusion criteria, planning zones, etc. Therefore, it is practically certain that initial SMRs in the EU would be built at existing nuclear sites (although the NuScale that is in advanced stage of planning for Romania will be sited at a disused thermal plant site).

At least some SMR developers are claiming, and there are several concepts published, that the SMRs could be used to "repower" old thermal plans, where a part of the existing infrastructure would be used. Such a possibility, which would make many more sites available to host a SMR is supported by the USNRC's acceptance for the emergency planning zone to be equal to the plant site (i.e. fence). It is hard to see such a concept being accepted in most of the Euratom MS.

In the terms of the site access, again smaller sizes of SMRs and their modules makes the requirements simpler, as there are no (very) large components to be transported and erected. Nevertheless, for the ACP100, whose steel containment comes in two halves, a very large crane was needed for the erection. Use of preassembled modules reduce site activities and makes the site organisation much simpler.

In the terms size of a site to host one or more SMRs, apart from rendering and info-graphics, there are limited information related to an area needed. Some information is provided in the Annex 1 for each SMR analysed. Given their modular design, multiple reactors and turbines, it is reasonable to expect that per installed power units (in MW) the site area needed might be a bit larger than for a traditional (high rated power – 900- 1600 MWe) NPP.

4.11 RADIOACTIVE WASTE ISSUES

A controversy developed in the technical circles regarding the generation of radioactive waste by SMRs. Some believe that SMRs would be generating more radioactive waste (per electricity produced) than the traditional NPPs, while the SMR developers claim differently. The facts are "bifurcating", and it is not obvious which side is right. It is not disputed that the SMRs will generate more SNF, primarily because of the lower burn up of the fuel. Then, the intermittent (load follow) operation of a SMR would even lower the burn up, adding to the SNF.

Multiple SMR modules needed to produce the same amount of energy as a large nuclear plant would likely indicate higher radioactive waste generation. The composition of waste generated is not expected to be much different of that for a large LWRs, having solid, liquid and gaseous contribution.

The SMR developers point out to the optimised design and materials used, that would lead to lower generation of waste. Some of SMRs use boron-free technology that might lead to reduction of operational waste as there is no need in processing boron containing liquids. Also, a longer refuelling cycle generally reduce the amount of operational waste generated, as compared with a shorter ones as much of the operational waste is generated during outages.

In the view of the authors of this report, a higher generation of SNF as compared with the large GEN II (and GEN III) reactors is likely to be proven. This will also have an impact on the on-site storage and ultimately the cost of disposal of SNF. Regarding the operational radioactive waste, larger number of smaller modules (up to 12 reactor modules, each would need to be opened for refuelling) could be expected to generate more waste than a single refuelling operation on a large reactor. However, promised optimisation of operation and maintenance and use of new materials might have an opposite effect.

None of the information and data that is presently available provides hard parameters in relation with the generation of radioactive waste at SMRs. Therefore, accurate estimates cannot be made at present.

In term of the facilities for processing and storage of radioactive waste on sites, those are again expected to be comparable with large reactors. All systems and structures that are needed to collect, retain, process and package (including volume minimisation) radioactive waste at a large plant is expected to be needed at each SMR site. That might be seeing as a (big) disadvantage in cases where e.g. one or a small number of SMRs are constructed at one site. When there is a large number, then this disadvantage diminishes, but possibly does not disappear.

The storage of SNF is another issue, where more used SNF elements would naturally be requiring more space/large facilities. Shorter fuel elements (length) help a bit, but it is ultimately the volume of SNF that is decisive.

4.12 LEGAL ISSUES

Some SMR developers and proponent have been advocating the SMRs as proliferation-proof, that the SNF could not be diverted and used for malevolent purposes. This might be, to some extent, true for SMRs that use e.g. the nuclear fuel in a form of graphite pebbles. For the LWR this advantage does not exist and all of the SMRs reviewed here are expected to be subject to the same safeguard requirements and arrangements as any other nuclear plant.

For the 6 SMRs reviewed, the intellectual property issues or the technology supply issues are not expected to be a limiting factor. While all the details are not known, nor would be available before the detailed design is completed, it is reasonably likely that each of the 6 will have its own technology to be able to manufacture and construct a SMR. It is also to be expected that the developers will acquire various supporting equipment and systems including, as needed, their technology.

4.13 ECONOMIC PARAMETERS

Any reliable predictions of costs of SMRs are not publicly available at the moment. There are some generalised estimates (more detail on which are provided in a separate chapter) but none of the SMR designers came with a firm and supported estimate of the costs. All of the SMRs are claiming to be, in term of LCOE costs, competitive with the renewables.

Nevertheless, it has to be stressed that the biggest expected contributor to cost reduction for SMRs would be the (serial) industrial production of SMR components and modules, meaning expected competitive price and relatively short construction times, and resulting low cost of capital. However, both of those are not likely to be achieved in the prototyping or in early phase of the rollout of a SMR model than only in later phases, when multiple (similar) examples are ordered, manufactured and constructed. This means that until several NOAKs are completed, the actual cost for both of the construction/erection and later of the operation would not be known.

For the critical analysis it is nevertheless instructive to look at the genesis of the development of NuScale SMR. Originally proposed as 50 MWe modules, to increase its cost competitiveness the module power was increased to 77 MWe- which is likely the maximum what could be achieved without significantly modifying module's parameters. As the design licencing process with USNRC was concluded and the preparation for the construction at Idaho site is advancing, NuScale announced a „revision of economic parameters“ while not revealing the details. The user of the Idaho project, UAMPS (Utah Associated Municipal Power Systems), reportedly said that it "expect the project to generate electricity at the price of 89 USD/MWh", which is said to be an increase of 53 % as compared with the price estimate by NuScale in 2020.

As it could be seen in the Annex 2, only generic price ranges are indicated for the SMR modules. There is no clear information on eventual price reduction for multiple modules (or in a case of larger SMRs, for multiple units at the same site). In the view of the authors of this report, this is mainly because those are not really known, nor those would be known until a detail design and likely even the initial manufacturing commences. It is to be expected that the multiple units will have a lower price than a single one (because of site arrangements, shared systems, etc.), but those savings might not be very significant.

There is little information on the operation concept for SMRs. It is expected that those would follow good practices of new large NPP design, meaning (risk) optimised operations, maintenance and surveillance. At NuScale, the concept is that a single operator controls multiple units.. In the view of the authors of this report, even with this the number of operators (but also maintenance personnel) per installed MW or per generated energy will be higher than for the large Gen III units. It is hard to see where multiple smaller units might offer the costs reduction. The operation of SMRs will very likely require more qualified human resources per installed MWe than traditional NPPs.

There are no publicly available studies on the costs nor the independent reviews of the cost estimates. It is very likely that several feasibility studies (e.g. already mentioned Idaho in US, the Romanian SMR project or BWRX at Darlington) looked into the costs in more details, but those are not publicly available. The investment plans for those are thought to exist. It has been reported that the Canadian infrastructure bank would provide a 970 million CAD support for the Darlington SMR project, which at least as it was published, would (only) support the preparation of the project.

To conclude, the costs of construction as well as the costs of operation of SMRs are subject to multiple uncertainties. It is reasonable to expect that even if there are numerous SMR units built and operated , the cost might become equal to those or a large NPPs. The cost comparison with other electricity generators, in particular renewables will also depend on the actual operating costs of SMR that are, apart from the discussion as above (that more smaller units would tend to cost more; the operating costs of large NPPs are well known and wide publicised), not possible to predict.

4.14 SECURITY RELATED ISSUES

In terms of the security challenges, the SMRs are not offering any advantages as compared with traditional nuclear plants. A potential disadvantage is that there would be larger number of smaller units. The site security, the material security, etc. will all be needed, likely using the same concepts as for large nuclear. This per se will add to the costs of SMRs, as generally those will produce less energy than large NPPs.

It is nevertheless likely that SMR design will, from the beginning, take much more stringent approach to cyber security, where in large NPPs it was an add-on. Likely, plant's systems will be completely isolated, preventing any cyber-attack (that is also a disadvantage due to lack of possible remote control and maintenance of the equipment).

5 PROSPECTS FOR DEPLOYMENT

When judged by announcements and all the various agreements signed, one would expect that there will be dozens of SMR projects already starting up around the world. In reality this is not the case and it is very likely that a broad roll-out of SMRs might not happen in the mid-term future. This is partially due to licensing issues. The whole process of the approval of both the design and the site might be expected to last longer than expected, but also due to time and resources necessary for the detailed design and engineering and the preparation for the manufacturing of equipment, construction and operation of SMRs. Many utilities or other organisations that might have interest in SMRs as a low-carbon source of electricity would prefer to wait and see how the initial projects are rolling out. The key element of the decision would be whether the SMR designers would be able to deliver on time and budget, and whether the NOAK units would really be as competitive as it is now advertised.

In terms of deployment, the NuScale project in Idaho was announced several years ago. The project went through several rounds of changes and it was sized down from twelve modules to six. With the design certification issued by the USNRC and the combined construction and operation licence being applied for, one could expect relatively rapid licensing in particular because the Idaho National Laboratory site is a low population zone and at present houses all kinds of nuclear facilities. The financing for the construction also seems to be (as published) assured.

In the EU, feasibility studies for SMRs are advancing in Estonia and Romania, with strong interest in NuScale's SMR also coming from Poland. Romania seems to have moved most rapidly with the site selection, which was in 2022 reviewed by the IAEA [84], as well as with the definition of the project itself, including, as per latest news [110] the financing. The Estonian regulator and the promoter (Fermi energy) are undertaking extensive assessment of potential sites (4 sites were preliminarily selected). Upon completion of the site selection a national referendum is planned as a precondition to the initiation of the project. For these countries the licensing (in particular in Estonia that does not have operating nuclear facilities on its territory, and Poland that would be all busy with the licensing of the just-announced 3 units of Westinghouse AP 1000 and 3 units of Korean APR 1400 Gen III reactors) will be a challenge. Apart from feasibility studies there are no indications that any financing packages are assured. The US Exim Bank has announced its readiness to fund some of the SMRs in foreign countries, but that might take some time to materialise, as banks and also other countries prospective clients would simply wait until first NOAK SMR would start operation. In Estonia and Poland, the need for an experienced nuclear operator, as well as local construction and supply chain will be among challenges to resolve. It is less so in Romania, where Nuclearelectrica is leading the project, but it also plans to complete and put into operation the Cernavoda units 3-4 generally about the same time, adding the pressure on its own resources.

Relatively rapid deployment also looks feasible for the BWRX-300 at the Darlington site in Canada. Ontario Power Generation (OPG) looked into numerous SMR designs and decided for BWRX-300 because of the maturity of the design, relatively large size as compared with others, and relatively clear prerequisites for the licensing (as it is a downsized ESBWR that has the US design certification). Darlington is also the site of 8 CANDU reactors, adding to the availability of human resources needed for the implementation. The financing of the site is supported by a 970M CAD loan from the Canada Infrastructure Bank and likely will be supported by other low carbon grants. It has been announced that the beginning of the operation of BWRX-300 SMR at Darlington will be in 2028, which in the view of the authors of the report is an ambitious plan, as so while OPG already submitted application to CNSC for licence to construct and phase 1 and 2 of the pre-licensing vendor design review completed in March 2023 further licensing activities are just to start. Moreover BWRX-300 is also at very initial licensing phase in the USA (so far just 5 topical reports were submitted to the regulator).

In order to smoothen the deployment, NUWARD Consortium established the International NUWARD Advisory Board (INAB) that include EDF UK, Fortum (Finland), OPG (Canada), TVO (Finland), ÚJV Řež (a company of CEZ Group, Czech Republic), Bhabha Atomic Research Centre - BARC (India), MIT (USA) and Politecnico di Milano (Italy). The INAB is expected to meet regularly throughout the different phases of NUWARD development and would likely be a key driver for the successful NUWARD deployment. However, as NUWARD is just out of the conceptual design phase, this will take considerable time, even the announced date of first concrete in 2030 is challenging, given that EDF is interested to start construction of six (and possibly 10 more) EPR2 units at the same time. The consideration of deploying NUWARD outside France is not clearly visible at present, although there is a MoU signed in Poland just recently. The participation of the Finnish (STUK) and Czech (SUJB) nuclear regulators in the joint design review gives a support to eventual deployment in those two counties, but it is very likely that everyone would wait for the completion of the first NUWARD unit in France.

The same applies to the Rolls Royce SMR, which also has strong backing from the UK government, availability of nuclear sites (of old Magnoxes and Advanced Gas Reactors - AGRs) as well as prospects for government guaranteed financing. Nevertheless, one could expect that the basic and detailed design will take its time, which a full licensing process could take a good part of 2 or more years. Rolls Royce is said to have an advantage in the existing supply chain and management capabilities for the marine propulsion reactors, but it is questionable how much of those could be used for a very different reactor, as the RR SMR is. The author of this report does not see the prospect of first concrete for the RR SMR earlier than towards the end of this decade.

For the SMR 160, there are also various activities going on. While the SMR 160 was initially discussed with Ukraine a few years ago, with a plan to complete the licensing process there and start the construction, no practical steps were undertaken so far, even if there were discussions on some localization of SMR160 manufacturing in Ukraine.

Holtec has been discussing with its utility clients on possible deployment, and a MoU has been signed with CEZ in 2019, and followed more recently with an industrial agreement with Skoda and Doosan of South Korea. In the US, the MoU is in place with the large nuclear operator Entergy. Holtec is applying for a US Department of Energy (DOE) loan to build a factory to manufacture components for SMR 160. It is likely that at least one SMR 160 would be co-located with the manufacturing plant. The SMR 160 might have a challenging licensing. Unlike BWRX-300 that is building upon a certified design, SMR 160 is a new design (though using many features of the current LWR designs). As a result, the licensing process will take a longer period to proceed.

The 125 MWe Chinese PWR ACP100 is under construction, planned to enter the commercial operation in 2026. The original design was completed in 2014; licencing process by NNSA was on going in parallel with the design. It is claimed that the design's safety has been independently verified using western safety codes, including RELAP and MELCOR. Furthermore, as the first ever SMR, the ACP100 was subject to the generic review of the IAEA in 2016. The construction was approved by China's State council in 2021 and the first concrete poured in July 2021. The construction time is estimated within 58 months (which per se is a bit long for a SMR; though not necessarily for a FOAK). The construction is advancing though it is not known whether it is in accordance with the schedule.

Another important element of the deployment is that (many) of those expressing interest in SMRs are not traditional nuclear operators. When going deeper in the preparation, those may be finding that the requirements for nuclear operators are complex and not easy to fulfil. This would become obvious during licensing, where the regulators would inquire on the engineering capabilities, knowledge, resources, etc. It is likely that the deployment of SMRs for companies that are not nuclear operators/utilities will not come in the first wave, but wait for experience to build up (possibly the appearance of contract operators which will then, for a fee, operate several facilities) or some other arrangement might come to the market. Such arrangements are apparently being offered by RR SMR, who teamed up with Entergy of US, who operated multiple nuclear units at 4 US sites to provide the operators (and apparently broader operational support; the details of the arrangement are not known). Such an arrangement would still need to be scrutinised by the regulators.

In the estimate of the author of this report, the prospects for deployment of SMRs, at least in the EU, in this decade are limited. Unlike a prediction made by Fortum that projected "dozens" of SMR in the operation in the EU by 2035 and thousands by 2050", we believe that by 2030 there will a few SMRs under construction and possibly few in operation anywhere in the world. Also, it is even less likely that those would be in the EU. Any meaningful decision on massive deployment of the SMRs, especially in the EU, could be taken only after “pilot” projects are implemented and proved to be successful.

6 ECONOMICS OF SMRs

Some of the information revealed by the designers is provided in the specific tables later in this report. The estimates for the LCOE are between 40 and 60 Euro per MWh and in the range of 3000-4000 EUR per installed kW. Those are the targets rather than the values that are the basis of any reliable sources, and are likely subject to various assumptions e.g. the operating hours in a year; financing concept and costs; site construction schedule, etc. The developers and vendors are not publicly coming out with any detailed projections for the construction costs and the operation costs, likely because those are rather uncertain, given the early stage of the development (that is a part of the latest estimate by NuScale, which is quoted earlier in this report).

For the SMRs, the utilisation of passive systems as well as cost reduction both in the terms of fewer components, and in terms of optimised erection and construction are main pillars of the concept. For this, passive systems would result in (generally) fewer components. Modular construction by assembling pre-fabricated and tested elements would result in optimised costs due to a reduction of the on-site activities. However it should be noted that this will require substantial initial investments into SMR fabrication and supply chain.

The SMR design deploys simplification, modularisation and industrial production, while using inter alia proven safety concepts. The GE-Hitachi BWRX-300 is to an extent a scaled down ESBWR. The designer claims to be able to achieve a 60% cost reduction from an ESBWR on the installed kW basis. The Rolls Royce 470 MWe SMR is promising at least 40% cost reduction per installed kW. It has to be noted that only a fraction of those savings (in the view of the author of this report, small) might be due to passive system and other optimisations. The main driver of the cost reduction is in the very concept of a modular design, industrial production of modules, limited activities on site. Those are surely contributing to savings, but when compared to traditional NPPs, the biggest savings would be in the financing, as there is a big difference if the construction period is 2-3 years or 5-10 years, during which the interest on the capital needs to be paid.

It could be assumed that all those factors might impact the price of the installed kW of SMR, and that the price could ultimately be lower than the large NPPs that are under construction today. How much that would be is very difficult to estimate. In particular the perceived reduction would apply to the NOAK installation, for which it leads to a price reduction of 30% or more as compared to FOAK. That means that the kW unit price could become competitive only with several dozens of SMRs being constructed.

