ELSMOR

Towards European Licensing of Small Modular Reactors

Europe and SMRs – the ELSMOR project

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Contents

- Small modular reactors and Europe
- European R&D and ELSMOR
  - Investigation of potential gaps in the way of exploiting SMRs
- What defines SMRs
  - Technology
  - Ambition
  - Story

Nuclear energy history


Olkiluoto NPP. Image source: TVO

- First reactor designs from 1960s were demonstrations, with complications inherent in 1st generation designs
- Current commercial nuclear power plants built mostly in 1970s and 80s
  - Provide ~1/4 EU electricity
  - Mostly large light water reactors
  - Hundreds of MWs to gigawatt scale
- After a decade or two of not advancing, the early 2000s saw what was called a ”Nuclear Renessaince”
  - Start of new NPP projects in Finland, France, USA
  - Establishment of concept of ”Generation 4” nuclear reactors

- Nuclear renaissance was our last, best hope
  - It failed

Enter small modular reactors

- Aim to fit the current world
- Defined ”Small” as ”300 MW electric or less” in power per reactor, so to better fit in different roles
  - Some SMRs break this rule, and plants may have many reactors
- ”Modular”, to allow for serial production from the get-go
  - Implementations vary
- Still ”Reactors”, so have all the nuclear energy related responsibilities
  - But aim to take care of them with simpler ways, with good enough solutions instead of perfect
  - Faster deployment of LWR designs, easier demonstration of non-LWR tech

Large number of SMR designs under development– only some are shown here

Canada:

- Various reactor designs in pre-licensing pipeline
- Canadian Nuclear Laboratory provides site for demonstrations
- MMR licensing start
- OPG aims to build BWRX-300

United States:

- NuScale SMR generic design license

Several other projects at various stages:

- Natrium
- Xe-100
- BWRX-300

Strong export push

United Kingdom:

- Advanced Modular Reactor support
- UK SMR joint venture formed for deployment of 470 MW “SMR”

France:

- French SMR developer consortium - NuWard

Russia:

- Movable barge SMRs
- RITM-200 ship reactor usable on land also
- 22 RITM-200s in pipeline

China:

- HTR-PM dual unit SMR (210 MWe) high temperature reactor connected to grid
- District heating reactor demonstrations
- Various other SMR designs
- Aims for strong domestic and international expansion

South Korea:

- SMART light water SMR
- Barge reactor development announced

Example SMR: French Nuward

- Concept development originally by CEA, EdF, Naval Group and TechnicAtome
  - 3 out of 4 partners in ELSMOR
  - Some new partnerships (e.g. Tractebel) announced
- Large effort by France to create an ”European SMR” to complement EdF’s EPR lineup
  - Passive core cooling
  - Submerged containment cooling

