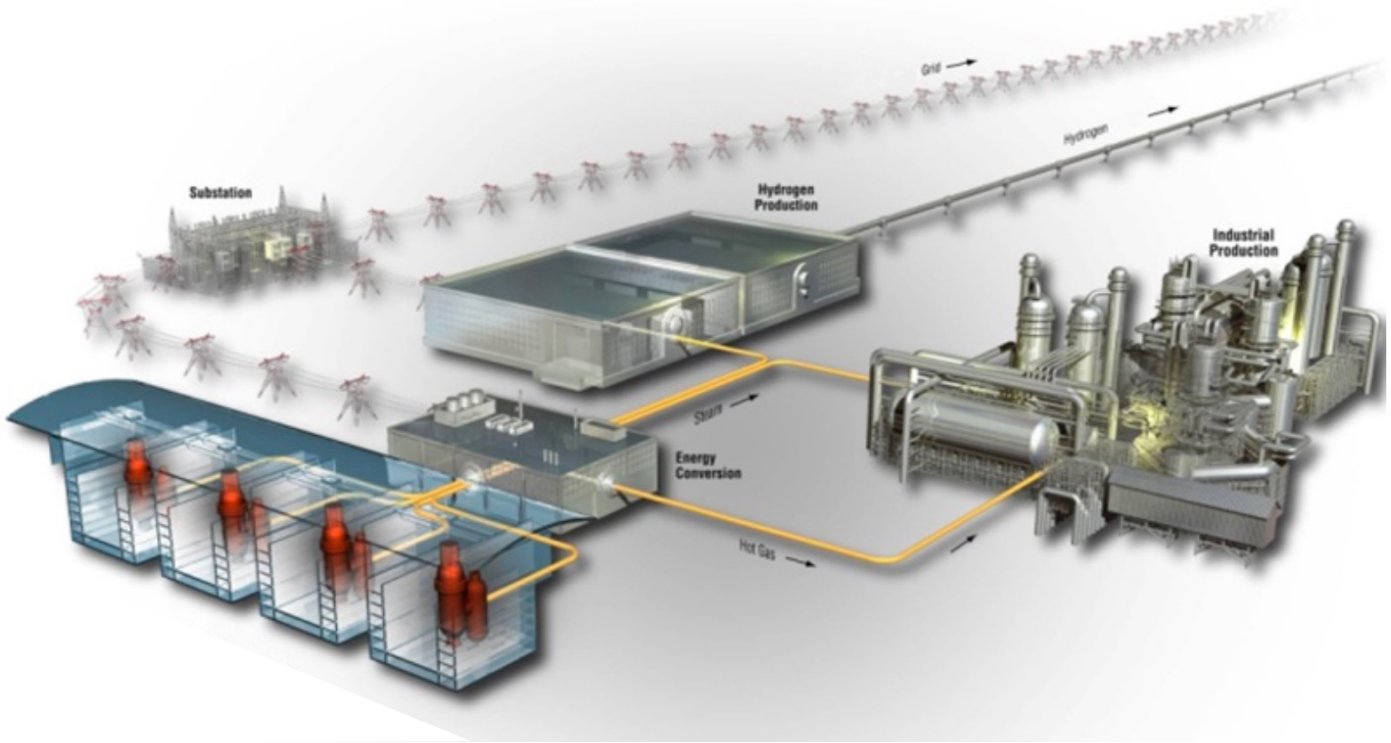
Small modular reactors: technology, applications and recent developments



dr.ir. Aliki van Heek
Bèta Research

IENE seminar
“Greece in the Global SMR Supply Chain”
Athens / online
14 October 2026

May I introduce myself? – Aliki van Heek

Resume

- MSc Technical Physics TU Delft, The Netherlands
- PhD RWTH Aachen / FZJ, Germany
- 23 years at ECN/NRG, The Netherlands
  - High-Temperature Gas-cooled Reactors
  - Generation IV nuclear systems
  - Nuclear safety – stress tests
  - Decommissioning and radioactive waste management
- 7 years at International Atomic Energy Agency (IAEA), Austria
  - 3E: Energy, Economics and Environment
- Self-employed since 2023
  - Bèta Research GmbH
  - Based in Vienna, Austria