The price of construction is only one factor that is a part of the LCOE. All nuclear units have operation and maintenance (O&M) costs, which while lower than thermal plants are still (much) higher than those of renewables. For the large nuclear, the overall O&M costs are in the range of 10 – 20 Euro per MWh (those very much depend on how the modifications are calculated, as investment or as being included in O&M).

There is not much information available on projected O&M costs for SMRs. It should be highlighted that all SMRs reviewed here are designed to have a long operation period (24 months between refuelling) to reduce the maintenance of equipment, positioning of components for ease of access, etc. Still, having 12 modules (each having a reactor) to refuel as compared with one for a large reactor could be expected to add to the cost of operations. The secondary circuit equipment like turbines, generators, secondary circuit pumps, etc., are all more or less traditional, requiring energy to operate, testing and maintenance, etc. Having multiple modules would naturally increase the number of active secondary circuit components that are subject to maintenance. Taking all this into account may lead to the conclusion that the O&M costs of SMRs would likely be higher (per generated MWh) than the large NPPs.

Another issue with the SMRs is their operating time. Large nuclear and SMRs likewise are economically best suited to operate as the baseload, when the cost of construction would be split over the maximal production hours. However, when operating in the load-following mode and generating electricity for a shorter period of time, the construction costs is distributed to a lower total energy produced. The O&M cost remains only marginally lower with lower generation, as the savings resulted from the lower fuel utilisation represent a small fraction of the O&M costs;

the staff costs, maintenance, consumables, etc., all remain more or less the same).

The utilisation factor of SMRs is claimed to be in the range of 90-95%, but this will strongly depend on how often and how much the load will be reduced in the load follow mode.

Therefore, for the SMRs to be cost competitive, other ways of utilising energy are to be found. The SMR designers are all envisaging various utilisation modes for SMRs, including district/industrial heating, desalination, etc. LWR SMRs are not appropriate for the high temperature industrial heat (gas cooled reactors are). LWRs could be used for heating and special industrial purposes. Generating hydrogen from electricity when the grid does not need it and then using hydrogen when there is a need to produce additional power (so called "power2storage2power") is one often mentioned way improving utilisation of nuclear. However, with current technologies of the electrolyser and the turbine both are very expensive and have a low efficiency, with almost 50% of electricity being lost.

Given the above considerations, in the terms of pricing, the SMRs will have multiple challenges to be competitively priced in a renewables dominated grid.

Another issue with the SMRs is that both the construction costs and the operation cost are now only being projected. The initial experiences of FOAKs and operating costs of first SMRs will reveal the actual truth about those. One thing is obvious, that due to a significant saving on the financing cost, both due to a shorter period before a SMR would start production and a lower unit price (which results in a lower "risk premium"), SMRs might have a sizable investment cost advantage to the large nuclear plants. Then the factory-based production, multiple identical modules and comparably little site work are all likely to add to the cost competitiveness. Even considering the "penalty" for likely higher construction costs per installed kW and possibly higher O&M cost, the SMRs are very likely to be more financeable than large NPPs. Nevertheless, it has to be noted that at least some cost projection by SMR promoters and developers are likely to turn out to be too optimistic.

7 COMPLEMENTARY OPERATION WITH RENEWABLES, OTHER APPLICATIONS

Many SMRs developers are indicating as one of their design goals is to be able to efficiently and economically operate with renewables. In order to do that, the SMR designers are envisaging fast ramping up and down possibility between a 20 and 100% load. For the SMRs that are indeed "modular" (e.g., NuScale SMR, that has up to twelve 77 MWe reactors; but not really the RR SMR, which is a single 470 MWe unit) there are possibilities to shut down some of the modules when there is no need for power. When properly designed all SMRs (as other plants) could use the turbine bypass, and in such a way allow for even more flexibility.

While there are not many publicly available studies of operation of SMR with renewables, a noteworthy one, that provides information on the possibilities and limitations, is the NuScale study Ref [35], where the developer models the operation of one NuScale module on an isolated grid with renewables. As part of its design concept, NuScale offers a power management option (marketed as "NuFollow"), which includes:

- Manoeuvring reactor power of one or more modules during intermediate periods to compensate for hourly changes in demand or wind/solar power generation;
- Bypassing the module's steam turbine directly to the condenser for rapid responses to load variations;
- Taking one or more modules offline for extended periods of low grid demand or sustained wind output.

To illustrate this ability, NuScale uses a hypothetical scenario of a single module (50 MWe) coupled with a small wind farm within an isolated grid. For such a case, as shown in the Figure 1 a NuScale module could adequately compensate for the variability of wind output by deploying the power manoeuvring and the turbine bypass.

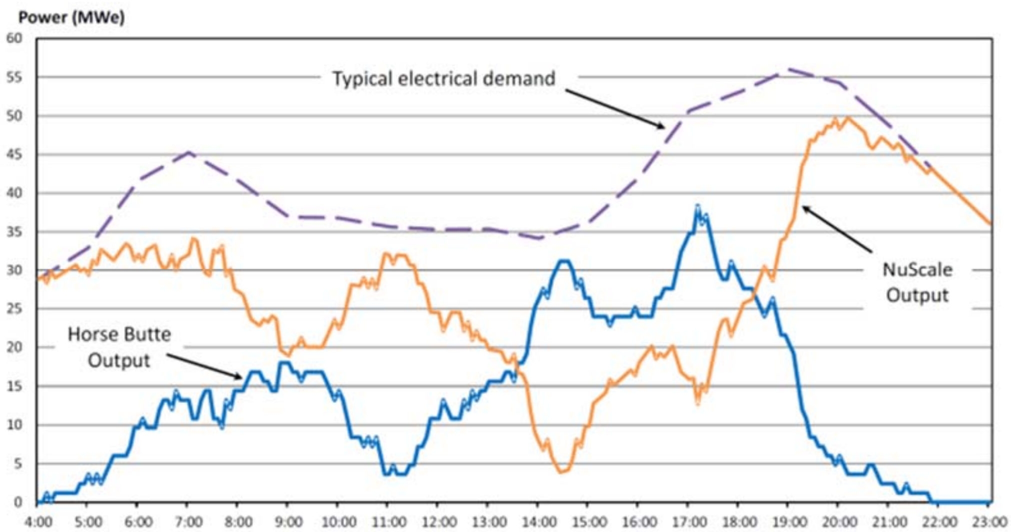

Figure 1: Hypothetical case of operation of NuScale module with a wind farm (Source ref [35], "Can Nuclear Power and Renewables be Friends")

While this case study shows a possibility for a joint operation (i.e., complementary) of a SMR and renewables, it also illustrates the extreme challenges of such an operation. In this case (at least it appears so) there is enough installed capacity of each wind and SMR, to cover the full consumption at any time. In other words, this means that this isolated system has 200% capacity to cover a maximum of 100% needs.

The above NuScale study modelling indicates that SMRs could compensate for the variability of the output of renewables. Such operation is technically feasible, though there are some limitations to be considered. When operating on reduced power, neutron flux in the core is distorted, leading to an inefficient utilisation of nuclear fuel. There are limits of such operation, in particular as the core is coming towards the end of fuel cycle, due to low excess reactivity available. Operating the reactor at a certain power level and dumping steam into the condenser by using the bypass is a waste of generated energy. Finally, the operating mode when some modules are shut down, and then would restart would be, for some time, limited by the "Xe poisoning" effect in a reactor, which requires a high positive reactivity to overcome. This might create certain operational limitations when a relatively quick restart after shutdown is required to follow the load.

Nevertheless, likely the biggest obstacle of such operation is the cost. When operating in a grid that is dominated by renewables, SMRs might be having relatively few active operating hours. With O&M costs being more or less the same regardless whether a SMR is generating power or not, that means that the LCOE of an SMR will be high.

Therefore, to be economical and indeed to make best use of the energy they generate, the SMRs likely need other uses beyond generation of electricity. Those might be uses of residual heat (which is not that much different than for thermal or nuclear plants that are used for district heating, or heating greenhouses, etc.) or industrial heat. Uses like desalination are often mentioned for SMRs, including in particular the ACP100, where it was a part of its design concept. Generation of hydrogen is another potential possibility to use the energy generated by SMRs.

It needs to be said that those alternative applications are proposed or considered and none, so far, have been implemented and tested. The development over the next few years, coupled with construction of initial SMRs is likely going to show the challenges that would need to be addressed prior further deployment of SMRs and alternative uses of energy they could generate.

8 CONCLUSION

Some countries including several EU MS are presently using and considering the use of nuclear power in their energy mix. The traditional large nuclear plants, with their high complexity and ever expended construction periods are being seen by many as (far) too expensive (and uncertain) to build and operate. This triggers the interest in different types of reactors, that could be (largely) factory built, with short(er) construction periods and manageable financing. This led to the concept of Small Modular Reactors, that would consist of (numerous) prefabricated modules that would be assembled on a site, to provide power comparable to a large nuclear plant. The SMRs are claimed to deploy the best features of nuclear plants while addressing two of the biggest drawbacks of large Gen III plants: complexity/duration of construction and related costs.

With this in mind, nuclear developers worldwide started designing a wide variety of SMRs, exploring all possible reactor concepts. The IAEA book on SMRs lists more than 80 different types in various stages of development. Those SMRs also use a wide variety of technologies, from traditional light water reactors, over gas, liquid metal and salt cooled reactors to fast reactors. Furthermore, various SMRs are designed for different utilisations. Most SMRs are designed for electricity production and there are some that are mainly or only focused on generating heat that is to be used either industrially or for other purposes. From that variety of SMR models, the light water technology (both pressurised water reactors- PWRs and boiling water reactors BWRs) are the most advanced in the development, and most likely to be licensed, contracted and likely constructed in the future. It is reasonable to expect that all other SMR models (among which high temperature gas cooled reactors are likely more advanced than e.g. molten salts ones) would be at least 5 or more years behind the LWRs. This is the specific reason why this study focused on the LWRs, as there is the highest likelihood that those might be selected for construction and possibly also constructed in the neighbouring counties or other EU MS within the next decade.

When judged by announcements and all the various agreements signed, one would expect that there will be dozens of SMR projects already starting up around the world. In reality this is not the case and it is very likely that a broad roll-out of SMRs might not happen in the next ten years.

Although the 6 designs covered in the report - NuScale VOYGR, BWRX-300, NUWARD , Rolls-Royce UK SMR HOLTEC SMR-160 and ACP100 are the likely most prominent and developed ones, these still have numerous challenges to overcome. Some of those challenges for the 6 reviewed SMRs are technical, other are licensing related and large challenges remain with manufacturing and then actual deployment of SMRs. The proof that the SMR models fulfil what their developers or promoters are claiming would only be obtained when not only a FOAK, but also series of NOAKs are constructed and successfully operated. Until then, all the predictions, promises and prognoses need to be considered somewhat speculative.

Licensing may be expected to remain a challenge for SMRs in the EU, as some novel design solution, material and manufacturing may/would require detailed assessment to be undertaken by regulators. In some cases the established acceptance criteria would need to be modified. Among challenges during licensing are the wide deployment of passive systems, design concept of the containments, shared systems and/or MCR among modules/units, specific design features (e.g. lack of boron injection) as well as impact of external hazards. The other licensing challenges might be expected related with the qualification of operators, as well as of the operating organization, in particular when an operator is a newcomer to nuclear operations.

One of the arguments for SMR is that the safety level is higher than for traditional reactors, even that for Gen III plants. The smaller size of the core means that less heat needs to be removed and dissipated in the environment (ultimate heat sink). Multiple passive systems and features would assure safety in cases like loss of offsite power or station blackout. While passive systems could generally be considered more reliable than active ones, those need to be thoroughly analysed in every operating mode to ascertain that this is really the case.

While SMR designs in general claim a possibility to seamlessly operate in a grid that is dominated by renewables, even if technical capabilities are there, such a generation will increase the costs of the operation resulting in the electricity generated being more expensive than it would be otherwise. Prolonged operation at low power level might negatively impact the core and the fuel utilisation, both increasing the costs and needs for management of SNF and radioactive waste.

Unlike modern large NPPs, some of SMRs analysed are reporting a lower burn up, which means that the generation of SNF will be higher than in a reactor with higher burn up. Apart from that, the fuel and fuel cycle related issues are not significantly different for SMRs than for traditional NPPs.

Multiple SMR modules that need to produce the same amount of energy as a large nuclear plant would likely indicate higher radioactive waste generation. The composition of waste generated is not expected to be much different than for a large LWR, having solid, liquid and gaseous radioactive waste. In term of the facilities for processing and storage of radioactive waste on sites, those are expected to be comparable with large reactors. All systems and structures that are needed to collect, retain, process and package (including volume minimisation) radioactive waste at a large plant is expected to be needed at each SMR site. That is a disadvantage in cases where e.g. one or a small number of SMRs are constructed at one site. The storage of SNF is another issue, requiring more space/large facilities as there will be more fuel elements to be stored

In terms of supporting generation of hydrogen using an electrolyser, there would be no distinctive advantage of a SMR as compared with any other electricity generating facility. In a mode, where the electrolyser would operate when there is excess electricity, would result in intermittent operation and likely limit operating hours at full capacity of the electrolyser. In this respect more promising technology for hydrogen production are the HTG SMRs with their higher operating temperatures, as effectiveness of the high-temperature steam electrolysis improves at high temperatures.

For the 6 SMRs reviewed, the intellectual property issues or the technology supply issues are not expected to be a limiting factor. While all the details are not known, nor would be available before the detailed design is completed, it is reasonably likely that each of the 6 will have its own technology to be able to manufacture and construct a SMR.

Any reliable predictions of costs of SMRs are not seriously possible at this stage of the development. While there are some parameters offered by the developers, only when the detailed design is completed, manufacturing including the supply chain is in place and not just FOAK but NOAKs are constructed the actual cost would become reliably available. It is nevertheless quite feasible that the modular design and factory based manufacturing will lead to a significant reduction of the on-site activities and in relation with this less complexity and significant reduction of construction schedule as compared with large NPPs. All of this directly might contribute to lowering cost of capital, and in establishing the cost advantage of SMRs as compared with large plants, but this would need to be proved by construction and safe operation of the SMR based plants.

The SMRs are promoted to be addressing the most critical issues related with traditional nuclear power plants, by promising enhanced safety, higher flexibility in operation and reduction of construction duration/complexity while offering reduced costs. Some of those might became reality (e.g. financing cost being lower due to shorter construction), but other challenges remain to be resolved, those being e.g. design and materials, manufacturing and supply chain, as well as those licencing related. It cannot be ruled out that problems, which are difficult to foresee today, could arise during the realisation of SMR, from overoptimistic projections over licensing challenges, limited market size, etc.

Considering the numerous challenges and uncertainties as highlighted throughout this report, it is questionable whether currently announced predictions regarding the deployment of SMRs would indeed materialise and in which timeframe.

Therefore, a conclusion whether the SMRs could be expected to become a part of the future energy mix cannot be reliably made at this stage. Only when first few SMRs are constructed and operational, when more experience is gained in all phases of the lifecycle of SMRs, it would be possible to comprehensively assess their value on all points of interest.

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ANNEX 1: FACTSHEETS OF 6 SELECTED SMRS

NUSCALE

The design of the NuScale SMR includes the following novel features:

- Integrated reactor design (Nuclear Steam Supply System (NSSS) and primary containment is a single module)
- Extensive use of passive systems
- All Nuclear Power Module (NPM) are partially submerged in safety pool, which serves as ultimate heat sink and located below the grade (underground)
- Containment maintained under vacuum during normal operation.

MAIN NUSCALE FEATURES AND CHARACTERISTICS

The NuScale VOYGR [3, 5, 6, 7] is Small Modular Reactor which design is based on PWR technology. Depending on request/needs the design might include four, six or twelve Nuclear Power Modules (NPM) module with 250 MW thermal power/77 MW electric output.

Each of NPM includes reactor coolant system (RCS), reactor pressure vessel (RPV), pressurizer, two steam generators (SG), reactor vessel internals (RVI) and associated piping and valves and all of those are accommodated inside a containment vessel with vacuum maintained inside, which in turn is submerged in the reactor pool.

The reactor core is formed by 37 assembles in standard 17 x 17 LWR configuration, using UO2 fuel with Gd2O3 as a burnable absorber.