French-developed SMR design unveiled

17 September 2019

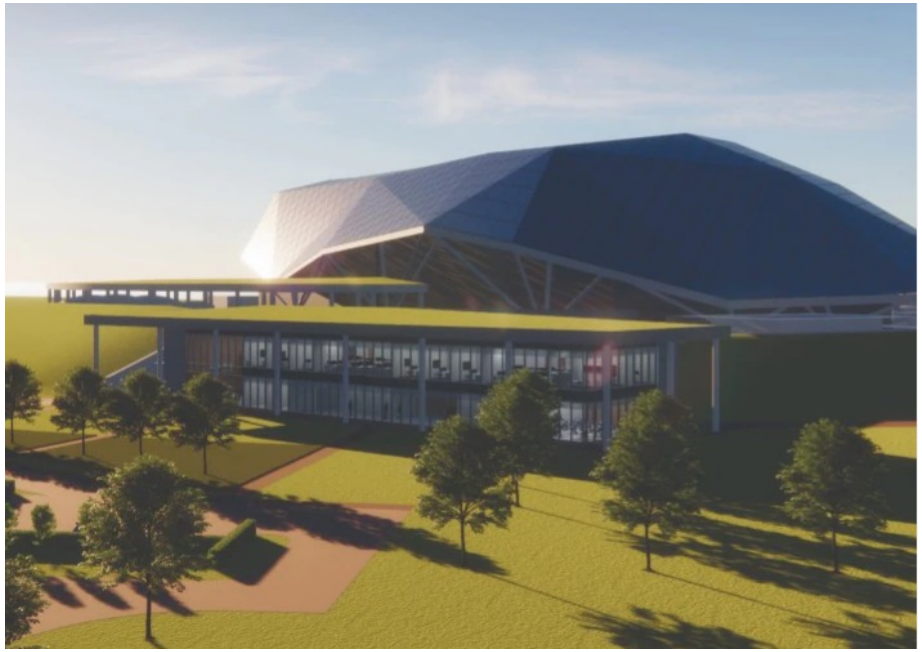
Share

A new small modular reactor (SMR) design has been announced by the French Alternative Energies and Atomic Energy Commission (CEA), EDF, Naval Group and TechnicAtome. The Nuward - with a capacity of 300-400 MWe - has been jointly developed using France's experience in pressurised water reactors (PWRs).

Lähteet:http://world-nuclear-news.org/Articles/French-developed-SMR-design-unveiled

Example SMR: UK SMR – aim to foster national industry

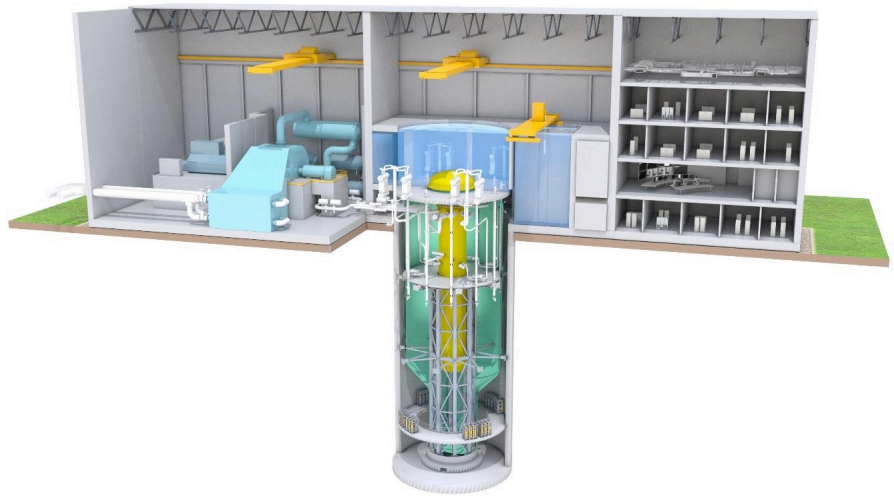
- UK had a domestic NPP program
  - Gas cooled reactors, one LWR, whole industry run down in 1990s
  - International large LWRs being bought
- National program to kickstart industry using SMRs
  - 470 MW light water reactor
  - Development spearheaded by Rolls-Royce, supported by UK government to foster national industry
  - Aiming for the first NPP on grid in early 2030s
- £490 million in commercial equity and UK government investment



Press releases | Rolls-Royce - Rolls-Royce plc, Qatar Investment Authority, Announce Agreement to Invest in New Low Carbon Nuclear Power Business

Example SMR: BWRX-300 – pivot to SMR

- GE-Hitachi previously had large nuclear pow plants on offer
  - ESBWR fully licensed in USA – but no customers
- Came up with highly simplified 300 MW BW
- Cautious to start with SMR before getting customers, but getting them now
  - Ontario Power Generation in Canada
  - TVA in USA
  - Potentially 10 for industrial sites in Poland
  - Reference design for Estonian startup



BWRX-300_2020.pdf (iaea.org)

New kinds of customers for nuclear energy

European R&D and SMRs

- In European Union, the nuclear energy collaboration is handled under Euratom treaty
  - Framework for national nuclear energy programs
- R&D part in Euratom Research and Training programmes
  - Fission and fusion research, with for long the fission focus being in the safety of long term operation of nuclear power plants and waste disposal
  - From 2016 onwards, a focused call on SMRs has been part of these programmes
- Now also a joint ”EU SMR partnership” under preparation
  - To respond to high level of commitment in e.g. USA and UK to deploy SMRs

Example of a call text

Scope of the action

This action should **investigate improved safety features of Light Water SMRs** and provide a set of fundamental technical specifications, against which compliance of SMRs with Directive 2009/71/Euratom could be tested by safety regulators. **The research should also propose the methodology** for the performance of these tests, including the experimental validation of essential items of the proposed models of safety demonstration as well as **their effects on the SMR licensing process** under various typical fields of application. Due account should be taken of safety features for the refuelling and spent fuel management of SMRs in the above safety demonstration as well as to decommissioning. To increase the impact of the action, **particular attention should be paid to Light Water SMR concepts deployable in the short-term**.