- Expert groups
  - IAEA
  - OECD Nuclear Energy Agency
  - World Nuclear Association
  - STENFO Cost Committee
    - The nuclear decommissioning and waste management fund of Switzerland

- Contributed to

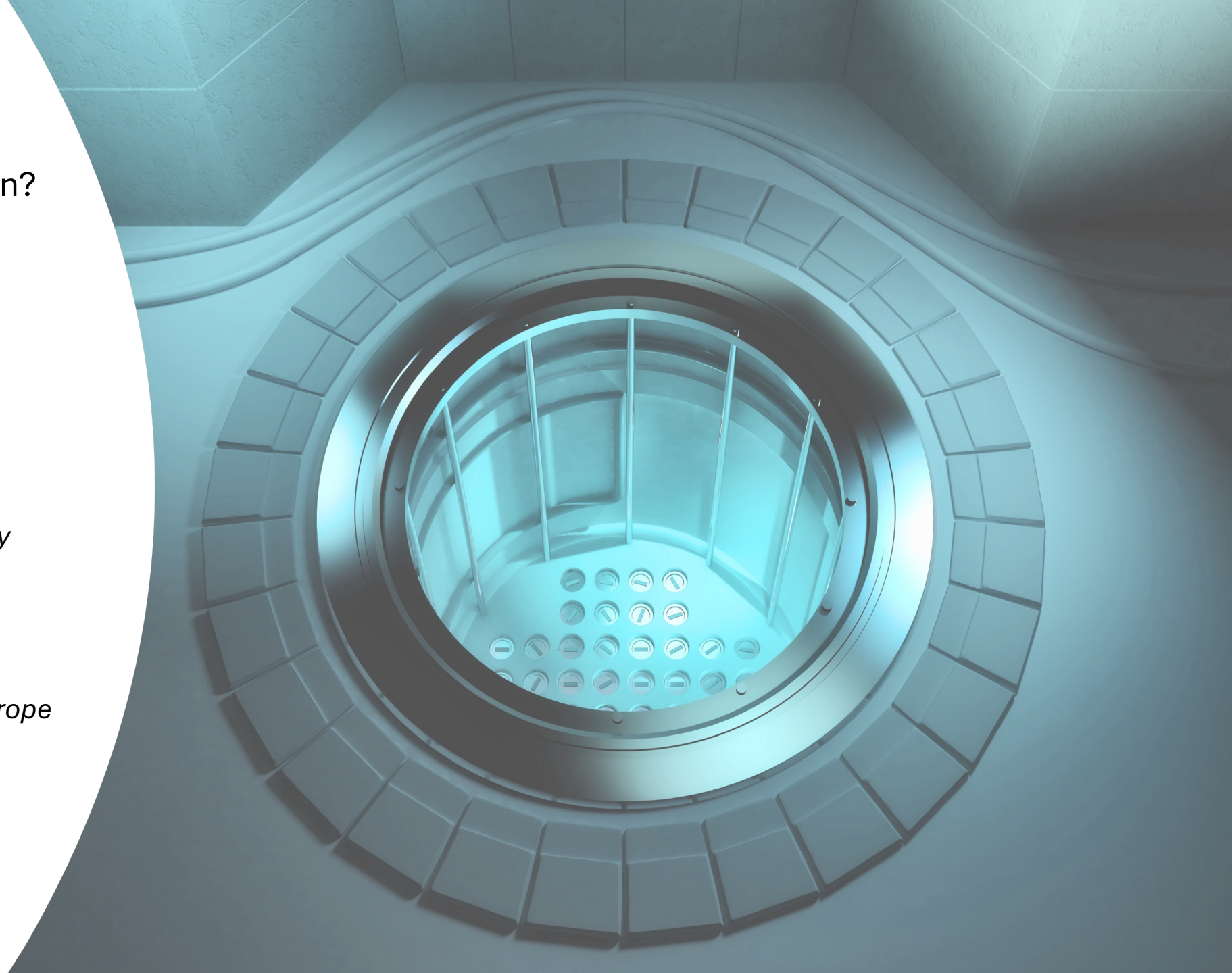


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Content

- What does SMR mean?
  - *Small*
  - *Modular*
- SMR types
  - *By reactor coolant*
- Applications
  - *More than just electricity*
- Development
  - *Progress in the world*
  - *Focus on South East Europe*