Parameter	Description[3, 5, 6, 7]
Reactor type	PWR
Rated power	250 MWth / 77 MWe per module (up to 12 generation modules at the plant)
Reference site	A standard nuclear or a site of a thermal plant
Design lifetime	60 years
Seismic Design (SSE)	0.5 g
Intended application	Commercial-Electric, heat generation, hydrogen production
Concept of utilisation	Baseload, Cogeneration, Load Following
Load following modes	20% to 100% power (~1% per minute), *(compliant with EPRI URD)*
Coolant/moderator	H_2O/ H_2O
Neutron spectrum	Thermal
Primary circulation	Natural
NSSS Operating Pressure (primary/ secondary), mPa	13.8 / 4.3
Core Inlet/Outlet Coolant Temperature (°C)	249 / 316

Parameter	Description[3, 5, 6, 7]
Fuel type	UO_2
Fuel enrichment (%)	≤ 4.95
Burnable absorber	Gd_2O_3
Number of fuel assemblies	37
Core Discharge Burnup (GWd/ton)	≥ 45
Refuelling Cycle (months)	24
Reactivity control	Control rod drive, Gd_2O_3, boron
Safety features	NSSS and CNV immersed in reactor pool (passive long-term cooling and retention of fission product) No operator actions are required for safety Decay Heat Removal System–- 2@100% Emergency Core Cooling System Spent Fuel Cooling–- 150 days of passive cooling
Ultimate heat sink	30 days heat removal capacity for 12 modules without AC/DC, followed by air cooling for an unlimited length of time
CDF	$3*10^{-10}$ per module per year (internal events)
LERF	$2*10^{-11}$ per module per year (internal events)
Main Control Room	Single room for 12 modules plant
Design life (years)	60
Site footprint (m^2)	140 000 (VOYGR -12 modules)
Construction time	36 months from the first safety concrete [24, 38]
Target operation date for FOAK	2029 [3, 33, 40]

NUSCALE PRO AND CONTRA

PRO	CONTRA
Design features	
Proven PWR/LWR technology	Low secondary side parameters reduce efficiency of the plant
Modular design and size/rated power eliminate on-site modules assembling	Each power generation module is equipped with own turbine and Balance of the Plant systems, thus substantially increasing maintenance activities
Natural circulation of the coolant eliminates active elements, and has a positive impact of plant's reliability	Natural circulation, increases thermal stresses on the NSSS components as core Delta-T is higher if compared with forced circulation reactors
Concept of passive safety systems eliminates active elements and improves their reliability	Novel integrated design has not been proved by operation Concept of passive safety systems is not proved by operation
	Hydrogen cogeneration feature will increase plant's capital costs. If feature is not used on continuous basis generation of hydrogen using only "spare" electricity will completely

	diminish its added value as "stability" of generation will not be ensured.
Small size EPZ (plant fence) approved by the USNRC	Small size EPZ is unlikely to be accepted in the EU countries where population density is higher than in many US locations.
Low CDF and LERF values due to specific of the design (i.e. submerged containment and passive safety systems)	Currently claimed low CDF and LERF values are related to internal events only and therefore could substantially increase due to site specific external factors While use of single MCR to certain extent reduce the costs, this solution is however to certain extent questionable as increases the probability of Common Cause Failure (CCF) of MCR caused by e.g., fire. Single MCR also has some operational deficiencies, as will distract all operators by start-up, shut-down or unit trip alarms having place in a single MCR. Reference US NuScale design has very limited capacity of the on-site RAW management facilities and this might become a bottleneck when numerous SMRs deployed, thus requiring regular transportation of RAW to the storage/processing facilities by generic public roads.
Licencing status	
Design Certification Application completed in Aug 2020. Final ruling approving NuScale design published in January 2023 USA: Combined licence application (COL) for SMR UAMPS plant planned to be submitted in January 2024. CANADA: Pre-licensing Vendor Design Review (VDR) started in January 2020 In 2019 Memorandum of Cooperation between the U.S. NRC and the CNSC to accelerate the review and approval of NuScale's SMR technology in Canada was signed.	No licensing activities in the EU so far Numerous exemptions of the standard review plan in US likely to increase scrutiny in the EU The initial licencing process did not addressed: (1) the shielding wall design in certain areas of the plant; (2) the potential for containment leakage from the combustible gas monitoring system, and (3) the ability of the steam generator tubes to maintain structural and leakage integrity during density wave oscillations in the secondary fluid system All these issues will be addressed at COL stag
Deployment status and prospects	
USA: Utah Associated Municipal Power Systems (UAMPS); with 6 modules and rated power on 462 MWe 2023 Start fabrication/construction of first full-scale NuScale SMR COL planned to start in January 2024 and be completed by 2025 2029-30 Commercial operation of first NuScale plant in US in Idaho Falls, Idaho in frame of the Carbon Free Power Project (CFPP)	
Romania: MOU for NuScale 6-module, 462 MWe, signed with Nuclearelectrica in May 2022 for Doicești site. Nuclearelectrica and Nova Power & Gas have launched in September 2022 a joint venture, RoPower Nuclear, for the development of NuScale SMR technology. The Doicești site peer reviewed by the IAEA and found acceptable Estonia: A MoU sinned in August 2022 between NuScale Power and Fermi Energia in evaluating the deployment of a NuScale SMR plant in Estonia by 2031.	While preferred Doicești site is pre-selected it is not quite clear what would be the scope of licensing and whether and to which extend licensing in US will be considered by CNCAN.

BWRX-300

The design of the BWRX-300 SMR includes the following novel features:

- The Containment housing NSSS is located mostly below grade
- Passive containment cooling system
- Passive decay heat removal
- Submerged section of the containment dome

MAIN BWRX-300 FEATURES AND CHARACTERISTICS

The BWRX-300 [3, 5, 6, 7] is Small Modular Reactor which design is based on BWR concept of the Light Water Reactor. The reactor represents itself a single module with 870 MW of thermal power and 300 MW electric output. The BWRX-300 use of passive systems like Isolation condenser system, passive containment cooling system and Reactor Pressure Vessel Isolation valves. All three systems are aimed at isolation of the Reactor Pressure Vessel and residual heat removal for the reactor and containment.

The reactor core is formed by 240 GNF2 fuel assemblies that are using Hf, Gd_2O_3 burnable absorbers.

Parameter	Description[3, 5, 6, 7]
Reactor type	BWR
Rated power	870 MWth / 300 MWe
Reference site	Single module
Design lifetime	60 years
Seismic Design (SSE)	0.3 g
Intended application	Commercial – Electric, District Heating
Concept of utilisation	Baseload, load following.
Load following modes	Load following within a range of 50 to 100% (0.5% per minute)
Coolant/moderator	H_2O/ H_2O
Neutron spectrum	Thermal
Primary circulation	Natural circulation
NSSS Operating Pressure (primary/ secondary), mPa	NSSS Operating Pressure (primary/secondary) 7.2 / n/a
Core Inlet/Outlet Coolant Temperature (°C)	Core Inlet / Outlet Coolant Temperature 270 / 287 (°C)
Fuel type	UO_2
Fuel enrichment (%)	3.40 / 4.95% (avg./max.)
Burnable absorber	Hf, Gd_2O_3
Number of fuel assemblies	240 GNF2 fuel assemblies
Core Discharge Burnup (GWd/ton)	49,5 GWd/t
Refuelling Cycle (months)	12-24 months

Parameter	Description[3, 5, 6, 7]
Reactivity control	Control rods, Hf, Gd_2O_3 and natural circulation flow control
Safety features	Isolation condenser system–- ICS (four 33 MWth trains) Passive containment cooling system (PCCS) Reactor Pressure Vessel Isolation valves
Ultimate heat sink	ICS 7 days of reactor decay heat removal without power or operator action during abnormal events. Duration could be extended by replenishing the ICS pool inventory PCCS does not have any active elements and is always in stand-by mode
CDF	$<10^{-7}$
LERF	$<10^{-8}$
Main Control Room	Single per unit
Site footprint (m^2)	26300
Construction time	30-36 months from the first safety concrete [43, 44, 54]
Target operation date	2028 Commercial Operation in US and Canada[43, 45, 54]

BWRX-300 PRO AND CONTRA

PRO	CONTRA
Design features	
Proven BWR technology	
Natural circulation of the coolant eliminates active elements and has a positive impact of plant's reliability	Module design with rather high rated power might require some on-site module assembling works
Lower primary circuit pressure due to BWR design specific Inerting containment with nitrogen	BWRX—300 hydrogen accumulation risk in case of accidents is not yet demonstrated (subject to specific PSAR analysis)
Decay heat removal without power or operator action could be extended by replenishing the ICS pool inventory	While BWRX-300 claims use of passive safety systems and no necessity of the AC power, the operation of the ICS for RPV depressurization and decay heat removal requires one-time automatic actuation using onsite Class 1E battery-backed DC power (subject for additional review during application process) PCCS design is not finalized yet (2022 Licensing Topical Report)
Passive containment cooling system does not have any active elements and is always in stand-by mode	Concept of passive safety systems is not proved by operation
Safety Relief Valves are the most likely cause of a LOCA eliminated from the design.	
Use of well proven GNF 2 fuel	
Licencing status	

USA: GEH submitted to NRC total of five Topical Reports for the GEH BWRX-300 SMR Design CANADA: Pre-licensing vendor design review started in January 2020 UK: Pre-licensing vendor design review started in January 2020.	Licensing of the BWRX-300 is at very initial phase in countries with most clear prospective for the SMR deployment. Licensing process in US, Canada and UK might be used to study/investigate potential open issues
Deployment status and prospects	
USA: August 2022 Tennessee Valley Authority (TVA) entered an agreement with GEH on deployment of a BWRX-300 at the Clinch River site near Oak Ridge	
Canada: December 2021–- Deployment of BWRX-300 at Darlington nuclear site in Ontario by 2028 June 2022— BWRX-300 small modular reactor (SMR) has been selected by SaskPower for potential deployment in the mid-2030	
Estonia: September 2022–- Fermi Energia AS has issued invitations to tender for three new generation small modular reactor developers: General Electric / Hitachi BWRX-300, NuScale VOYGR and Rolls Royce UK SMR.	

NUWARD

The design of the NUWARD SMR includes the following novel features:

- Integrated reactor design
- Passive core injection
- Passive decay heat removal
- Submerged containment providing passive cooling for several days
- Small core in a large vessel supports in-vessel retention strategy
- Passive flooding of vessel pit
- Boron-free design to reduce generated effluents

MAIN NUWARD FEATURES AND CHARACTERISTICS

The NUWARD [3, 5, 6, 7] is Small Modular Reactor which design is based on PWR concept. The SMR is of dual-unit concept with 2*540 MWth thermal power and 2*170 MWe electric output modules.

The NUWARD safety concept is that in Design basis conditions no operator's action required for more than 3 days, no additional external ultimate heat-sink required for more than 3 days, no external power supply (normal and emergency) required for more than 3 days; no primary depressurization system required. The unit reactivity control is not using soluble boron acid and therefore limits amount of effluents generated during operation.

The reactor core is formed by 76 assemblies in 17 x 17 configuration that are using Gd2O3 burnable absorber. The core discharge burnup characteristics will be determined at detailed design phase.

Parameter	Description[3, 5, 6, 7]
Reactor type	PWR
Rated power	2*540 MWth / 2*170 MWe
Reference site	Dual unit
Design lifetime	60 years
Seismic Design (SSE)	0.3 g
Intended application	Commercial – Electric and desalinisation
Concept of utilisation	Baseload and load following
Load following modes	Load following within a range of 20 to 100% (5% per minute)
Coolant/moderator	H_2O/ H_2O
Neutron spectrum	Thermal
Primary circulation	Forced circulation (6 pumps)
NSSS Operating Pressure (primary/ secondary), mPa	NSSS Operating Pressure (primary/secondary) 15/4.5
Core Inlet/Outlet Coolant Temperature (°C)	Core Inlet / Outlet Coolant Temperature 280/307 (°C)
Fuel type	UO_2
Fuel enrichment (%)	<5%

Parameter	Description[3, 5, 6, 7]
Burnable absorber	Gd_2O_3
Number of fuel assemblies	76 assemblies in 17 x 17 configuration
Core Discharge Burnup (GWd/ton)	Burnup characteristics will be determined at detailed design phase
Refuelling Cycle (months)	24 months
Reactivity control	Control rods and Gd_2O_3 burnable absorbers (boron-free design)
Safety features	Reactor shutdown–- 2 trains Core injection–- 2 trains Decay heat removal–- trains Containment N_2 injection Containment submerged in underground pool
Ultimate heat sink	No heat sink outside the Nuclear Island (NI) is required to ensure the safe-state for at least 3 days
CDF	$< 1x10^{-5}$
LERF	Practical elimination
Main Control Room	2 units share control room
Plant footprint (m^2)	3500 (site footprint is not yet defined)
Construction time	36 months from the first safety concrete [57]
Target operation date	2030 (first concrete) [57, 59, 60]

NUWARD PRO AND CONTRA

PRO	CONTRA
Design features	
Proven PWR technology	Low secondary side parameters reduce efficiency of the plant
Integrated reactor design Boron-free design reduces amount of generated effluents	Novel integrated and boron free design has not been proven by operation
The design includes 2 trains' passive reactor shutdown systems, 2 trains' passive core injection systems, 2 trains' decay heat removal and containment isolation and cooling	Forced circulation of the coolant requires use of active elements and has some negative impact of plant's reliability Concept of passive safety systems is not proved by operation CDF and LERF values are of preliminary nature. LERF is identified on qualitative basis
Licencing status	
NUWARD is at conceptual design phase, so no licensing activities carried out elsewhere	
Deployment status and prospects	

Strong state support–- intervention of the State up to €500 million for the NUWARD State investment in small, innovative nuclear reactors with better waste management foresees up to EUR 1 billion by 2030.	Strong state support is not always used to improve safety, but might have focus on the improved efficiency of the investments.
EDF plans to achieve first concrete in 2030.	Due to conceptual design phase prospective sites are not defined yet

ROLLS ROYCE

The design of the Rolls Royce SMR includes the following novel features:

- Passive Containment Cooling System
- Passive Decay Heat Removal system
- Passive Emergency Core Cooling System
- Small Leak Injection System
- Boron-free design to reduce generated effluents

MAIN ROLLS ROYCE FEATURES AND CHARACTERISTICS

The ROLLS ROYCE [3, 5, 6, 7] is Small Modular Reactor which design is based on PWR concept of the Light Water Reactor. The ROLLS ROYCE SMR is of single-module concept with 1358 MWth thermal power and 470 MWe electric.

The ROLLS ROYCE SMR design includes numerous passive systems aimed at supporting plant nuclear safety including among others: passive reactor shutdown systems, passive core injection systems, decay heat removal, containment isolation and cooling supported by two emergency diesel generators powering plant's active equipment and components.

The reactor core is formed by 121 fuel assemblies in 17 x 17 configuration that are using Gd2O3 burnable absorber. The core discharge burnup characteristics is claimed to be 55-60 GWd/t and is similar to values reached by large NPPs

Parameter	Description[3, 5, 6, 7]
Reactor type	PWR
Rated power	1358 MWth / 470 MWe
Reference site	Single unit
Design lifetime	60 years
Seismic Design (SSE)	>0.3 g
Intended application	Commercial – Electric
Concept of utilisation	Baseload, load following
Load following modes	Load following within a range of 50 to 100% (3-5% per minute)
Coolant/moderator	H_2O/ H_2O
Neutron spectrum	Thermal
Primary circulation	Forced circulation (3 pumps)
NSSS Operating Pressure (primary/ secondary), mPa	NSSS Operating Pressure (primary/secondary) 15.5 / 7.8
Core Inlet/Outlet Coolant Temperature (°C)	Core Inlet / Outlet Coolant Temperature 295 / 325 (°C)
Fuel type	UO_2
Fuel enrichment (%)	4.95%
Burnable absorber	Gd_2O_3

Parameter	Description[3, 5, 6, 7]
Number of fuel assemblies	121 fuel assemblies in 17 x 17 configuration
Core Discharge Burnup (GWd/ton)	55-60 GWd/t
Refuelling Cycle (months)	18-24 months
Reactivity control	Control roads and Gd_2O_3 burnable absorber (boron-free design)
Safety features	Emergency Boron Injection Passive Containment Cooling System Passive Decay Heat Removal Emergency Core Cooling System Small Leak Injection System Decay Heat Removal (DHR) System including Condenser DHR and Normal Residual Heat Removal (NRHR) Reactor Cavity Flooding PARs, Filtered Venting
Ultimate heat sink	72 hour grace time following a DBA, during which time no operator action is required
CDF	$<10^{-7}$
LERF	$<10^{-7}$
Main Control Room	Single control room
Site footprint (m^2)	40000 m^2
Construction time	24 months from the first safety concrete (NOAK) 48 month build schedule, which includes site preparation, construction, and commissioning [61]
Target operation date	2029-2030 planned FOAK commercial operation [67, 68]

ROLLS ROYCE PRO AND CONTRA

PRO	CONTRA
Design features	
Proven PWR technology	
No operator action is required during 72 hours following DBA	Forced circulation of the coolant requires use of active elements and has some negative impact of plant's reliability
The design includes 2 trains' passive reactor shutdown systems, 2 trains' passive core injection systems, 3 trains' decay heat removal, 3 trains containment isolation and cooling supported by two emergency diesel generators	Concept of passive safety systems is not proved by operation Claimed value of the SSE >0.3g is too vague as in fact does not limit it. Clarification will be required at later licensing phase
Boron-free design reduces amount of effluents	Boron free design has not been proven by operation
	Module design with rather high rated power might require some on-site module assembling works
Licencing status	

UK: April 2022, ONR announced Step 1 of the General Design Assessment GDA process focuses on the design of a generic nuclear power station and is not site-specific.	Outcome of the GDA will be of limited usability due to its non-site specific, however it will allow to look at potential critical issues
Deployment status and prospects	
Rolls Royce identified in November 2022 a range of the existing nuclear power plant sites in the UK that could potentially host SMRs: Trawsfynydd, Sellafield, Wylfa, Oldbury, Berkeley, Hartlepool, Heysham, Bradwell. 2029-2030 Planned FOAK commercial operation	While sites' potential locations were preselected detailed site evaluations are still to be carried out.

HOLTEC SMR-160

The design of the HOLTEC SMR-160 SMR includes the following novel features:

- Integrated design
- NSSS located underground
- Passive Core Cooling System
- Secondary decay heat removal system
- Passive Containment Cooling System
- Start-up without off-site power (i.e., “Black start” capability)
- On-site underground storage of SNF
- 80-year service life

MAIN HOLTEC SMR-160 FEATURES AND CHARACTERISTICS

The HOLTEC [3, 5, 6, 7] is Small Modular Reactor which design is based on PWR concept of the Light Water Reactor. The HOLTEC SMR is of single-module concept with 525 MWth thermal power and 160 MWe electric output

The HOLTEC SMR design relies on use of passive safety systems with overall concept of indefinite passive cooling air cooling using available water inventories.

The reactor core is formed by 57 fuel assemblies in 17 x 17 configuration that are using burnable absorber. The core discharge burnup is 45 GWd/t that is lower than big NPPs.