First SMR call

- First SMR call was answered by several different consortium proposals
- Three at least mostly focusing on light water reactor technologies
  - Coordinators VTT, PoliMi, and GRS
  - None got funded – waste of resources
- For the next call, a joint ”LWR SMR” proposal was collaborately initiated based on the core group of the coordinators of prior proposal and the Nugenia leadership
  - Thus ELSMOR, ”towards European Licensing of Small Modular Reactors” was born

SMRs in EURATOM 2014-2018 training&research programme

- To acknowledge the interest in SMRs in total of 4 projects are funded by the EURATOM programme
  - GEMINI+
    - Investigating gas-cooled reactors
  - ELSMOR
    - Investigating LWR SMRs
  - McSAFER
    - High-fidelity modelling of SMRs
  - EEC SMART
    - SCWR materials studies

ELSMOR towards European licensing of SMRs

- Project aiming to investigate selected safety features of LW-SMRs
  - Focus in investigating safety functions and safety justification methodology
- 3.5 year research project started on 9/2019

- Project website:
  - www.elsmor.eu

Funded from the Euratom research and training programme 2014-2018 under Grant Agreement No. 847553

ELSMOR concept

- To investigate selected safety features of LW-SMRs
  - Prevention of early release
    - Core cooling functions
    - Containment
- Research on methods for robust safety assesments
  - Several prior proposals / methodologies developed for both currently operating plants as well as non-conventional, e.g. for GenIV, fusion…
- Demonstration of the applicability of developed tools and methods
  - Test case ”E-SMR” (”European SMR”)
- Dissemination to stakeholders

Project consortium

- 15 partners
- 8 countries represented
- Initial consortium building by Nugenia T.A. 6

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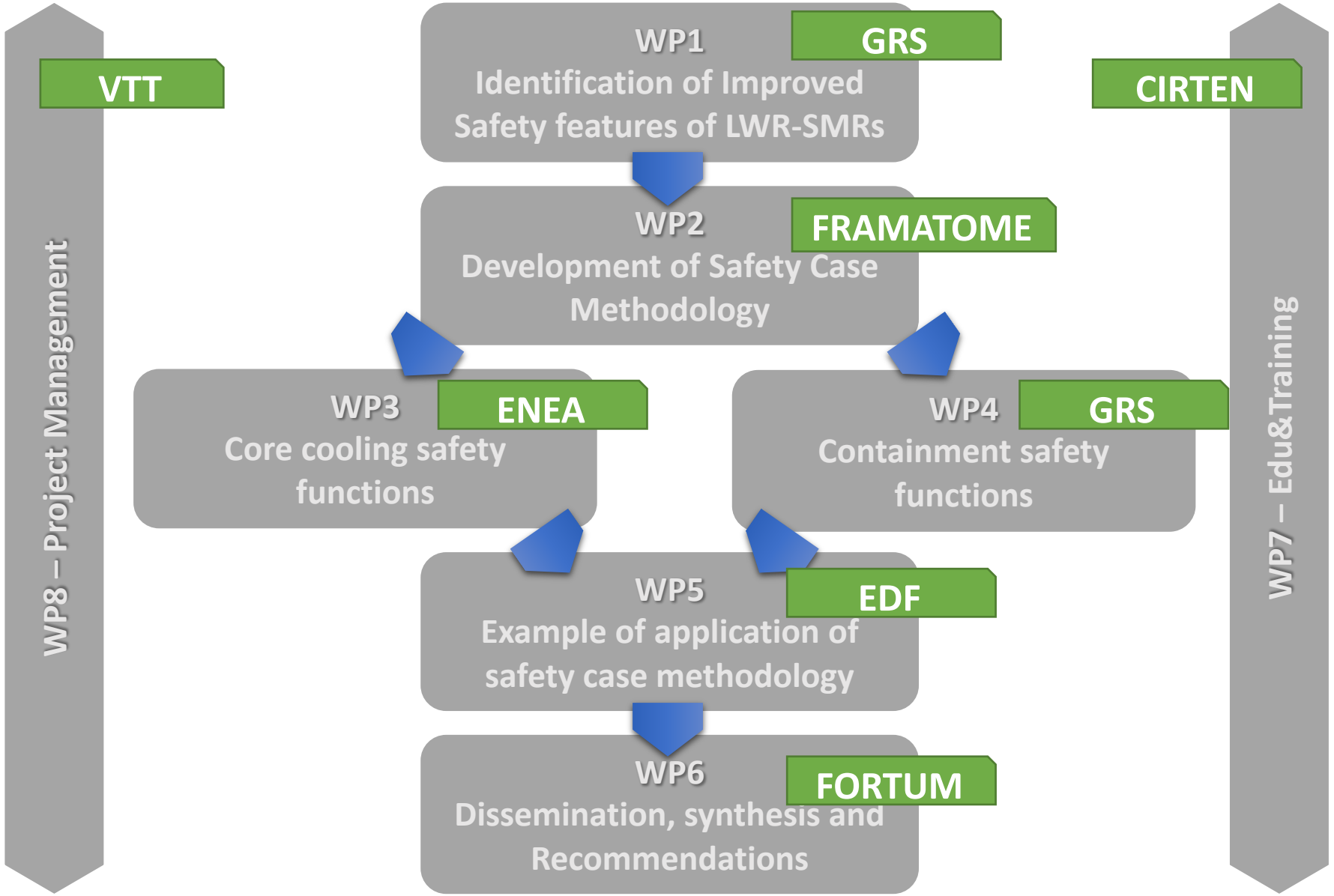