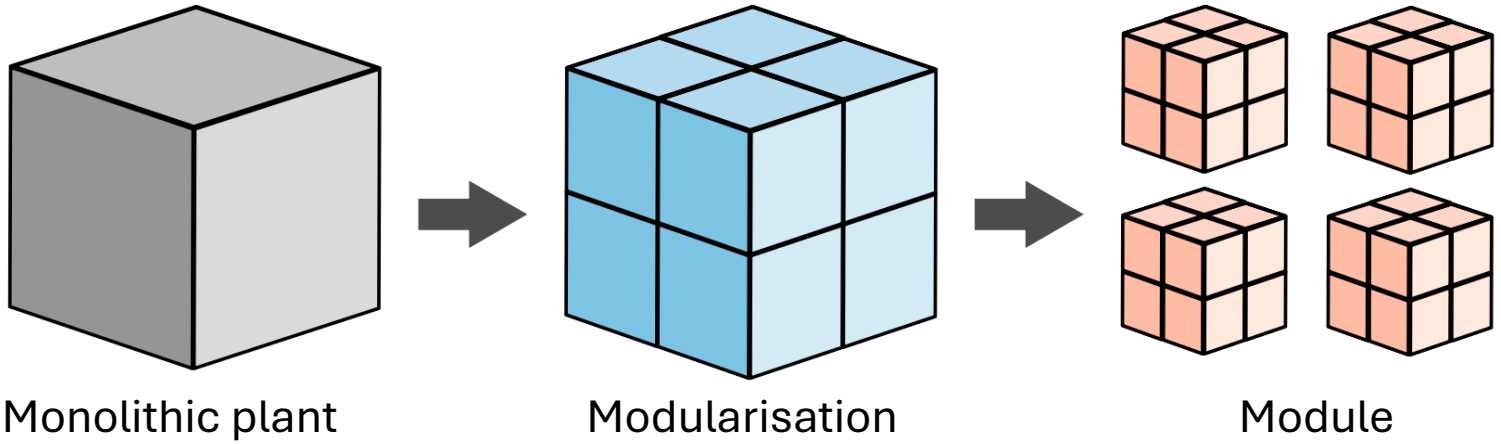


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Small Modular Reactor - definition

- Small reactor in the power category <≈ 300 MWe
- What does modular mean?
  - The required power plant output is not built as one large plant, but from a series of smaller ones instead - modules
  - Production in a factory instead of on the power plant site
  - Cost reduction through series production → compensation for economies of scale
  - Production as in the aviation industry





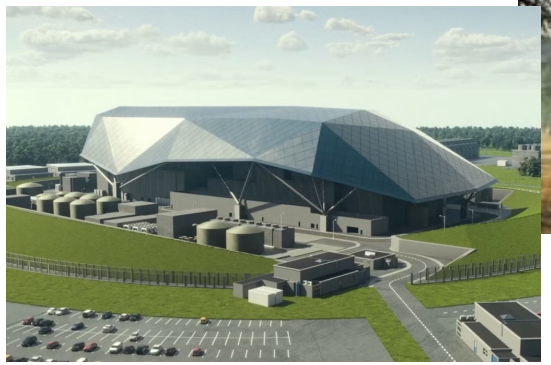
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Small Modular Reactor - types

- Small LWR:
  - Large LWR (PWR, BWR) are current “workhorses”
- Other types, categorized by coolant:

	Acronym:
• Helium gas: High temperature gas-cooled reactors	HTGR
• Sodium or lead: Liquid metal cooled reactors	SFR or LFR
• Molten fluoride or chloride salt: reactors with fuel dissolved in coolant	MSR

- Microreactors: <30 MWth





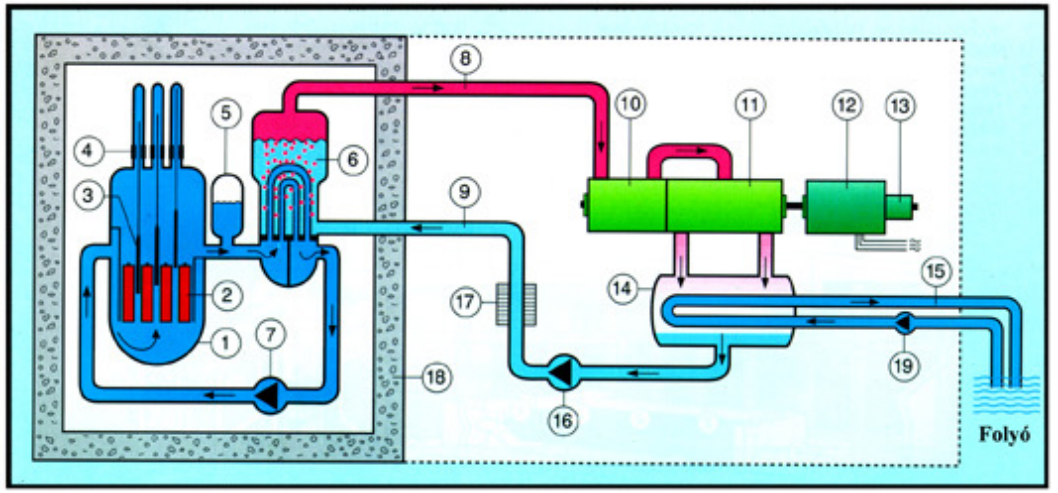




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Light Water Reactor based SMR

- Small version of current large LWR
  - Mostly PWR
- Use of existing technology basis
  - Plant design
  - Fuel design
  - Supply chains
  - Waste routes
- Power level 20 - 470 MWe
- Usually traditional nuclear vendors
- Also floating plant versions