Parameter	**Description**[3, 5, 6, 7]
Reactor type	PWR
Rated power	525 MWth / 160 MWe
Reference site	Single unit
Design lifetime	80 years
Seismic Design (SSE)	0.5 g
Intended application	Commercial – electric, district heating
Concept of utilisation	Baseload, load following, cogeneration, island-mode operation
Load following modes	Load following foreseen in design (range and ramp rates will be known at later design phase)
Coolant/moderator	H_2O/ H_2O
Neutron spectrum	Thermal
Primary circulation	Natural circulation
NSSS Operating Pressure (primary/ secondary), mPa	NSSS Operating Pressure (primary/secondary) 15.5 / 3.4

Parameter	Description[3, 5, 6, 7]
Core Inlet/Outlet Coolant Temperature (°C)	Core Inlet / Outlet Coolant Temperature 243 / 321 (°C)
Fuel type	UO_2
Fuel enrichment (%)	4.95% (4.0 average)
Burnable absorber	Foreseen, but not identified (subject to design development)
Number of fuel assemblies	57 fuel assemblies in 17 x 17 configuration
Core Discharge Burnup (GWd/ton)	45 GWd/t
Refuelling Cycle (months)	24 months
Reactivity control	Control rods and soluble boron
Safety features	Passive Core Cooling System Primary decay heat removal system (PDHR) Secondary decay heat removal system (SDHR) Automatic depressurization system (ADS) Passive core make-up water system (PCMWS) Containment and the Passive Containment Heat Removal System(PCHR) Start-up operations independent of the grid or “black-start.”
Ultimate heat sink	First 72 hours cooling by PCCS and PCHR < 90 days, passive cooling by PCHR > 90 days, indefinite cooling via passive air cooling
CDF	$<10^{-7}$
LERF	No data
Main Control Room	Single control room
Site footprint (m^2)	28,000
Construction time	36 months for the 1st SMR-160, with construction times reduced to 30 months or less for subsequent units (24 months for NOAK) [72]
Target operation date	2029-2030–- commissioning first set of SMR-160 plants in the US [75, 78]

HOLTEC PRO AND CONTRA

PRO	CONTRA
Design features	
Proven PWR technology	Low secondary side parameters reduce efficiency of the plant
Concept of passive cooling with indefinite passive air cooling	Concept of passive safety systems is not proven Indefinite passive cooling concept should be proved by calculations and tests.

Large size of the pressurizer eliminates any need in relief valves Fabrication and assembly of the largest shippable components prior to delivery to a site	Novel integrated design has not been proved by operation Unloading of the SNF into dry storage facility after second refuelling claimed by HOLTEC is to be further analysed as wet storage time is shorter than in any of known designs
Licencing status	
Pre-licensing activities started in USA in 2014, licensing activities in other countries did not start yet	Status of licensing activities and further delays could jeopardise target construction date even in US
Deployment status and prospects	
2030–- commissioning first set of SMR-160 plants in the US	Availability of SMR-160 for the deployment in the EU and other European countries could fall some 5-7 years behind scheduled deployment in US

ACP100

The design of the ACP100 SMR includes the following novel features:

- Integrated design
- NSSS located below the grade
- Passive core cooling
- Passive residual heat removal system
- Passive containment cooling
- Automatic Depressurization System
- Passive cavity flooding

MAIN ACP100 FEATURES AND CHARACTERISTICS

The ACP100 [3, 5, 6, 7] is Small Modular Reactor which design is based on PWR concept of the Light Water Reactor. The ACP100 SMR is of single-module concept with 385 MWth thermal power and 125 MWe electric output

The integrated design of the ACP100 reactor coolant system (RCS) foresees installation of the major primary circuit's components inside the reactor pressure vessel (RPV). The ACP100 safety concept is based on passive safety systems and use of the natural convection for cooling the reactor.

The reactor core is formed by 57 fuel assemblies in 17 x 17 configuration that are using Gd2O3 burnable absorber. The core discharge burnup is <52 GWd/t that is slightly lower than big NPPs.

Parameter	Description[3, 5, 6, 7]
Reactor type	PWR
Rated power	385 MWth / 125 MWe
Reference site	Single unit
Design lifetime	60 years
Seismic Design (SSE)	0.3 g
Intended application	Commercial – electric, district heating, industrial heating, seawater desalination
Concept of utilisation	Baseload
Load following modes	Load following is not highlighted among ACP100 features
Coolant/moderator	H_2O/ H_2O
Neutron spectrum	Thermal
Primary circulation	Forced circulation (4 pumps)
NSSS Operating Pressure (primary/ secondary), mPa	NSSS Operating Pressure (primary/secondary) 15.0 / 4.6
Core Inlet/Outlet Coolant Temperature (°C)	Core Inlet / Outlet Coolant Temperature . 286.5 /319.5 (°C)
Fuel type	UO_2
Fuel enrichment (%)	<4.95%

Parameter	Description[3, 5, 6, 7]
Burnable absorber	Gd_2O_3
Number of fuel assemblies	57 fuel assemblies in 17 x 17 configuration
Core Discharge Burnup (GWd/ton)	<52 GWd/t
Refuelling Cycle (months)	24 months
Reactivity control	Control rods, Gd_2O_3 and soluble boron
Safety features	Passive Core Cooling System Passive Residual Heat Removal System Passive Containment Cooling System Passive Cavity Flooding System Passive Hydrogen Re-combiner System Multi stages Automatic Depressurization System (ADS) No need for operator intervention after accident for 72 hours (DC) power source for accident mitigation up to 72 hours, supported by system to recharge the battery for up to seven (7) days ACP shell, protection from External Events Deep-buried NSSS
Ultimate heat sink	No active Emergency Core Cooling System No active containment spray and recirculation system
CDF	$<10^{-6}$
LERF	$<10^{-7}$
Main Control Room	Single control room
Site footprint (m^2)	200,000
Construction time	55-38 months (FOAK) [3, 106]
Target operation date	Target commercial operation in 2026 [3, 106]

ACP100 PRO AND CONTRA

PRO	CONTRA
Design features	
Proven PWR technology	Low secondary side parameters reduce efficiency of the plant
Novel integrated design Concept of passive core cooling, passive residual heat removal, passive containment cooling improves safety and reliability of the plant	Novel integrated design has not been proved by operation Concept of passive safety systems is not proven
No need for operator intervention after accident for 72 hours	Results of safety analysis are not available
Licencing status	
IAEA performed a generic reactor safety review for the ACP100 in 2016	No experience in licensing of the Chinese NPPs/nuclear facilities in the EU

CNNC has more than 30 years' experience in design and licensing of power reactors and nuclear facilities in China The ACP100 preliminary safety assessment report (PSAR) is approved by NNSA and detailed engineering design is ongoing	
Deployment status and prospects	
Commercial operation of SMR Linglong One demonstration SMR unit in 2026	

ANNEX 2: COMPARISON OF SIX SMRS ON DIFFERENT PARAMETERS

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD CEA/EDF/Naval Group/ TechnicAtome	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
1) Basic concept of the SMR						
Reactor type an	Integral PWR	BWR	PWR	PWR	PWR	Integral PWR
All six SMRs are LWR of designs that considered long-term operational experience and trend on extensive utilisation of various passive safety systems.						
Power level	250 MWth / 77 MWe	870 MWth / 300 MWe	2*540 MWth / 2*170 MWe	1358 MWth / 470 MWe	525 MWth / 160 MWe	385 MWth / 125 MWe
All six SMRs are of modular design that ease construction of the plants, however only 2 out of six - NuScale VOYGR and NUWARD use multiple generation module concept – 2 for NUWARD and 4, 6 or 12 modules for NuScale VOYGR. Multiple generation module concept improve SMR plant dispatching capabilities.						
Design lifetime	60 years	60 years	60 years	60 years	80 years	60 years
Five out of six SMRs have design life of 60 years. Eighty years of HOLTEC SMR-160 might not be accepted in the EU as it will be first precedent to assign 80 years lifetime at the design phase						
Coolant type	H_2O	H_2O	H20	H_2O	H_2O	H_2O
Neutron spectrum	Thermal	Thermal	Thermal	Thermal	Thermal	Thermal
All six SMRs are thermal-neutron reactor using water as coolant and moderator						
Core Damage Frequency (CDF)	$3*10^{-10}$/module (internal events)	$<10^{-7}$	$< 1x10^{-5}$	$<10^{-7}$	$<10^{-7}$	$<10^{-6}$
Large Release Frequency (LERF)	$2*10^{-11}$/module (internal events)	$<10^{-8}$	Practical elimination	$<10^{-7}$	No data	$<10^{-7}$
CDF and LERF substantially differ from one SMR model to other, however currently only NuScale VOYGR has a SAR that could confirm claimed values by calculations. SARs/proofs for CDF/LERF for other than NuScale SMRs, including the one of ACP100, which is said to have a level 1 PSA for internal events independently reviewed are not publicly available.						
Seismic Design (SSE)	0.5 g	0.3 g	0.3 g	>0.3g	0.5 g	0.3 g
The value of the SSE for 4 out of six designs is 0.5 g, claim for a robust design that could be installed almost at any location globally. However, it should be noted that only NuScale VOYGR has detailed design and SAR that could confirm value by calculations. SSE values are anyhow to be also confirmed by tests for some specific plant SSCs, as well as must consider specific site seismicity.						
Basic design data	Natural circulation NSSS Operating Pressure	Natural circulation NSSS Operating Pressure	Forced circulation (6 pumps)	Forced circulation (3 pumps)	Natural circulation NSSS Operating Pressure	Forced circulation (4 pumps)

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD CEA/EDF/Naval Group/ TechnicAtome	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
	(primary/secondary), MPa 13.8 / 4.3 Core Inlet/Outlet Coolant Temperature 249 / 316 (°C)	(primary/secondary) 7.2 / n/a Core Inlet / Outlet Coolant Temperature 270 / 287 (°C)	Integral NSSS NSSS Operating Pressure (primary/secondary) 15/4.5 Core Inlet / Outlet Coolant Temperature 280/307 (°C)	NSSS Operating Pressure (primary/secondary) 15.5 / 7.8 Core Inlet / Outlet Coolant Temperature 295 / 325 (°C)	(primary/secondary) 15.5 / 3.4 Core Inlet / Outlet Coolant Temperature 243 / 321 (°C)	NSSS Operating Pressure (primary/secondary) 15.0 / 4.6 Core Inlet / Outlet Coolant Temp. 286.5 /319.5(°C)
Three out of six SMRs use natural circulation of coolant. Use of natural circulation has a positive influence on plant reliability however, this at the same time increases thermal stresses on NSSS components as core Delta-T is higher (especially in case of NuScale) if compared with forced circulation reactors.						
Intended application	Commercial-Electric Heat Hydrogen generation	Commercial – Electric, District Heating	Commercial – Electric Heat Desalinisation	Commercial – Electric Heat	Commercial – Electric Heat Hydrogen generation	Commercial – Electric Heat Desalinisation
Intended application is quite the same for all six SMRs. In fact, all non-electric applications will be introduced in the SMR designs upon requests of customers and in this regard, there are no big differences between all six SMRs.						
Concept of utilisation	Baseload, Cogeneration, Load Following	Baseload, load following within a range of 50 to 100% power and district heating.	Baseload, load following and Cogeneration	Baseload, load following within a range of 50 to 100%	Baseload, load following, cogeneration, district heating, island-mode operation	Baseload, district heating, industrial heating, seawater desalination
All six SMRs are intended for commercial electric application in baseload, cogeneration. Five of the the six plan to haveload following modes						
Integration options into existing electricity system	NuScale VOYGR-12 power plant Power Module™ includes twelve 77 MWe modules with gross output of 924 MWe. Also smaller with four-module VOYGR-4 (308 MWe) and six-module VOYGR-6 (462 MWe) configurations	BWRX-300 only requires one incoming/outputting transmission line that must be capable of handling the 300 MWe/355 MVA plant output. There is no reliance on grid power for safety functions.	Basic grid interface compliant with ENSTO-e and EUR requirements. The dual unit concept provides the operator with a possibility to adapt the maintenance schedule having at least one reactor of the plant in-operation and supplying the grid,	The RR SMR produces 443 MWe and is capable of load follow. When disconnected from the grid, the plant is capable of house load, not reliant on grid power for safety related functions due to the passive nature of the RR SMR safety systems	Could be integrated in existing grids including those. Able to operate in remote locations. To maximize fuel economy and minimize maintenance costs, it is preferable to run the reactor as a base load facility, not as a "peaking" unit.	Integration with grids having high variable renewable capacities is not specified

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD CEA/EDF/Naval Group/ TechnicAtome	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
			whereas another one may be in outage.			
Due to module concept and reasonably low output all six SMRs are easily integrable into existing electricity system even in isolated grids with limited installed capacity of the electric system						
Load following modes EPRI URD requirements for SMR: 24 hour load cycle: 100% → 20% → 100% Ramp rate of 40% per hour Capable of automatic frequency response Step change of 20% in 10 minutes Frequency variation tolerance	NuFollow™ load-following capability, feature of increasing from 20% to 100% power (~1% per minute) (compliant with EPRI URD)	Load following within a range of 50 to 100% (0.5% per minute)	Load following within a range of 20 to 100% (5% per minute) (compliant with EPRI URD)	Load following within a range of 50 to 100% (3-5% per minute) in compliance with the U.K. Grid Code	Load following foreseen in design (range and ramp rates will be known at later design phase)	Load following capability is not specified
Only 2 SMRs - NuScale VOYGR and NUWARD comply with EPRI URD load-following requirements for the SMRs towards power change range and rate: 24 hour load cycle: 100% → 20% → 100% /Ramp rate of 40% per hour /Capable of automatic frequency response/Step change of 20% in 10 minutes/Frequency variation tolerance Two other designs (BWRX-300 and RR SMR) have announced range of 50 to 100%, Holtec SMR announced the possibility, but no any range data (considering US origin it will likely comply with EPRI URD requirements) and ACP100 did not provide any information on use of load following mode.						
Operation in the power grid with renewables	Suited for integration with renewables: Dispatchable modules: Taking one or more modules offline for extended periods of low	The BWRX-300 is capable of daily load following to compensate for the effect of renewable energy, but according to GEH load following is not	The NUWARD has load following feature that will allow to work within the grid with installed renewable sources	The plant produces 470 MWe and is capable of load following and operation on house load where required.	Ready for integration with grids containing high renewable capacity by virtue of its broad load-following capability	Operation in grids with high ratio of renewable s is not specified.

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD CEA/EDF/Naval Group/ TechnicAtome	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
	grid demand or sustained renewables output, Power Manoeuvrability: Manoeuvring reactor power for one or more modules during intermediate periods to compensate for hourly changes in demand or renewables generation, or Turbine Bypass: Bypassing the module's steam turbine directly to the condenser for rapid responses to load or to intermittent generation from renewables.	the preferred method for frequency control			HOLTEC envisages pairing an SMR-160 plant with a its Green Boiler CESG system to store surplus energy from the power plant itself and from the general grid, which can then be used in periods of generation deficit. A variation of the CESG system called HI-HEAT has been engineered to provide district heating systems.	
Five out of six SMRs specified possibility to operate in the power grid with the majority of renewables. Use of frequency control operation mode is so far not announced for any of SMRs under review. No information on load following for ACP100.						
Multiple use - electricity and hydrogen generation	Hydrogen cogeneration with Electrolysis	Hydrogen cogeneration is not foreseen by BWRX-300 design	Hydrogen production envisaged	Hydrogen cogeneration is not foreseen by RR UK SMR design, but power for production of future fuels (for example Hydrogen and Synthetic Aviation Fuel (SAF) or heat generation is a potential option for RR SMR.	SMR-160 is designed with flexibility for hydrogen generation	Hydrogen cogeneration is not specified for ACP100,
Capability to co-generate hydrogen is indicated for 3 out of 6 SMRs, however, in principle, all 6 have the possibility to use hydrogen generation						

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD CEA/EDF/Naval Group/ TechnicAtome	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
2) SMR developer and its records, set goals						
Developer history, experience, existing and planned commitments	NuScale Power, LLC, USA www.nuscalepower.com	GE Hitachi and Hitachi GE Nuclear Energy, USA https://nuclear.gepower.com/	CEA, EDF, Naval Group and TechnicAtome	Rolls-Royce and Partners, UK https://www.rolls-royce.com/innovation/small-modular-reactors.aspx#/	SMR LLC, owned by Holtec International	CNNC https://www.cnnc.com.cn
Four out of six SMR vendors analysed have previous large experience in designing nuclear plants. In-house experience and use of LWR technology would ease technical and licensing reviews, but still require a lot of efforts to develop safety analyses and justifications for newly invented features, like passive safety systems, submerged confinements etc.						
Development schedule	2003 Precursor concept developed (Multi-Application Small LWR—MASLWR Program) 2007 NuScale Power, Inc. created to commercialize new design 2011 Fluor Corporation became major NuScale investor and strategic partner 2013 NuScale won its first competitive U.S. Department of Energy funding opportunity 2017 Design certification application (DCA) submitted to U.S. NRC 2018- 2020 Phase 1 to 6 of DCA review completed 2020 Start of US NRC pre-	2014 ESBWR design control document issued 2017 BWRX-300 Evolution from ESBWR Initiated 2018 Pre-licensing engagement with the UK ONR 2019 Start of US NRC pre-licensing engagement including Licensing Topical Report Submittal 2020 Start of CNSC pre-licensing vendor design review (VDR) combined Phase 1 & 2 (eight submittals of the 19 VDR focus areas in early 2020) 2024 Submittal of license application in US and Canada	2012- 2016 Preliminary studies and technological innovation (using previously developed patents). 2017-2019 Pre-conceptual design phase and technology validation Conceptual design + preparation to pre-licensing 2019-2022 Basic design + pre-licensing 2022-2025 Commercialisation as early as 2025 Detailed design + licensing 2025-2030 Safety options validated + First Concrete in France by 2030	2015 development of initial reference design 2016 Formation of consortium for design of whole power station concept 2017 Conceptual design developed 2021 Generic Design Assessment (GDA) regulatory process started in UK 2025 Projected earliest start of construction 2029-2030 Planned first of a kind commercial operation	2012 Conceptual design of SMR-160 commencement 2015 Conceptual design completed 2020 Preliminary design completed 2020 Phase 1 of the CNSC "Pre-Licensing Review of a Vendor's Reactor Design" completed 2022 begun pre-licensing interactions with the NRC. HOLTEC submitted to NRC two Topical Reports for the SMR-160 PSAR for commercial project by 2023, with detailed design to complete by 2025 2030 – commissioning	2011 Conceptual design 2012 Preliminary design 2014 PSAR 2016 Generic reactor safety review for ACP100 by IAEA finished. 2017 CNNC signed an agreement with the Changjiang municipal government to host FOAK ACP100 demonstration unit. 2018 Preliminary safety assessment report (PSAR) finished. 2019 PSAR submitted to National Nuclear Safety Authority, Site Preparation started.