WP1: Identification of improved safety features of LW-SMRs

WP1 will focus on the identification of advanced or innovative safety features of LW-SMRs that potentially pose challenges to established safety demonstration approaches.

- Review of the European nuclear safety directive(s) and good practices on the safety assessment of LWR reactors,
- Screening of current LW-SMR designs (based on available material) related to improved or innovative safety features
- Summary of safety challenges for further consideration in the project

SMR concepts at different maturity stages which affects assessment

- A lot of information about the safety systems for decay heat removal, reactivity control as well as severe accident mitigation publicly available
  - Information about refuelling, fuel management and decommissioning or human factors lacking

WP2: Development of safety analysis methodology for LW-SMRs

WP2 will focus on developing a methodology with qualitative and quantitative recommendations to support the safety demonstration of LW-SMRs.

- Complementary methodology development
  - Assessing the applicability of technology neutral Integrated Safety Assessment Method (ISAM) developed by GenIV International Forum
  - Systems engineering approach
- Various aspects of SMRs
  - High-level objectives (reactivity control, core cooling, containment)
  - Multi-unit plants, human factors, decommissioning, fuel management

WP3: Core cooling safety functions

Work Package 3 will focus on core cooling safety functions of integral LW-SMRs.

- Work to be performed is associated with safety analysis, development and assessment of codes and models
- Experimental investigations at SIET facility
  - Heat exchanger mock-up tests
  - Blind and post test modelling, model development

WP4: Improved Safety Analysis Methods and Tools for Containment Safety Functions

The objective of this WP is the development, assessment, and validation of analysis methods and tools for the safety demonstration of improved or innovative **containment safety function features** of integral LW-SMRs in general and the currently proposed French F-SMR design as a reference SMR in particular.