PWR schematic

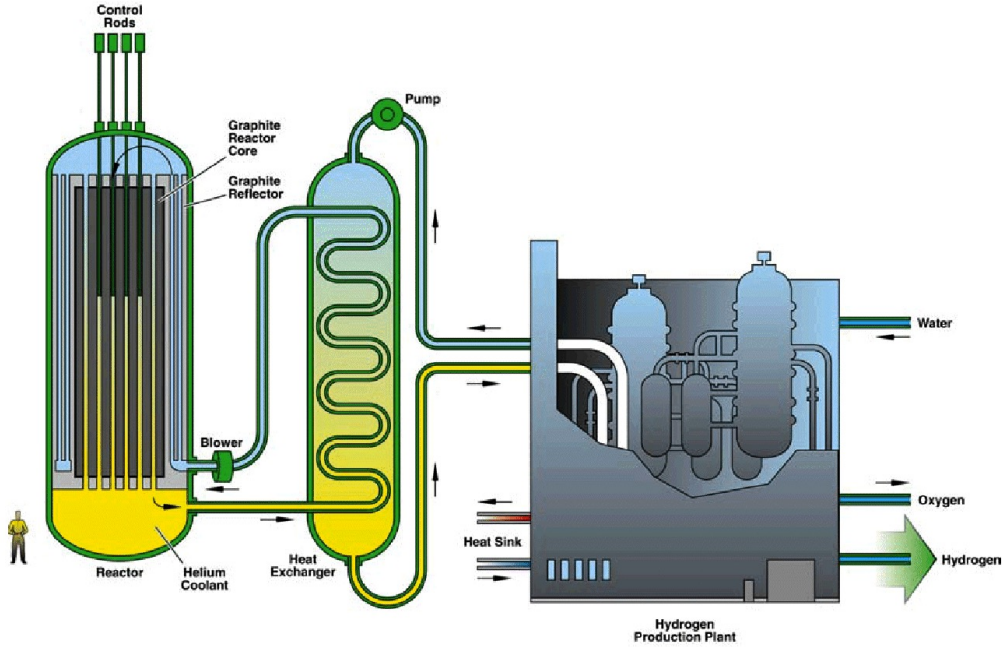


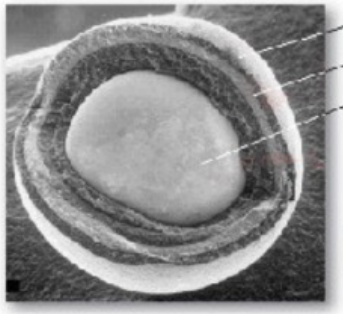
”Akademik Lomonosov”
floating SMR, Russia

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High Temperature Gas-cooled Reactor

- Outstanding feature: higher temperatures for better efficiency and cogeneration: 300 → 950°C
- Design conditions:
  - Heat-resistant materials
  - No water
- Resulting design features:
  - Coolant: helium
  - Reactor core and fuel: graphite and silicon carbide
  - Fuel in coated particles
- Resulting additional quality: inherent safety
  - For small reactors: no fuel damage possible by coolant leak or other lack of heat removal
    - By combination of low power density and heat-resistant materials





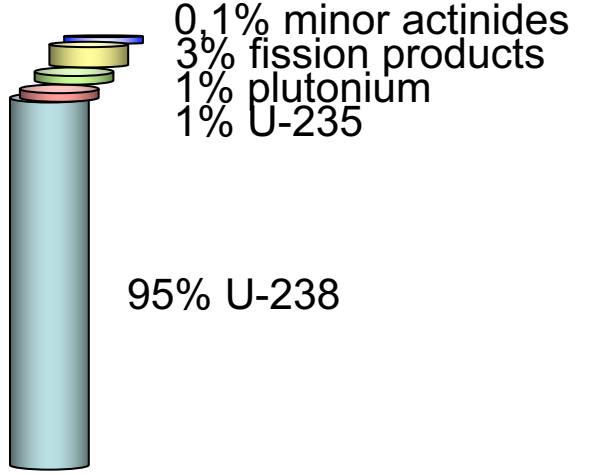
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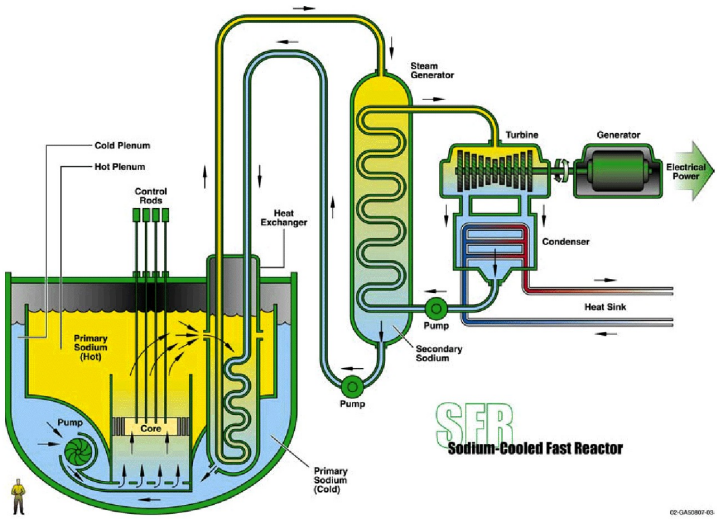
Fuel particles: uranium dioxide with 4 coatings of graphite and silicon carbide

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Liquid metal cooled reactor SMR

- Outstanding feature: better fuel efficiency and therefore lower waste production
  - Especially better use of uranium-238
    - Can be converted into fissionable plutonium by neutron absorption
- Compact reactor core
  - High power density
- Coolant: liquid sodium or lead
  - Good thermal conductivity
  - Little neutron absorption
- Additional qualities:
  - Low pressure
  - Can also burn spent fuel from other reactors
- Challenges:
  - Sodium: high chemical reactivity with air and water
  - Lead: high density