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD CEA/EDF/Naval Group/ TechnicAtome	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
	licensing vendor design review combined Phase 1&2 2023 Start fabrication/construction of first full-scale NuScale NPP in the US 2029-30 Commercial operation of first NuScale plant in US in Idaho Falls, Idaho in frame of the Carbon Free Power Project (CFPP)	2024/5 Start of construction in US and Canada 2028 Commercial Operation in US and Canada			first set of SMR-160 plants in the US	2020 Apply for authorize to Changjiang nuclear power site 2021 First concrete 2026 Target commercial operation
All vendors started design of SMRs in range of 2013 – 2015 and target operation in 2030th with exception of the CNNC that in fact started construction of the ACP100 in 2021 and so far is in line with the intended schedule of works. While it is highly likely that ACP100 will be the first out of six reviewed SMRs in operation (targeted for 2026)						
Sources of finance and their reliability	NuScale Power Reports Second Quarter 2022: Raised $381 million from successful Spring Valley Acquisition Corp. merger and associated PIPE offering Reaffirms financial outlook; reports strong balance sheet featuring cash and equivalents of $350.8 million and no debt NuScale Power reaffirms its financial outlook including $16 million cash	GE Hitachi Nuclear Energy (GEH) is an alliance created by GE and Hitachi to serve the global nuclear industry. GE revenue of 2021 is ~71B USD Hitachi Group revenue of 2021 is ~8730B Yen that is equal to ~ 59B USD	CEA – 2020 income 5.7 BEUR EDF – 2021 revenue 84.5 BEUR Naval Group – 2020 revenue – 3.3BEUR TechnicAtome – average annual turnover – 400-450 MEUR	Rolls-Royce – 2021 revenue 11.2 B£ Constellation -2021 revenue 19.6B USD Qatar Investment Authority – total funding amount – 98B USD UKRI Innovate UK – multibillion investment portfolio BNF Resources Limited Rolls-Royce's $546 million funding round to develop the country's first SMR was backed by a 210-million-pound ($273 million) investment from	Holtec International – 2021 revenue - $240M	Information on CNNC revenue is not available, but corporation currently has 24 nuclear power units in operation and 6 units under construction that indirectly confirms its financial capabilities.

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD CEA/EDF/Naval Group/ TechnicAtome	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
	revenue for full year 2022.			the government, alongside 193 million pounds from Rolls-Royce, BNF Resources UK and Exelon Generation.		
All SMR developers with possible exception of Holtec have sizable own financing or commitments from other sources to complete the design and eventually also construction of the FOAK..						
Commitments received and future prospects	USA: October 2020 a 720-MWe NuScale for Utah Associated Municipal Power Systems (UAMPS); July 2021 the project was downsized to 6 modules Poland: September 2022 NuScale Power and KGHM Sign Task Order to Initiate the Deployment of First Small Modular Reactor in Poland Romania: MOU for first NuScale 6-module, 462 MWe, power plant in Romania signed with state nuclear power corporation S.N. Nuclearelectrica in May 2022 for SMR in Doicești site. Ukraine: MOU signed with: Ukraine Energoatom 09.2021	USA: August 2022 Tennessee Valley Authority (TVA) entered an agreement with GEH on deployment of a BWRX-300 at the Clinch River site near Oak Ridge UK: September 2022 GEH and UK-based Sheffield Forgemasters have agreed to cooperate in support of the potential deployment of the BWRX-300 in the UK. Canada: December 2021 – Deployment of BWRX-300 at Darlington site by 2028 June 2022— BWRX has been selected by SaskPower for potential deployment in the mid-2030s Poland: October 2022: A master services	NUWARD is at conceptual design phase, so there are no commitments from potential users, however with experience and many years successful work in nuclear sector the Consortium has very good potential on SMR market	UK SMR is at detailed design phase, however there are no commitments from potential users, however RR reached numerous agreements with partners who will be supporting SMR project development and implementation : Atkins, Assystem, Jacobs, Nuclear AMRC, Laing O'Rourke, Bam Nuttal, National Nuclear laboratory, TWI, Keppel Fells as well as with Department for Business, Energy & Industrial Strategy September 2022 Rolls-Royce SMR has signed a MoU with Czech nuclear engineering and manufacturing firm Škoda	In Nov. 2022 Holtec concluded a MOA with Škoda Praha and Hyundai Engineering and Construction to advance the planning for construction of SMR-160s in the Czech Republic. 09.2022: MOU with ČEZ was signed to enable continued exchange between the parties for evaluation of SMR-160 deployment at Temelin, where ČEZ plans to deploy a pilot SMR as early as 2032. 03.2022: Holtec reached an agreement with Mitsubishi Electric Corporation's U.S. to design and engineer the digital instrumentation and control systems (I&C) for its SMR-160 small	CNNC did not publish any information on other than ACP100 Linglong One demonstration unit

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD CEA/EDF/Naval Group/ TechnicAtome	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
	Czech Republic CEZ Group- 09.2019 Bulgaria KNPP-NB PLC – 02.2021 United Kingdom Shearwater Energy, Ltd – 01.2021 A MoU sinned in August 2022 between NuScale Power and Fermi Energia in evaluating the deployment of a NuScale SMR plant in Estonia by 2031.	agreement signed by Laurentis Energy Partners and Synthos Green Energy will support the development and deployment of small modular reactors (SMRs) in Poland. The agreement enables international collaboration between the two companies, beginning with early project planning. December -2021 – GEH, BWXT Canada Ltd. And Synthos Green Energy announced their intention to cooperate in deploying BWRX-300 in Poland Estonia: September 2022 – Fermi Energia AS has issued invitations to tender for three new generation small modular reactor developers: General Electric / Hitachi BWRX-300, NuScale VOYGR and Rolls Royce UK SMR October 2019 – GEH and Fermi Energia agreed to collaborate on potential		JS. The MoU presents an opportunity to explore areas of collaboration for the Rolls-Royce SMR plant, for deployment both in the Czech Republic and broader central European regions.	modular reactor. 11.2021: Holtec has finalised an agreement with Hyundai Engineering & Construction of South Korea for the turnkey supply of Holtec's SMR-160 small modular reactor plant worldwide. 04.2020: Holtec has selected Framatome to supply nuclear fuel for its SMR-160, including completion of all necessary engineering to fuel the SMR-160 with GAIA fuel assembly. Ukraine :03.2018 A memorandum of understanding signed by Holtec and Energoatom envisages the adoption by Ukraine of SMR with country becoming a manufacturing hub for SMR-160 reactor components 07.2017: Holtec has signed a teaming agreement with Canada's SNC-Lavalin to collaborate in the	

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD CEA/EDF/Naval Group/ TechnicAtome	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
		deployment applications for GEH's BWRX-300 Estonia Fermi Energia, entered into preliminary agreements with Estonian business customers. The agreements are the basis for the conclusion of subsequent contracts for the purchase and sale of electricity. The target price per MWh in these agreements is 55 euros. The company entered into agreements for 500 GWh, which is about a tenth of the annual production of the first reactor.			development of Holtec's SMR-160	
The confirmed site for NuScale with Carbon Free Power Project (CFPP) is Idaho National Laboratory, and in Doicești, Romania. The other site that is announced is OTG BWRX-300 at Darlington nuclear site in Ontario with scheduled planned completion in 2028						
3) Design and technology and its maturity						
State of development of design	Detailed design, Equipment Manufacturing in Progress	Detailed Design, Pre-Application review of Licensing Topical Reports	Conceptual design	Advanced Design	Preliminary Design Completed , Pre-Application review of Licensing Topical Reports	Detailed design developed Linglong One plant is under construction since July 2021

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD CEA/EDF/Naval Group/ TechnicAtome	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
Three out of six SMRs are having detailed design and one is under construction. Unavailability of NUWARD and SMR-160 detailed design could delay construction of the SMRs in the EU, with NUWARD having more prospective for the licensing in the EU.						
Technology development needs	Technology for fabrication of helical tubes SGs should be restored (there was experience in UK for gas-cooled reactor, but currently those are not produced)	GEH possess all technologies that are of need for the BWRX-300	CEA, EDF, Naval Group and TechnicAtome possess all technologies and experience required for the design and deployment of the NUWARD SMRs	Rolls-Royce SMR is an independent company, drawing on decades of Rolls-Royce experience in nuclear design and engineering. The company also plans to involve partners who will be responsible for the design of specific plants' systems/ parts.	Holtec said it has completed construction of the world's first dedicated SMR manufacturing facility in Camden. The factory has the lifting, cutting, welding, cladding, drilling, machining, inspection, and shipping capacities necessary for all of the SMR-160's capital nuclear equipment fabrication needs.	CNNC possess in house expertise required for the design and deployment of the ACP100 SMRs
All vendors are said to have in house expertise for the design of the SMRs that could be, in case of necessity, supplemented by the expertise of partners/counterparts in design specific areas like I&C, nuclear fuel , etc.						
Novel vs. evolutionary	NuScale's SMR technology is the evolutionary built on proven and established fundamentals of PWR fuel and technology. The novelty of NuScale includes: Integrated reactor design (containment and NSSS are within single module) Extensive use of passive systems	The BWRX-300 is the 10 th generation boiling water reactor that use features of previous designs – natural circulation from the ESBWR; key components from the ABWR, GNF2 fuel assemblies used worldwide GEH has more than 20 BWR plants currently in service with extensive operating experience.	The design will "benefit from best in class French technologies from more than 50 years of experience in PWR design, development, construction and more than 2000 reactor years of PWR operating experience". The novelty of NUWARD design includes: Innovative integrated reactor design	Rolls-Royce SMR will draw upon standard nuclear energy technology that has been used in 400 reactors around the world supported by 60 years' experience in producing small reactors for submarines. Novel in design - use of pre-cast concrete elements, manufacturing and construction	The SMR-160 represents innovation through simplification and use of entirely passive safety systems, while relying on decades of proven operating history for the existing commercial pressurized light water reactor fleet. The novelty of SMR-160 design includes: Integrated design	The ACP100 design concept is based on PWR technology and use of passive safety systems. CNNC has more than 30 years continuous experience in the design of NPPs and nuclear facilities ACP100 innovations include: Integrated design NSSS located below the grade

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD CEA/EDF/Naval Group/ TechnicAtome	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
	All NPM are partially submerged in safety pool, which serves as ultimate heat sink and located below the grade Containment maintained under vacuum during normal operations	The BWRX-300 is water-cooled, natural circulation SMR with passive safety systems. The novelty of the BWRX-300 includes: Located mostly below grade containment housing NSSS Passive containment cooling system Passive decay heat removal Submerged section of the containment dome	Passive core injection Passive decay heat removal Submerged containment providing passive cooling for several days Small core in a large vessel supports in-vessel retention strategy Passive flooding of vessel pit Boron-free design to reduce generated effluents	methods, extensive use of digital systems. The novelty of UK SMR design includes: Passive Containment Cooling System Passive Decay Heat Removal system Passive Emergency Core Cooling System Small Leak Injection System Boron-free design to reduce generated effluents	NSSS located underground Passive Core Cooling System Secondary decay heat removal system Passive Containment Cooling System Start-up without off-site power (i.e., "Black start" capability) On-site underground storage of SNF 80-year service life Optional - air-cooled condenser for water scarce regions	Passive core cooling Passive residual heat removal system Passive containment cooling Automatic Depressurization System Passive cavity flooding
While all SMRs' designs are based on LWR technology (PWR and BWR type of reactor installation) and also possess new features that are not typical for large NPP designs: *Extensive use of passive safety systems – all six SMRs under review* *Integrated design – NuScale, Nuward, SMR-160, ACP100* *Sub-grade location of NSSS - NuScale, BWRX-300, Nuward, SMR-160, ACP100* *Boron-free design of reactivity control system - Nuward ,RR UK SMR* *Submerged/partially submerged containment - NuScale, BWRX-300, Nuward* *80 years lifetime – SMR-160. Eighty years of HOLTEC SMR-160 might not be accepted in the EU as it will be first precedent to assign 80 years lifetime at the design phase*						
Proven technologies	NuScale is using technologies for manufacturing fuel and main equipment that are used for number of years for construction of PWRs, however novelty of the design and use of	Building on ESBWR development, the BWRX-300 uses design and licensing basis of the the NRC-certified ESBWR, but reduces the scale and complexity of the installation.	The design relies on French experience with PWR NPPs	The design is based on optimized and enhanced use of PWR technologies	SMR-160 is a conventional fission PWR reactor, using water as the cooling medium, and is designed with world-wide industrial operating experience with	The ACP100 design incorporates accumulated operational experience and uses proven in operation of PWR technologies

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD CEA/EDF/Naval Group/ TechnicAtome	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
	modular design is a FOAK plant, so this might cause difficulties/ problems when things will come to commissioning and operation of the plant				pressurized water reactors.	
All SMRs' designs are based on LWR (PWR|BWR) technology supplemented by novel SMR features that are still to be proved in design and in operation						
Potential problems with the technology and design	While NuScale will be factory assembled and thus delays could be avoided, those could not be overruled Novel features and integrated design has not been proven by operation	Both GE and Hitachi are having experience in delivery of big power reactors combined with experience in licensing of the ESBWR in USA, therefore they should not have difficulties/ problems with technologies or design. Novel features has not been proven by operation	CEA, EDF, Naval Group and TechnicAtome experience in the design and operation of nuclear facilities will help in the development and deployment of NUWARD. Novel features and integrated design has not been proved by operation	The SMR design is based on decades of Rolls-Royce experience in nuclear design and engineering, therefore big technological problems are not expected, however FOAK plants are always challenging projects Novel features has not been proven by operation	SMR-160 HOLTEC design is first company experience in design of NPPs, however HOLTEC has broad experience in the design of SNF management facilities.	CNNC has more than 30 years' experience in design and licensing of power reactors and nuclear facilities in China, however experience in licensing of NPPs abroad is rather limited with no experience in the EU countries. Novel features and integrated design has not been proved by operation
With the exception of Holtec (and maybe RR) there are no big challenges related to the ability of developers to master the technology. Nevertheless Novel features and integrated design (used in)has not been proven						
Material needed and new issues/challenges	NuScale is using typical for PWR pattern of materials, having similar range of pressures and temperatures like in PWRs	BWRX-300 has typical for BWR range of pressures and temperatures, so material challenges are not expected	NUWARD is using typical for PWR pattern of materials, having similar range of pressures and temperatures like in PWRs	RR SMR is using typical for PWR pattern of materials, having similar range of pressures and temperatures like in PWRs	SMR-160 is using typical for PWR pattern of materials, having similar range of pressures and temperatures like in PWRs	ACP100 is using typical for PWR pattern of materials, having similar range of pressures and temperatures like in PWRs

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD CEA/EDF/Naval Group/ TechnicAtome	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
All six SMRs are using typical for PWR pattern of materials, standard fuel and having similar range of pressures and temperatures like in PWRs, so materials should not be a challenge for the development/deployment.						
Technology readiness level assessment	Technology is under development, so some challenges are unavoidable for the FOAK SMR designs					ACP100 is under construction
Known and potential challenges before maturity						
Technology for five out of 6 SMRs is under development, so it is not yet ready. The potential challenge for development, manufacturing and operation of SMR could be represented by novelty of their features, like integrated design of NuScale, NUWARD and SMR160, passive safety systems, boron-free reactivity control etc., that were not yet tested/proven by operating experience.						
4) Licensing						
Standards and regulations which were the basis for the design development	US: 10 CFR Part 50, Domestic Licensing of Production and Utilization Facilities, 10 CFR Part 51, “Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions” 10 CFR Part 52, “Licenses, Certifications, and Approvals for Nuclear Power Plants” NRC Regulatory Guides – Power Reactors	US: 10 CFR Part 50, Domestic Licensing of Production and Utilization Facilities, 10 CFR Part 51, “Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions” 10 CFR Part 52, “Licenses, Certifications, and Approvals for Nuclear Power Plants” NRC Regulatory Guides – Power Reactors	EU: EUR Volume 1, Chapter 5 – EUR KEY POSITIONS ON SMLWR AFCEN: RCC-M – Design and Construction Rules for Mechanical Components of PWR Nuclear Islands PTAN 2018 RCC-MRx Seismic analysis components RSE-M In-Service Inspection Rules for Mechanical Components of PWR Nuclear Islands RCC-E- Design and construction rules for electrical and I&C	UK: Nuclear Installations Act Nuclear Installations Regulations Nuclear Industries Security Regulations 2003 Nuclear Safeguards (EU Exit) Regulations 2019 Ionising Radiations Regulations 2017 The Radiation (Emergency Preparedness and Public Information) Regulations 2019 The Construction (Design	US: 10 CFR Part 50, Domestic Licensing of Production and Utilization Facilities, 10 CFR Part 51, “Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions” 10 CFR Part 52, “Licenses, Certifications, and Approvals for Nuclear Power Plants” NRC Regulatory Guides – Power Reactors	China: Domestic standards and requirements. The IRRS mission to China of 2016 concluded that country achieved significant progress in developing the regulatory framework in the six years since the last review in 2010.