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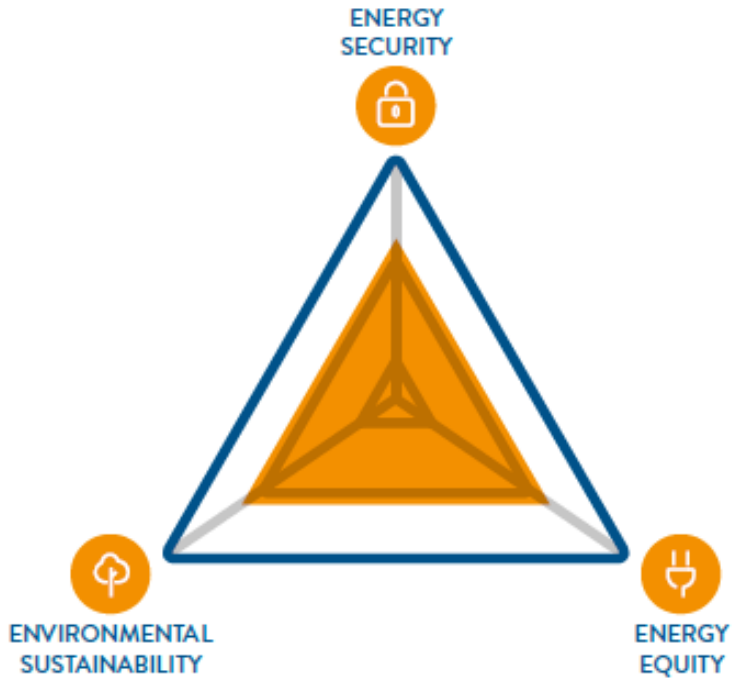
Small modular reactors

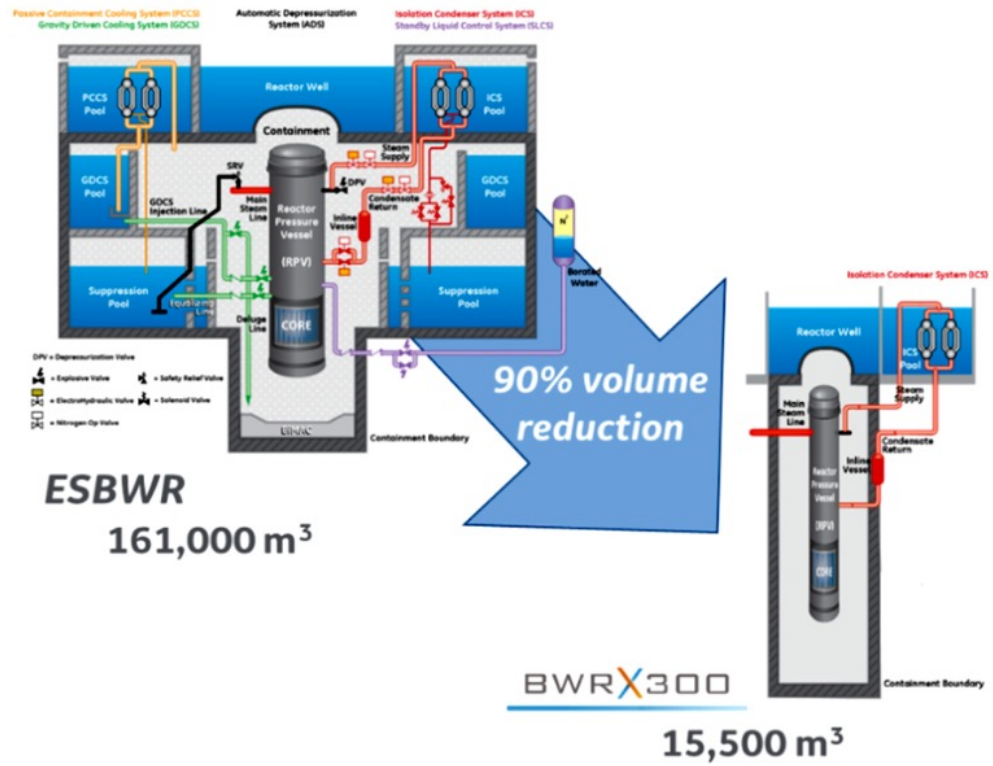
What drives the development

- Technology push
  - Development of novel technology
  - “Appeal to novelty” fallacy, innovation is favoured over maintenance
  - Improvement over previous designs
- Market pull
  - Need of markets
  - Not only costs, but also considerations for energy security, technology policies, externalities
  - What people (think they) want



Technology

- Potentially simpler safety systems
  - Relying on passive features like natural circulation of coolant
- Potentially less complexity
  - Passive systems allow for less complexity
- All allow for simpler projects that eventually should lead to faster deployment and more resilient systems
  - If these can be verified and licensed
  - If this can be done in many countries similarly