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD CEA/EDF/Naval Group/ TechnicAtome	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
			systems and equipment RCC-C – Design and Construction rules for Fuel Assemblies of PWR Nuclear Power Plants	and Management) Regulations 2015		
Each country where six SMRs being developed/constructed has own regulatory framework that includes set of standards and regulations governing design and operation of NPPs. While this will be considered during licensing in the EU it is highly likely that vendors will be requested to adjust their designs against specific national requirements and licensing process.						
Licencing reviews undertaken or planed	US: https://www.nrc.gov/reactors/new-reactors/smr/licensing-activities/nuscale.html Design Certification Application completed in Aug 2020 Combined licence application (COL) for SMR UAMPS plant planned to be submitted in January 2024. CANADA: Pre-licensing vendor design review started in January 2020	US: https://www.nrc.gov/reactors/new-reactors/smr/licensing-activities/pre-application-activities/bwrx-300.html GEH submitted to NRC total of five Topical Reports for the GEH BWRX-300 SMR Design CANADA: Pre-licensing vendor design review started in January 2020 UK: Pre-licensing vendor design review started in January 2020. In Dec 2020 ONR accepted that disclosure of BRWX-300 information would prejudice the commercial interests of GE-Hitachi and assist its competitors. As any formal consideration of	NUWARD is at conceptual design phase A preliminary documentation submitted to French ASN	UK: RR SMR is at detailed design phase, but no licensing reviews done so far. On 1 April, 2022 ONR has announced Step 1 of the Generic Design Assessment (GDA) for Rolls-Royce SMR 470 MW design. ONR received a request from the Department of Business, Energy and Industrial Strategy to begin a GDA on the design proposed by Rolls-Royce, following the government's readiness review of the Rolls-Royce application. ONR has signed a charging agreement with Rolls-Royce SMR Limited and mobilised sufficient management,	US: https://www.nrc.gov/reactors/new-reactors/smr/licensing-activities/pre-application-activities/holtec/documents.html HOLTEC submitted to NRC two Topical Reports for the SMR-160	China: The ACP100 Final safety assessment report (FSAR) is approved by NNSA and construction licence issued No licensing reviews in other countries.

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD CEA/EDF/Naval Group/ TechnicAtome	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
		the BWRX-300 design in a GB context that may or may not take place in the future would involve regulatory assessment and judgements by ONR, which are documented in public documents, any public interest associated with the release of GE-Hitachi's commercial information at this time is significantly diminished.		assessment and business support resource to conduct the GDA.		
So far only two out of six SMRs (NuScale and ACP100) developed licencing documentation that was reviewed by national regulatory authorities. It should be also noted that ACP100 licensing documentation is not available, but ACP100 in 2016 passed Generic Reactor Safety Review carried out by the IAEA. Other four reactors are at different stages of preparation of licensing documentation, targeting its readiness by 2025-2030.						
Missing standards or regulations	There are no missing standards and regulations in the US, however NRC is considering certain changes in the 10 CFR parts towards SMR certification requirements. It might be necessary to develop relevant regulations in other countries where deployment is planned	There are no missing standards and regulations in the US, however NRC is considering certain changes in the 10 CFR parts towards SMR certification requirements. It might be necessary to develop relevant regulations in other countries where deployment is planned	There are no missing standards and regulations in the France for the development of the PWR type reactors, however some changes might be necessary to accommodate SMR specifics. It might be necessary to develop relevant regulations in other countries where deployment could take place.	Currently there is no legal definition of an SMR and NIA 1965 [**Fehler! Verweisquelle konnte nicht gefunden werden.**] does not contain any specific provisions for SMRs, so the act needs to be amended to have SMR specific provisions	There are no missing standards and regulations in the US, however NRC is considering certain changes in the 10 CFR parts towards SMR certification requirements. NRC defined deadline for submission comments as October 2022 It might be necessary to develop relevant regulations in other countries where deployment is planned	The IRRS mission to China of 2016 concluded that country achieved significant progress in developing the regulatory framework.

<table>
<tr><th></th><th>NuScale VOYGR</th><th>GE/Hitachi BWRX-300</th><th>NUWARD CEA/EDF/Naval Group/ TechnicAtome</th><th>Rolls-Royce UK SMR</th><th>SMR-160 HOLTEC</th><th>ACP100</th></tr>
<tr><td colspan="7">All countries where six SMRs being developed/constructed has set of standards and regulations governing design and operation of NPPs. This however will not help much for the licensing outside of vendors/countries, as in this case country specific national standards and regulations are to be used. This might be a challenge for most of countries who will decide to import SMR technology, as beside decision in principle the country would need to update/develop own regulatory framework appropriate for the purpose.</td></tr>
<tr><td>Licencing status in countries where deployment is envisaged and need for additional development</td><td>DCA completed in August 2020; design obtained final certification in February 2023 in USA, Pre-Licensing Vendor Design Review (VDR) in Canada (2020)</td><td>Pre-licensing activities started in USA in 2019, Pre-licensing vendor design review by CNSC of Canada started in January 2020
Pre-licensing vendor design review by ONR of UK started in January 2020.</td><td>Pre licencing request submitted to ASN</td><td>UK: April 2022, ONR announced Step 1 of the General Design Assessment
GDA process focuses on the design of a generic nuclear power station and is not site-specific.</td><td>Pre-licensing activities started in USA in 2014, licensing activities in other countries did not start yet</td><td>No deployment plans/agreement with other countries are announced by CNNC yet</td></tr>
<tr><td colspan="7">The only SMRs that are currently licensed in countries of origin are NuScale and ACP100. Licensing process for other four SMRs and for other countries is in an initial phase.</td></tr>
<tr><td>Overall assessment of the licencing duration</td><td>DCA took about 3 years to complete. COL planned to start in January 2024 and be completed by 2025 (considering construction time of 48 months and plan to start operation in 2029)
It is likely that COL will experience delays and it is not feasible to get it in one year after process start (for large PWRs COL process took 8-10 years from start to completion)</td><td>Duration should be comparable with NuScale, but this will strongly depend on timing and quality of licensing submittals</td><td>Duration should be comparable, but this will strongly depend on the position of the regulator regarding SMR</td><td>Typical minimum duration according to ONR (guide to the Regulatory Process rev.0 2013) is ~ 48 months without GDA Step 1</td><td>Duration should be comparable with NuScale,</td><td>Dec. 2012, Basic Design Approved
2019 FSAR submitted to NNSA, construction licence issued
2021 First concrete</td></tr>
<tr><td colspan="7">The licensing process is completed for ACP100, but licensing schedule milestones information is not available. The other SMR with advanced licensing is NuScale that received final design certification by US NRC in January 2023. The overall duration of NuScale licensing is planned to be ~ 4 years, but this is rather optimistic plan that might be delayed (as licensing of big NPPs shown)</td></tr>
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Other regulatory challenges	DCA did not addressed the following issues: (1) the shielding wall design in certain areas of the plant; (2) the potential for containment leakage from the combustible gas monitoring system, and (3) the ability of the steam generator tubes to maintain structural and leakage integrity during density wave oscillations in the secondary fluid system All these issues will be addressed at COL stage	Potential challenges during licensing are possible, but extent and nature could not be predicted. The smoothness of the licensing process will strongly depend on quality of submittals.	Considering that NUWARD Consortium established INAB and that it is planned to carry out joint regulatory review by ASN of France, SUJB of Czech and STUK of Finland this will smoothen regulatory review in these, but also in other EU countries.	Currently there are no legal definition of an SMR and NIA 1965 does not contain any specific provisions for SMRs so the act needs to be amended to have SMR specific provisions	To be seen	CNNC experience in licensing of NPPs abroad is rather limited with no experience in the EU countries.
Other regulatory challenges beside listed above could be attributed to licensing in countries of SMRs deployment, as for all of those it will be licensing of the FOAK plant in a country.						
5) Construction and deployment						
Factory vs site activities, % each	NuScale Power Module™ (NPM), including containment, is fully factory-built and shipped to the plant site by truck, rail, or barge without the need for field fabrication. ~700 tons in total are shipped from the factory in three segments Turbine-generators,	60/40 Based on cost ratio. This ratio is heavily influenced the existence of a marine off load facility at the site	Factory vs site activities ratio is not yet defined	Targeting a 500-day modular build, RR says this concept minimises the onsite time and effort required to construct and build the plant, with about 90% of manufacturing and assembly activities carried out in factory conditions.	Factory vs site activities ratio is not yet defined SMR-160 rely on the plant being substantially manufactured in a factory environment and are comprised of pre-built assemblies to reduce on-site construction cost and schedule.	According to CNNC site installation processes of the ACP100 is to be optimized (considering experience of ACP100 demonstration project)

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	chemical control processes, and other modular systems will be assembled off-site, skid mounted, and shipped to the plant site. USA domestic supply chain manufacturing capacity is 36 modules per year			Man-power requirements cut by over 40% due to dedicated offsite module manufacture. SMR design is about 85% standardized and 15% is site specific.		
As claimed by the vendors from 60 to 90 % of assembling works are to be performed in factory conditions.						
Expected construction duration	36 months from the first safety concrete	30 -36 months from the first safety concrete	36 months from the first safety concrete	24 months from the first safety concrete (NOAK) 48 month build schedule, which includes site preparation, construction and commissioning	36 months for the 1st SMR-160, with construction times reduced to 30 months or less for subsequent units, and with multiple units at a site only limited by site constraints or owner needs.	58 months for FOAK and it is currently on schedule
Planned construction duration is in range of 30-36 months for the FOAK . The ACP100 FOAK schedule is more lengthy – 58 months for dual unit plant						
Concept of deployment- single or multiple units – how many	Up to 12 NPM per plant	Reference design – 1 Unit	Reference design – Dual Unit	Single unit	Single unit	Demonstration project is dual units' plant
SMRs deployment concept foresees deployment of single, dual or up to 12 modules (NuScale), but design of specific plant could be adjusted according to the Customer needs						
Gradual deployment	Gradual deployment of NPMs is possible, however some common structures are to be in place before first module	Not foreseen by reference design	Not foreseen by reference design	Not foreseen by reference design	Not foreseen by reference design	Not foreseen by reference design

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	become operational – e.g., common pool, turbine and auxiliary buildings etc.					
Gradual deployment of SMRs is possible multi-module/multi-unit plants						
6) Complementarity of operation with renewables						
Assessment of the compatibility of operation with intermittent electricity sources	Module design and operating parameters allow reactor power changes using only control rod movement down to 40% reactor power, i.e. it does not require adjustments to the boron concentration in the primary coolant.	Load following within a range of 50 to 100% (0.5% per minute) 0.5% per minute The BWRX-300 is capable of daily load following to compensate for the effect of variable renewable energy but load following is not the preferred method for frequency control.	Load following within a range of 20 to 100% (5% per minute)	Load following within a range of 50 to 100% (3-5% per minute)	Load following foreseen in design (rates will be known at later design phase)	Load following capabilities are not specified
Compatibility of SMRs with renewable sources is ensured by load following feature that is indicated for all reactors except ACP100. Use of frequency control operation mode is so far not announced for any of SMRs under the review.						
Ramp-up or ramp-down velocity to complement increased/decreased production of renewables	100% load rejection using turbine bypass Load ramp-increase/decrease 5% per minute (15-100%) Step load increase/decrease 10% in 60 seconds without trip	Load change rate – 0.5% per minute Load rejection capability (ability to reject load without shutdown) is not part of the standard design, but could be provided as option	Load change rate – 5% per minute 100% load rejection without shutdown Ability of plant to operate on house load Other characteristics will	Load change rate – 3- 5% per minute 100% load rejection and stable self-sustaining operation on house load subsequent to the disconnection. Other characteristics will	Load following foreseen in design (rates will be known at later design phase)	Load following capability is not specified

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	while operating between 50 and 100 percent power. 20 percent of rated power step demand increase or decrease within ten minutes Module design and operating parameters allow reactor power changes using only control rod movement down to 40% reactor power	More detailed info on load ramping will be made available at later phase	be made available at detailed design phase	be made available at later phase		
Ramp-up or ramp- down rates are specified in detail for the NuScale SMR, with more details to come for other when respective licensing submittals will be prepared by vendors. It should be highlighted that only 2 of SMRs under the review are compliant with EPRI URD requirements for SMRs (NuScale and NUWARD) towards power change range and rate						
Operation at minimum technically feasible performance level, permissible operation at minimum, intermittent performance level	Minimum technically possible power level is determined by turbine restrictions. Considering that so far NuScale design foresees that each NPM will have own 77 MWe turbine and typically turbine recommended load is within 25-100% range the minimum long time operation load would be in range of circa 20 MWe. 12 NPM design gives flexibility to run	Minimum technically possible power level is determined by turbine restrictions. Considering that GEH foresees 300 MWe turbine load and typically turbine recommended load is within 25-100% range the minimum long time operation load would be in range of circa 75 MWe.	Minimum technically possible power level is determined by turbine restrictions. Considering that NUWARD foresees two units design, 170 MWe turbine load of one turbine and typically turbine recommended load is within 25-100% range the minimum long time operation load would be in range of circa 42 MWe.	Minimum technically possible power level is determined by turbine restrictions. Considering that RR SMR foresees rated power of 470 MWe and typically turbine recommended load is within 25-100% range the minimum long time operation load would be in range of circa 118 MWe.	Minimum technically possible power level is determined by turbine restrictions. Considering that SMR-160 foresees rated power of 160 MWe and typically turbine recommended load is within 25-100% range the minimum long time operation load would be in range of circa 40 MWe.	Minimum technically possible power level is determined by turbine restrictions. Considering that ACP100 foresees rated power of 125 MWe and typically turbine recommended load is within 25-100% range the minimum long time operation load would be in range of circa 30 MWe.

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	plant at load from 20 to 924 MWe by starting up additional NPMs.					
The lower limit of operation is determined by the turbine recommended load range that is within 25-100% of rated power						
Technical and economic issues and „penalties“ in a case of cyclical or intermittent operation	There is no technical difficulty to operate SMR plants at any permissible, for long term operation turbine, load or cyclically, however reduced load operation will result in longer investment return. Intermittent operation “penalties” are to be agreed between operator and electric grid when concluding power supply contract.					
There is no technical difficulty to operate SMR plants at any permissible, for long term operation, turbine load. Intermittent operation “penalties” are to be agreed between operator and electric grid when concluding power supply contract.						
Technical possibility for fast start-up after a full shutdown (e.g., limitations by “xenon effect”) and/or other limitation on the operations	Multi-module design of the NuScale plant and the staggered refuelling of individual modules result in a plant configuration in which at least one module is near beginning of life (BOL). It is generally easier to perform power manoeuvres on BOL cores because of the higher reactivity in the core enables better xenon override.	Due to large negative moderator density (void) coefficient of reactivity, the BWRX-300 has a number of inherent advantages, including 1) self-flattening of the radial power distribution, 2) spatial xenon stability, and 3) ability to override xenon in order to follow load. The inherent spatial xenon stability of the BWRX-300 permits daily load following over a large core power level range.	Information and data will be available at detailed design phase	Information and data will be available at detailed design phase	Information and data will be available at detailed design phase	Information and data is not available
Technical possibility for a fast start-up after a full shutdown might be impacted by “xenon effect” at the end of fuel cycle, but this behaviour is typical for all LWRs.						

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Economic effects of complementary operation	Complementary generation of heat for industrial applications or district heating could be beneficial , both for plant operator, industry and population and heating could be competitive if compared with gas or electric heating options					
Economic effects of complementary operation data are not yet available, as none of FOAK SMRs foresees any complementary operating facility(ies).						
7) Co-generation-electricity and heat production						
The level of the development of a concept of co-generation i.e., using waste heat of heat for district heating	Use for heat for industrial applications and district heating is possible depending on client requirements	Use for heat for industrial applications and district heating is possible	NUWARD design will be adapted also for non-electric usages All details will be made available at detailed design phase of specific plant	RR SMR design will foresee opportunities for co-generation of e.g., heat or hydrogen or Synthetic Aviation Fuel, but all details will be made available at detailed design phase of specific plant	SMR-160 design will foresee opportunities for co-generation of e.g. hydrogen generation, thermal energy storage, district heating, seawater desalination, but those options will be defined in detail during design phase of specific plant	ACP100 design foresees opportunities for co-generation e.g. district heating, seawater desalination, etc., but those options will be defined in detail during design phase of specific plant
While non-electric application of SMRs indicated as possible, including hydrogen, district/industrial heating, desalination etc., none of SMRs included these facilities in FOAK plant design as standard option. These features will be subject of Vendor-Customer agreement on adjustment of design of specific plant according to the Customer needs						
8) Fuel cycle related issues						
Type of fuel	UO_2, NuFuel-HTP2 with Gd_2O_3 as a burnable absorber Standard LWR fuel in 17 x 17 configuration, each assembly 2 meters long/ 37 fuel assemblies per NPM Pin burn-up (max) – 62	UO_2 240 GNF2 fuel assemblies with solid burnable absorber B_4C, Hf, Gd_2O_3 Pin burn-up (max) – 62 MWd/kgHM Core discharge burnup - 49,5 GWd/t	UO_2 76 assemblies in 17 x 17 configuration Solid Burnable Absorber Gd_2O_3 Burnup characteristics will be determined at detailed design phase	UO_2 121 assemblies in 17 x 17 configuration Solid Burnable Absorber Gd_2O_3 Pin burn-up (max) – not defined yet Core discharge burnup - 55-60 GWd/t	UO_2 57 assemblies in 17 x 17 configuration Solid Burnable Absorber – no data Pin burn-up (max) – not defined yet Core discharge burnup - 45 GWd/t	UO_2 57 assemblies in 17 x 17 configuration Solid Burnable Absorber – Gd_2O_3 Pin burn-up (max) – not defined yet Core discharge burnup - <52 GWd/t

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	MWd/kgHM Core discharge burnup – 45 GWd/t					
All six SMRs under review use "standard" UO2 fuel						
Efficiency/utilisation factors	> 95%	95%	90%	>90%	> 95%	>90%
Utilisation factor of SMRs is claimed to be in range of 90-95%, but this will strongly depend on how often and for how deep load will be reduced in load following mode. Frequent operation in load following mode might also have negative impact on investment return terms as well as might increase "on demand" electricity price						
Refuelling intervals	24 months The multi-module design of the NuScale VOYGR power plant allows for staggered refuelling. For example, in a 12-module NuScale plant that produces 924 MWe (gross), one 77 MWe module can be refuelled while the remaining 11 modules continue to produce 847 MWe (gross).	12-24 months	24 months	18-24 months	24 months	24 months
Enrichment level	<4.95%	3.40 / 4.95% (avg./max.)	<5%	4.95%	4.95% (4.0 average)	< 4.95
All six SMRs have refuelling intervals in range of 12-24 months and are using UO2 fuel enriched up to 4.95% (typical enrichment for LWR designs)						
Use of thorium and plutonium	Recycled fuel, or mixed uranium-plutonium oxide (MOX) fuel. UK National Nuclear Laboratory carried out study evaluated and confirmed	Use of thorium and plutonium not defined yet, but potentially possible as at other commercial NPPs	Recycled fuel, or mixed uranium-plutonium oxide (MOX) fuel	Not defined yet, but potentially possible as at other commercial NPPs	Not defined yet, but potentially possible as at other commercial NPPs	Not defined yet, but potentially possible as at other commercial NPPs

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	that MOX could be used in the NuScale core.					
Use of thorium and/or MOX fuel is possible, but this option is not considered as standard.						
Specific fuel needs	Standard LWR fuel in 17 x 17 configuration, each assembly 2 meters long. Cycle length is adjustable.	GNF is looking to use higher uranium enrichment to reduce fuel load requirements, decrease SNF volumes, and extend refuelling intervals to 30–36 months. Approximately 32 bundles are replaced following a 12-month cycle and 72 bundles following a 24-month cycle.	The reference plant refuelling cycle is for half a core every 2 years.	Industry standard UO2 enriched up to 4.95%, clad with a zirconium alloy and arranged in a 17x17 assembly. The core has an active fuelled length of 2.8 m. The Rolls-Royce SMR operates on an 18-month fuel cycle, with a three-batch equilibrium core	The SMR-160 fuel cycle is designed to discharge approximately one third of the fuel assemblies in the core each refuelling cycle, along with shuffling of a portion of the remaining fuel assemblies.	Fuel assembly in 17 x 17 configuration
All six SMRs under review use "standard" UO2 fuel that is adjusted to the height of the SMR core						
Fault-accident tolerant fuel	Could be used when ATF technology will be commercially available Introduction of ATF fuel will allow increase in the burnup limit					
Use of accident tolerant fuel is not considered in the SMRs, but the issue could be revisited when such a fuel will be made available and tested						
Concept of conditioning and proposed, spent	18 years of operation	8 years of operation	10 years of operation	5 years of operation	Unloading to dry storage facility after second refuelling	Temporarily stored in spent fuel pool for 10 years.

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nuclear fuel management concept (e.g. once through, reprocessing, utilisation of MOX, etc.	NuScale reactor building a stainless steel lined concrete pool holds used fuel for at least 5 years under 10 meters of water. The used fuel is protected both by the ground and the Seismic Category 1 reinforced concrete reactor building designed to withstand an aircraft impact, and a variety of natural and man-made phenomena. The NuScale's standard facility design includes an area for the dry storage of all of the spent fuel for the 60-year life of the VOYGR plant. Fuel reprocessing is possible, but this will be decided at later phase of the project development (no firm info/commitment yet known)	Spent Fuel Pool capacity is sufficient to store SNF generated during 8-years operation at full power + full core offload Decision on use of reprocessing and use of MOX fuel will be taken at detailed design phase, or even during operation	Spent Fuel Pool capacity is sufficient to store SNF generated during 10-years operation (20 -years as option) Decision on use of reprocessing and use of MOX fuel will be taken at detailed design phase, or even during operation	Spent Fuel Pool capacity is sufficient to store SNF generated during 5 years of full-power operation Decision on use of reprocessing and use of MOX fuel will be taken at detailed design phase, or even during operation	The spent fuel is stored briefly in the spent fuel pool which is uniquely protected within the same containment as the reactor (duration of SFP storage not defined yet). After removal of spent fuel from the SFP within a Multi-Purpose Canister (MPC-37), all spent fuel for the life of the plant can be stored on-site within an array of HI-STORM UMAX modules (an underground vertical storage cask design).	
*SNF concept for all SMRs foresees temporary storage of the SNF assemblies in the SFPs. De[pending on the design this lasts from 5 till 18 years. The only confusing information is in HOLTEC the interview of the Nuclear Advisory Council that stated that SNF will be moved to the dry storage facility after second refuelling [**Fehler! Verweisquelle konnte nicht gefunden werden.**]. SFP wet cooling time of just 48 months looks unusually short for currently used enrichments and burn-ups.*						
9) Safety related issues				operation		

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Safety concept	NuScale's plant design provides multiple levels of defence for accident mitigation (defence-in-depth): integrated design, passive core cooling and submerged NPM resulting in extremely low core damage probabilities. Natural circulation of the coolant. Set of engineered safety features NSSS and CNV immersed in reactor pool Decay Heat Removal System Emergency Core Cooling System designed to provide stable long-term nuclear core cooling under all conditions, along with severe accident mitigation. The reactor pool provides passive containment cooling and decay heat removal. The reactor pool provides an assured heat sink with a capacity to absorb the	The basic BWRX-300 safety design philosophy is built on utilization of inherent margins (e.g., larger structure volumes and water inventory) Natural circulation of the coolant. rigor the power plant design normal operating system's ability to handle transients and accidents using adjustable speed, motor driven feedwater pumps and higher capacity Control Rod Drive (CRD) pumps with backup power Use of passive safety-related systems: Isolation condenser system Passive containment cooling system Reactor Pressure Vessel Isolation valves	Large primary water inventory (kg/MWth) providing inertia versus power transients - Integrated reactor coolant system architecture thus reducing the maximum LOCA size - Internal CRDMs preventing from rod-ejection accidents -A metallic submerged containment providing passive cooling for several days -A small core in a large vessel enabling in-vessel retention strategy Passive management of all DBC scenarios Active management of DEC-A accidents Passive management of DEC-B -Boron-free operation preventing dilution accidents and reducing generated effluents	Wide range of safety measures used, including: - heat removal via the closed loop SG steam - feedwater - Passive Decay Heat Removal (PDHR) system -Passive Emergency Core Cooling System (ECCS) - Additional Small Leak Injection System (SLIS) for smaller leaks. -Three safety relief valves to protect against overpressure. - Control Rod shutdown (SCRAM) and Emergency Boron Injection to shut down reactor - Steel containment to mitigate the release of fission products to the environment in case of core damage. -Boron-free operation preventing dilution accidents and reducing generated effluents	The reactor core is located deep underground. - Natural circulation of the coolant. - No reliance on on-site or off-site power to shut down the reactor and remove decay heat -Passively cooled for design basis shut down. - Natural coolant circulation - NSSS components are located underground. -Containment steel structure will dissipates heat to the environment using passive cooling for a design basis event. - All safety-related systems are inside containment. - Large pipe break loss of coolant accidents (LOCA) are non-credible by design: no large piping in the Reactor Coolant System (RCS) loop. - Fuel is protected by an airplane crash resistant containment	ACP100 safety concept includes: - passive core cooling, -passive residual heat removal, -passive containment cooling, - passive cavity flooding, - passive hydrogen re-combiners, - multi stages automatic depressurization, - no need for operator intervention after accident for 72 hours, - DC power source for accident mitigation up to 72 hours +recharge the battery for up to seven (7) days, - ACP shell, protection from external events, - deep-buried NSSS

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	entire decay heat produced by up to 12 cores for duration longer than 30 days. After 30 days, the concept foresees air cooling that is sufficient to avoid fuel damage.				- Large coolant inventory, ensuring the core is never uncovered.	
Safety concept of all 6 SMRs rely on extensive utilisation of passive safety features, submerged containment (NuScale, BWRX-300, NUWARD), underground location of NSSS (NuScale, BWRX-300, Nuward, SMR-160, ACP100), boron-free design of reactivity control system (Nuward , RR UK)						
Level of defence in depth	Oxide fuel pellet and cladding Reactor vessel Containment vessel Reactor pool Underground stainless steel lined concrete pool walls and floor Biological shield Seismic Category 1 building with HVAC filtration	Defence Line 1 DL1 minimizes the potential for accidents to occur by applying high quality and conservatism in plant design, construction, operations, and maintenance. Defence Line 2 DL2 encompasses plant functions designed to control or respond to initiating events before any plant parameters reach a DL3 actuation setpoint Defence Line 3 DL3 contains plant functions that mitigate an initiating event by preventing fuel damage when possible, protecting	Defence-in-Depth approach usual for PWR: Prevent deviations from normal operation Detect and control deviations Incorporate safety features, safety systems and procedures to prevent core damage Mitigate the consequences of accidents Mitigate radiological consequences	Defence in depth is provided through the provision of robust active and passive safety measures, designed against conservative conditions, which meet the guidelines from the deterministic design basis analysis.	Defence-in-Depth with passive safety cooling systems and active non-safety systems; critical components below grade The SMR-160 incorporates multiple levels of defence-in-depth to remove heat from the reactor and assure safety. All safety systems are located inside the robust Containment Enclosure Structure, rendering them secure and safe from external threats, both natural and man-made. The systems are simpler than current operating reactors, eliminating active pumps	Defence-in-Depth concept is part of the ACP100 design

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		the integrity of fission product barriers, placing the plant in a safe state, and maintaining the plant in a safe condition following an event until normal operations are resumed. DL3 functions typically include reactor SCRAM and actuation of engineered safety features Defence Line 4 DL4a functions can place and maintain the plant in a safe state following initiating events with failure of DL3 functions. The DL4a functions are intended to prevent the progression of accidents and radioactive release to the public. DL4b functions prevent or mitigate a severe accident while maintaining radioactive releases at acceptable levels. DL4b also provides protection for events that exceed DL1 assumptions regarding initiating events as a result of			from the safety functions, thus making them more reliable. According to HOLTEC no operator actions are required to place and maintain the reactor in a safe shutdown condition, making it "walk away safe". All makeup water needed for a postulated loss of coolant accident is inside containment, thus making the containment fully isolable, eliminating dose to the public and effects on the environment from this event.	

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		extreme events, multiple events, or multiple failures. Defence Line 5 DL5 addresses offsite emergency preparedness to protect the public from substantial radioactive releases.				
All six SMRs employ defence-in-depth principles typical for the LWR - prevent deviations from normal operation; detect and control deviations; use safety features, safety systems and procedures to prevent core damage; mitigate the consequences of accidents; mitigate radiological consequences						
Spectrum of design basis threats/hazards	Loss-of-coolant accidents Failure of small lines carrying primary coolant outside containment Steam generator tube failure Main steam line break outside containment Rod ejection accident Fuel handling accident Iodine spike design basis source term Core damage event	DBA, DBC and DEC -A/B will be defined during detailed design	DBA, DBC and DEC -A/B will be defined during detailed design	DBA, DBC and DEC -A/B will be defined during detailed design	DBA, DBC and DEC -A/B will be defined during detailed design	The PDHRS prevents core meltdown in the case of DBA and beyond DBA, such as station black out, complete loss of feedwater, small-break LOCA (i.e., to prevent the change of beyond DBA to severe phase)
Spectrum of design basis threats/hazards is defined only for two out of six SMRs (NuScale and ACP100)						
Severe accidents	30 days heat removal capacity for 12 modules without AC/DC, followed by air cooling for an unlimited length of time. Normal alternating current (AC) power	Design of the BWRX-300 is based on passive cooling and natural circulation of the coolant No core injection required for LOCA mitigation	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	The plant targets a 72 hour grace time following a DBA, during which time no operator action is required. Design foresees 2 trains of emergency AC supply	First 72 hours cooling by PCCS and PCHR < 90 days, passive cooling by PCHR > 90 days, indefinite cooling via passive air cooling	(DC) power source for accident mitigation up to 72 hours, supported by system to recharge the battery for up to seven (7) days

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	systems are not safety-related and not credited to mitigate DBA/DBC	Emergency AC supply is not required DC Power Capacity – 24-72 hours	without the need for Intervention. No safety classified 1E electrical power is required.			
All six SMR rely on extended use of passive systems and have grace period of no operator actions of at least 72 hours						
Basic safety parameters including thermal-hydraulics	Natural circulation NSSS Operating Pressure (primary/secondary), mPa 13.8 / 4.3 Core Inlet/Outlet Coolant Temperature 249 / 316 (oC)	Natural circulation NSSS Operating Pressure (primary/secondary) 7.2 / n/a Core Inlet / Outlet Coolant Temperature 270 / 288 (oC)	Forced circulation (6 pumps) Integral NSSS NSSS Operating Pressure (primary/secondary) 15/4.5 Core Inlet / Outlet Coolant Temperature 280/307 (oC)	Forced circulation (3 pumps) NSSS Operating Pressure (primary/secondary) 15.5 / 7.8 Core Inlet / Outlet Coolant Temperature 295 / 325 (oC)	Natural circulation NSSS Operating Pressure (primary/secondary) 15.5 / 3.4 Core Inlet / Outlet Coolant Temperature 243 / 321 (oC)	Forced circulation (4 pumps) NSSS Operating Pressure (primary/secondary) 15.0 / 4 Core Inlet / Outlet Coolant Temperature 282 / 323 (°C)
Three out of six SMRs using natural circulation						
Availability of SAR, PSA and their results **Reviews undertaken**	Final Safety Evaluation Report NRC, U.S., 2020	Five Topical Licensing Reports are available NRC, U.S., 2020	NUWARD is at conceptual design phase, so no licensing reports available	Rolls-Royce UK SMR is at detailed design phase, but no licensing reports available so far	Two Topical Licensing Reports submitted to the US NRC in frame of pre-licensing consultations. SMR-160 has completed the Vendor Design Review (VDR) Phase 1 process in Canada	The ACP100 preliminary safety assessment report (PSAR) is approved by NNSA in 2019 PSA level 1 is said to have been independently reviewed
10) Siting requirements						
Mandated site characteristics, and exclusions	The total area within the protected boundary is nominally 140,000 m2	Marine off load facility at the site would be preferable to reduce on-	Plant footprint: 3500 m2 Sea-onshore and/or river-side sites, with open-loop	The UK SMR has a compact Site footprint of approximately 40,000m2.	Plant footprint ~28000 m2 for single unit configuration	Site footprint 200,000 m^2 for double units' reference plant

	NuScale VOYGR	GE/Hitachi BWRX-300	NUWARD CEA/EDF/Naval Group/ TechnicAtome	Rolls-Royce UK SMR	SMR-160 HOLTEC	ACP100
	(VOYGR TM -12) All safety systems are located in the reactor building positioned at the centre of the site. The reactor building is flanked by two turbine buildings containing six turbine-generator sets each, the control room building, and the radioactive waste handling building. Forced draft cooling towers are used for condenser cooling. The site also includes a switchyard, administration building, warehouse, and interim spent fuel storage facility.	site assembling works Plant footprint 9 800 m2 Site Footprint 26,300 m2	conventional condenser cooling. Inland-site with dry aero condensers is also a possible option. Most components/circuits are delivered as modules of the size of a Marine 20'-40' container. This requires standard roads accessible to lorry. Some heavy components (such as RPV, turbine and parts of steel containment) may need specific transportation. No heavy lifting devices are required for construction or for operation.	Plant footprint (m 2) 10,000 Design features such as seismic isolation for safety related areas and road transportable modules ensure that the power station can be constructed on a wide range of sites with varying soil conditions. Although the baseline design utilises direct cooling, and as such would be required to be installed in locations with access to sufficient cooling water, indirect or direct air cooling may be specified, facilitating installation on a wider range of in-land sites.		
Already proposed/discussed/ envisaged sites	Idaho National Laboratory, Idaho, USA Doicești, Romania	GEH has been selected by Ontario Power Generation (OPG) as the technology partner for the Darlington New Nuclear Project.	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.	Rolls Royce identified in November 2022 a range of the existing nuclear power plant sites in the UK that could potentially host SMRs: Trawsfynydd, Sellafield, Wylfa, Oldbury, Berkeley, Hartlepool, Heysham, Bradwell.	No site proposals were discussed so far	Linglong One, Changjiang NPP, Hainan, China