Constantly increasing ambition

- ELSMOR planning was done 2017-2018, project started in 2019
  - At the time most SMR plans had a timeline of first demonstration in mid-2030s
  - So approximately a decade from ELSMOR project results to first deployment
- Now the first LWR SMR projects target start of operations in 2029, 2030
  - EU SMR partnership targeting first deployment in 2030
  - Timeline means that the deployment should be imminent
- International organizations discuss harmonization of requirements
  - Regional such as European actors, or international ones globally

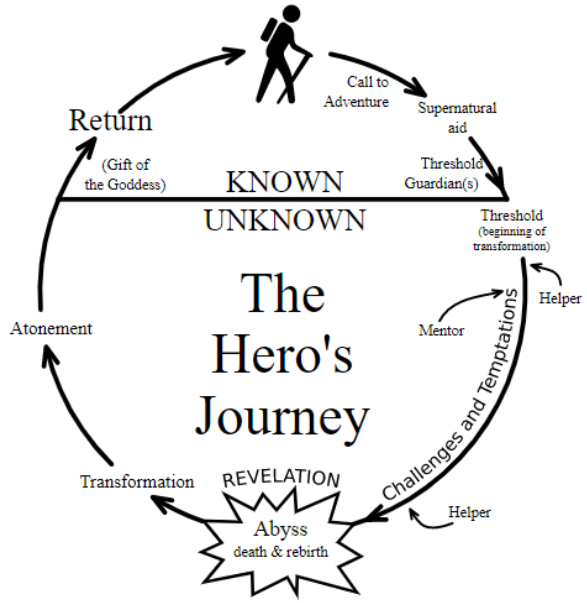
Small modular reactors under development worldwide with significant near-term milestones

Design	Net output per module	Type	Designer	Country	Status
ARC-100	100 MW electric	Sodium fast reactor	ARC Clean Energy	Canada	Demonstration project planned in New Brunswick
CAREM	25 MW electric	Pressurised water reactor	CNEA	Argentina	Under construction (Zárate)
BWRX-300	300 MW electric	Boiling water reactor	GE-Hitachi	United States / Canada	First commercial deployment announced with Ontario Power Generation (Darlington, Canada) and under discussion with Tennessee Valley Authority (Clinch River, United States)
eVinci	5 MW electric and up to 13MW thermal	Heat pipe	Westinghouse	United States / Canada	Pre-licensing application submitted in the United States in 2021
Kairos Power FHR	140 MW electric	Molten salt reactor	Kairos Power	United States	Under licensing with demonstration project planned with Oakridge National Laboratory
Micro-Modular Reactor Project	15 MW thermal	High temperature gas-cooled reactor	Global First Power / Ultra Safe Nuclear Corporation	Canada	Under licensing with demonstration project planned at Canada National Laboratories site (Chalk River)
Stable Salt Reactor – Wasteburner (SSR-W)	300 MW electric	Molten salt reactor	Moltex	Canada	Demonstration project planned in New Brunswick
NuScale SMR	50 MW electric (× 12)	Pressurised water reactor	NuScale Power	United States	Under licensing with demonstration project with Idaho National Laboratories and Utah Associated Municipal Power Systems
Natrium	345 MW electric	Sodium fast reactor	TerraPower / GE-Hitachi	United States	Demonstration project with preferred site identified at Kemmerer (Wyoming)
NUWARD	170 MW electric (x2)	Pressurised water reactor	EDF-led consortium	France	Demonstration project planned for 2030
RITM-200	55 MW electric	Pressurised water reactor	OKBM Afrikantov	Russia	First land-based version planned for 2028 in Yakutia
UK SMR	470 MW electric	Pressurised water reactor	Rolls-Royce led consortium	United Kingdom	Under licensing with Wylfa and Trawsfynydd identified as potential sites in the licence application
Xe-100	80 MW electric (x 4)	High Temperature gas-cooled reactor	X-energy	United States	Demonstration project with Energy Northwest (Washington)

Note: This list includes designs for which a site has been identified, a formal licence application made or that have been selected by government for near-term deployment.

Story

- Like it or not, ”SMR” has become a popular story
  - How nuclear energy production started, encountered obstacles, failed, got re-invented, and now is poised to bring fortune to world
  - Story not unlike the monomyth / hero’s journey
- These stories have power, as use of nuclear energy depends also on public acceptance



Can you name any examples?

Thank you for your attention

- Project website:
  - www.elsmor.eu

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