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Potential/pre-selected sites are identified for 4 out of 6 SMRs, with one (ACP100) under construction						
Emergency preparedness requirements	In the US the expected EPZ size should not extend beyond the plant site boundary (specific regulations to define SMR EPZ are under discussion)	It is envisaged that the EPZ sizes will be calculated using dose-based and consequence-oriented methods and, according to GEH, the TVA Clinch River Early Site Permit process is a representative estimate (specific regulations to define SMR EPZ are under discussion)	NUWARD is at conceptual design phase, so EPZ and emergency preparedness arrangements will be defined during detailed design phase	The UK SMR EPZ and emergency preparedness arrangements will be defined later during detailed design phase	The SMR-160 is at conceptual design phase, so EPZ and emergency preparedness arrangements will be defined during detailed design phase	Non-residential area less than 300 m; LPZ Less than 800 m EPZ internal zone Less than 400 m; external-Less than 600 m.
*SMR vendors claim that the EPZ will be substantially smaller than for large NPPs (10 miles in US), targeting that it should not extend beyond the plant site boundary. While the NuScale proposed methodology already approved by NRC, formal Safety Evaluation report is still to be prepared. The discussion on SMRs' EPZ sizing already started by the EU regulators [**Fehler! Verweisquelle konnte nicht gefunden werden.**] and will be continued further during review of vendors' proposed SMR EPZ. The EPZ for SMRs would be scalable depending on the results of a hazard assessment, the technology, novel features and specific design criteria, as well as for some, policy factors. The same design of SMR implemented in different countries may result in different EPZ sizes depending on the regulation, protection strategy, dose criteria, policy factors, and public acceptance.*						
Site access **Site utilisation**	Normal roads are sufficient to deliver to the site all plant components and materials required for construction	Marine off load facility at the site will assist in reduction of assembling works performed directly on-site	Most components/circuits are delivered as modules of the size of a Marine 20'-40' container. This requires use of standard roads. Some heavy components (such as RPV, turbine and parts of steel containment) may need specific transportation arrangements	Design features road transportable modules. The RPV diameter is constrained to be less than 4.5m to ensure that the UK road transport height limit of 4.95m is not exceeded.	Holtec SMR-160 largest piece of equipment by size and weight is the Steam Generator, and this is designed to be shipped as a single heavy module by rail, ship or road, consistent with Holtec logistic processes, and in strict accord with US and international transportation requirements, routes and limitations.	Site access is ensured. Construction activities at Linglong One, Changjiang NPP, are ongoing since July 2021

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All six SMRs consider normal roads or marine off load facility at the site as standard option for delivering SMRs' heavy components						
11) Operations						
Concept of operation for single, multiple units	NuScale offers: VOYGR-12 power plant Power Module™ of 924 MWe. VOYGR-four modules VOYGR-4 of 308 MWe and six-module VOYGR-6 of 462 MWe. Each module has its own 77 MWe turbine	Reference design foresees single unit, but this could change for other plant design	Reference design foresees dual unit concept	Reference design foresees single unit, but this could change for other plant'' design	Reference design foresees single or dual unit configurations	Reference design foresees dual unit configurations
SMRs concept of operation foresees operation of single, dual or up to 12 modules (NuScale), but design of specific plant could be adjusted according to the Customer needs						
Degree of automation	Digital Instrumentation & Control (I&C): NuScale's proprietary field programmable gate array digital I&C system provides comprehensive monitoring and control of all plant systems in a single control room. Control room layout and panel displays designed using simulator, comprehensive human factors' engineering and human system interface evaluation program.	The BWRX-300 control and instrument systems provide manual and automatic means to control plant operations and initiate protective actions should plant upset conditions occur. The BWRX-300 utilizes digital controllers, interfacing with plant equipment, sensors and operator controls through a multiplexing system, for signal transmission to achieve these functions.	I&C design architecture is compliant with IEC61226 standard. NUWARD uses state-of-art digital nuclear I&C compliant with the single failure criterion and diversity. The two units of a same plant share the same control room, with dedicated independent panels, for the reactors in operation. No operator action required for more than 3 days after any design basis accidents (DBA)	The plant is controlled and protected by a number of control and instrumentation (I&C) systems. The reactor plant control system, which manages duty operations, uses an available in industry programmable logic controller (PLC) or distributed control system (DCS). The reactor protection system (RPS) provides safe shutdown. The RPS uses digital systems, designed specifically for the nuclear industry.	Holtec will employ Mitsubishi Electric's MELTAC© Digital I&C Platform, which the U.S. Nuclear Regulatory Commission has approved for use in nuclear plants and nuclear safety applications and meets Holtec's strict demands of precision and excellence. Mitsubishi's MELTAC© Digital I&C Platform will assist in Holtec's objective to ensure that SMR-160 maintains its technological superiority amongst advanced	The Instrumentation and Control (I&C) system designed for ACP100 is based on defence in depth concept, compliance with the single failure criterion and diversity I&C systems of the NSSS include reactor nuclear instrumentation system, RPS, diverse actuation system, reactor control system, rod control and rod position monitoring system, reactor in–core instrumentation system, loose parts and vibration monitoring

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				All systems have been designed using defence in depth, diversity and redundancy, etc.	reactors being developed.	system and other process control systems.
All six SMRs control systems has been/will be designed using modern approach that is based on vendors' experience and commonly known and employed defence in depth concept, compliance with the single failure criterion and diversity I&C systems						
Critical issues related with Operation and Maintenance	Critical issue with operation and maintenance will become known after operation starts.					
Multiple unit crews	Estimate for NuScale 12-module 924 MWe power plant is that 270 plant personnel will support operations, online maintenance, refuelling, outage maintenance, security, etc.	Operation / Maintenance personnel ~75 in total	Operation / Maintenance Human Resources 56 / 50	Personnel/operators requirements are not yet defined	Personnel/operators requirements are not yet defined	Personnel/operators requirements are not published
Estimate on prospective number of personnel provided only for three out of six SMRs, however considering that none of six SMRs is in operation these estimates should be considered as preliminary						
Need for operators	MCR of NuScale 12-module 924 MWe power plant will require 6 licensed operators in each shift	Number of licensed operators is not defined yet	Number of licensed operators is not defined yet	Number of licensed operators is not defined yet	Number of licensed operators is not defined yet	Number of licensed operators is not published
Only NuScale provided information on number of licensed operators where 6 operators in single control room will control 12 NPMs. While this NuScale proposal was accepted by the NRC in US, the approach might be scrutinised the EU regulators.						
12) Radioactive waste issues						

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Effluents and radioactive waste generated: liquid, gaseous and solid	Radioactive Waste Building (RWB) houses equipment and systems for processing radioactive gaseous, liquid, and solid waste and for preparing waste for offsite shipment. Liquid releases and gaseous discharges are to be within 10 CFR 20 Appendix B limits	Radwaste system design and the classification of radwaste systems are not addressed in the Licensing Topical Reports. Further review will be done during future licensing activities when detailed design information will be made available.	Information and data will be available at detailed design phase	Waste Treatment Systems (WTS) The WTSs provide for the collection and processing for disposition and discharge of gaseous, liquid and solid radioactive wastes generated within the SMR. They are formed from the Gaseous Waste Treatment System (GWTS), Liquid Waste Treatment System (LWTS) and Solid Waste Treatment System (SWTS), which are located in the radioactive waste area next to the reactor containment vessel.	SMR-160 site layout foresees Radwaste Building. Further details will be defined during detailed design phase. What is already defined is that all spent fuel for the life of the plant can be stored on-site.	According to CNNC Waste management approach and disposal plan is similar to other nuclear power plants.
Comparison with traditional reactors	Some studies (Krall et al., "Nuclear Waste from Small Modular Reactors) highlight that NuScale will have substantially higher rates of RAW generated and lower burn-ups in comparison with large PWRs, however NuScale published data confirm that that those will be comparable. Module design and operating parameters allow reactor power changes using only control rod movement down to 40% reactor power, thus reducing generation of liquid RAW					

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Waste management concept	DCA stipulates that following RAW management system will be used at NuScale: Liquid Waste Management System, Gaseous Waste Management System, Solid Waste Management System. SNF is planned to be stored on-site: for 5 years in SNF pool under the ~18 m water layer. Standard design includes an area for the dry storage of all of the spent fuel for the 60-year life of the VOYGR plant. SAR defines amounts of gaseous, liquid and wet and dry solid waste generated per year					
Radioactive waste minimisation	Radioactive waste minimisation provisions are part of the design, e.g., spent resins processing, power reduction by tods only up to 40% od rated etc.					
Waste storage on site	NuScale concept is processing and transfer					

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	RAW off-site, so only temporary storage of RAW is foreseen before sender RAW outside for storage/disposal. Onsite storage is provided to hold solid waste for at least 30 days in accordance with ANSI/ANS-55.1-1992 and BTP 11-3.					
All six SMRs will have set of RAW treatment systems. The only SMR that published information on RAW management and RAW management concept is NuScale. Other SMRs' vendors published very limited information on RAW management. Boron-free design of reactivity control system proposed by Nuward and RR UK SMR and NuScale capability to reduce the load down to 40% using just control rods will reduce amounts of generated liquid RAWs.						
13) Legal issues						
Non-proliferation issues	There are no NuScale specific non-proliferation issues as plant use fuel with typical for LWR enrichment, will be equipped with respective security system and would be subject to domestic safeguards program	There are no BWRX-300 specific non-proliferation issues as plant use fuel with typical for LWR enrichment, will be equipped with respective security system and would be subject to domestic safeguards program	There are no NUWARD specific non-proliferation issues as plant use fuel with typical for LWR enrichment, will be equipped with respective security system and would be subject to domestic safeguards program	There are no Rolls-Royce UK SMR specific non-proliferation issues as plant use fuel with typical for LWR enrichment, will be equipped with respective security system and would be subject to domestic safeguards program	There are no HOLTEC SMR-160 specific non-proliferation issues as plant use fuel with typical for LWR enrichment, will be equipped with respective security system and would be subject to domestic safeguards program	There are no CNNC ACP100 specific non-proliferation issues as plant use fuel with typical for LWR enrichment, will be equipped with respective security system and would be subject to domestic safeguards program
All six SMRs do not have specific non-proliferation issues as use fuel with typical for LWR enrichment, will be equipped with respective security system and would be subject to domestic safeguards program						
Availability of components	Availability of components is subject for appropriate contract with industry. It should not be an issue for the SMR plants. However, this might become an issue for some of SMRs. If operation of the plants will show good results, so number of orders could increase. However even this issue might be addressed by involvement of new suppliers.					Availability of components for ACP100 SMR is already

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						addressed as plant is under construction. The issue might become actual if and when massive deployment will take place, but even this might be addressed by involvement of new suppliers.
Availability of components should not be an obstacle for the SMRs during initial deployment phase, but could become a challenge later, if number of orders will increase.						
Limitation of supplies due to intellectual properties **Licensing of technology issues**	NuScale use own design technologies, so limitation due to intellectual properties rights should not be a problem	GEH use own design technologies, so limitation due to intellectual properties rights should not be a problem	EDF lead Consortium will use own design technologies, so limitation due to intellectual properties rights should not be a problem	Rolls-Royce led Consortium will use own design technologies, so limitation due to intellectual properties rights should not be a problem	HOLTEC SMR-160 is proprietary design of HOLTEC. HOLTEC also concluded MoU/MoAs with number of companies that will be involved in design and manufacturing of equipment for SMR-160–- e.g., Skoda, Mitsubishi, Hyundai etc., so the intellectual properties limitations should not impose any risk on project implementation.	CNNC will use own design technologies, so limitation due to intellectual properties rights should not be a problem
All six SMR vendors are owners of the SMR design they are proposing. Use of own design and involvement of counterparts for designing specific SMR equipment – e.g., I&C will eliminate potential intellectual properties and Licensing of technology issues						
14) Economic parameters						
Cost at design stage	NuScale estimate: $3,600/KW (NOAK)	GEH target: $3,000/kW		Rolls-Royce estimate : 1.8 bn £ (~ £3800/kW)	Published estimates: $650 million per unit/	CNNC assessment: ACP100, demonstration

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Envisaged/projected construction costs	NOAK–- 4250 €/kWe FOAK–- 6850 €/	GEH estimate: FOAK 1 bn USD (3300 USD/kW) , NOAK 2250 USD/kW	Information and data will be available at detailed design phase	~ £75/MWh for FOAK plant ~ £40-60/MWh for NOAK plant	$4,000/kW (no reliable information so far on SMR-160 costs)	project, the cost is 2 times higher than that of large NPP. SMR with less power output, construction cost per kW is higher than large NPP according to the scale effect
FOAK and NOAK costs	LCOE - $40/MWh to $65/MWh $51/MWh–$54/MWh (PNNL)	GEH: LCOE - $35 to $50 USD/MWh, $44–$51/MWh (PNNL)		Rolls-Royce: LCOE–- of ~ £40-60/MWh for NOAK plant		
Reliability and plausibility of cost estimates	Reliability of cost estimates is questionable, given in particular that UAMPS estimated 89 USD/MWh	Reliability of cost estimates is questionable,		Reliability of cost estimates is questionable,	Reliability of cost estimates is questionable,	Not known
The economics parameters that are published by vendors and in various studies have substantially differ. The vendors indicate SMR cost in range of 3000 – 4000 $/kW, however reliability of cost estimates might be questioned and are likely to be overly optimistic.						
Any published studies, parameters that would support costs estimates	NEA 2016/2021: Small Modular Reactors: Challenges and Opportunities PNNL 2021: Techno-economic Assessment for Generation III+ Small Modular Reactor Deployments in the Pacific Northwest	NEA 2016/2021: Small Modular Reactors: Challenges and Opportunities PNNL 2021: Techno-economic Assessment for Generation III+ Small Modular Reactor Deployments in the Pacific Northwest	No studies covering NUWARD are available so far	No studies covering RR SMR are available so far	No studies covering SMR-160 are available so far	No studies covering ACP100 are available so far
PNNL study of 2021 shows LCOE in range of $51/MWh–$54/MWh for NuScale and $44–$51/MWh for BWRX-300 NOAK plants, however reliability of cost estimates might be jeopardised by current fluctuations of the gas/energy market prices.						
Independent reviews undertaken	Economics of nuclear power plants: bottom-up cost estimation model for	No independent reviews undertaken				

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	SMR Matteo Mauri 2020-2021					
The study indicates Overnight Capital Cost for the NuScale of 4.700 € /kWe for FOAK plant and 3.250 €/kWe for NOAK plant.						
Investment plans and commitments	DoE approved in Oct 2020 a $1.355 billion award to fund the Carbon Free Power Project (CFPP), a potential 720-MWe NuScale power plant for the Utah Associated Municipal Power Systems (UAMPS). The project was downsized to six 77 MWe modules totalling in 462 MWe Nuclearelectrica and Nova Power & Gas have launched in September 2022 a joint venture, RoPower Nuclear, for the development of NuScale SMR technology.	Fermi Energia, which plans to build a nuclear power plant in Estonia, has entered into preliminary agreements with Estonian business customers. The agreements are the basis for the conclusion of subsequent contracts for the purchase and sale of electricity. The target price per MWh in these agreements is 55 euros.	September 2020 - €50 million provided by the French government under the France Recovery plan. On 10 February the President announced an additional intervention of the State up to €500 million to accelerate France's efforts to export SMRs. The first of the France 2030 plan objectives is to " to develop small, innovative nuclear reactors in France with better waste management". EUR 1 billion will be invested by 2030 to achieve this goal.	In November 2021 the UK government committed that it would contribute £210 million in grant funding to Rolls-Royce SMR to match private investment in this venture. Rolls-Royce Group, BNF Resources UK and Exelon Generation will invest £195 million over about three years in it.	To support the development of the SMR-160, the US Department of Energy (DOE) awarded a grant valued at $147.5 million (DOE share is $116 million with Holtec's investment share being $31.5 million) in 2020. To date, Holtec has invested more than $400 million in the SMR-160 programme and holds 25 US patents on the SMR-160 technology with many patents also extended to other countries.	Construction activities at Linglong One, Changjiang NPP, are ongoing since July 2021. Deployment of other ACP100 units within or outside China will be decided at later phase (likely closer to demonstration project completion)
Investment plans for construction of SMR are established in US (Idaho UAMPS), Estonia (Fermi Energia), Canada (SaskPower) and China (CNNC ACP100). Beside those development of the SMRs is strongly supported by Governments of the US, UK and France aiming at development of SMR to be built in own country, but also for importing SMR technology worldwide.						
15) Security related issues						
Security challenges	The SMRs should not have design specific security challenges as design of security system is well developed for the existing NPP and will not differ too much for the SMRs.					

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Deployment of numerous SMRs will require implementation of robust security measures that might require significant police/local guards resources as to prevent unauthorised site/facilities access.						
Site protection	Fencing and intrusion systems are protecting a perimeter boundary and indication of unauthorized attempt to enter the area. Placement of the entire NSSS, the containment, the control room, and the spent fuel pool below grade level reduces vulnerabilities to external or internal malevolent acts of sabotage, or other potential security threats. Below grade pool provides enhanced physical security by adding additional challenges to fuel access.	The physical separation of redundant systems support the physical security of the plant. All vital systems and components are housed within robust reinforced concrete structures that are controlled and monitored by the site security system. Many of the components are located below site grade, thereby minimizing exposure to external threats.	The nuclear island is constructed underground for the reactors and SNF and protected. There is no direct access from outside to the Nuclear Island, all accesses is arranged via tunnels and locks. Such type design also contributes to better security. All other details will be made available at detailed design phase.	The SMR security is designed against the UK Office for Nuclear Regulation (ONR) Security Assessment Principles (SyAPS). Security is assured through by: 1. Dedicated security measures 2. Security measures which are integrated into the general design features of the SMR and plant layout (for example, entry/exit points, building/equipment location, structural resilience etc.)	From a security perspective, all SMR-160 safety systems are located within and protected by a robust and secure Containment Enclosure Structure (CES). Containment is inaccessible and resistant to radiological sabotage.	Site will be protected by similar fencing and intrusion systems that are employed at large NPPs. ACP100 enhanced safety and physical security are improved by locating NSSS and SFP underground.
SMRs site protection is using same principles as used for site protection of large NPPs.						
Security concept during operation	Current concept foresees 48 security personnel among plant personnel	Reduced on-site staff and security is among BWRX-300 top-level features, however no details are available at this stage	Information and data will be available at detailed design phase	Information and data will be available at later phase	The Containment is sealed during operation and entry is not possible. - SMR-160's components lie deep below the ground, inaccessible to direct attack by drones or missiles. - The SMR-160 control	ACP100 enhanced safety and physical security are ensured by locating NSSS and SFP underground. Specific ACP100 information and data are not available in open sources.

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					room is underground, with multiple layers of security.	
Cost of security	Data on cost of security might be available at later phase of projects development					
Comparison with traditional reactors	Cost of security of the SMRs will likely be similar as for traditional NPPs per site					