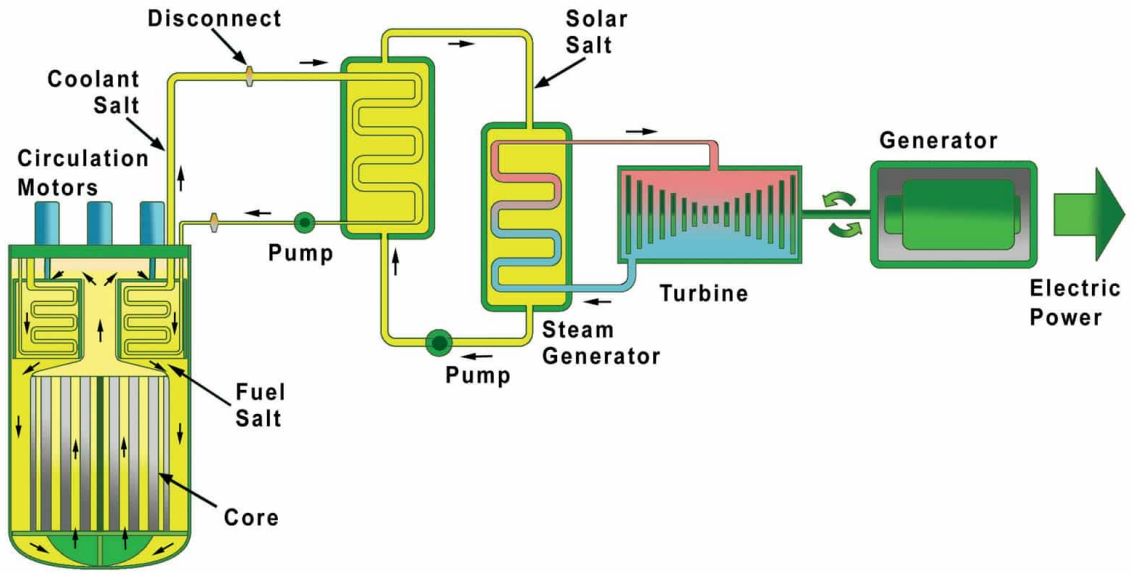




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SMR with liquid fuel: Molten Salt Reactors

- Outstanding feature: also better fuel efficiency, and therefore lower waste production (also thorium)
- Fissile material in liquid form: dissolved in molten salt
  - Different types of salt: fluoride salt, chloride salt
- Additional qualities:
  - Low pressure
  - Can also burn spent fuel from other reactors
- Challenges:
  - Corrosion
  - Missing safety barrier of fuel lattice
- Also related concepts with e.g:
  - Solid fuel elements with molten salt cooling
  - Dissolved fuel in cassettes



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Experience with the non-water-cooled reactor types

- Developments started already in the 1950s and ‘60s
- For specific applications:
  - High temperature reactors: nuclear process heat
  - Liquid metal cooled reactors: improved fuel efficiency (breeding)

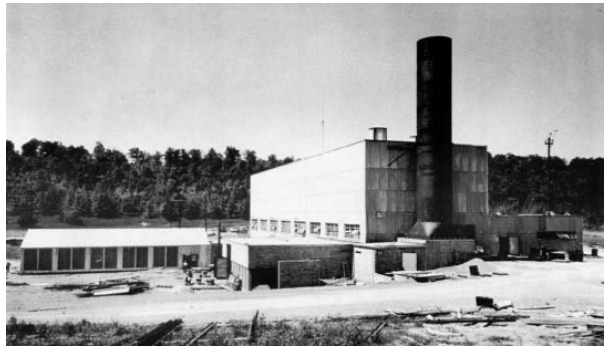
  } Demonstration plants

  - Molten salt reactor: efficient use of thorium → Experiments only

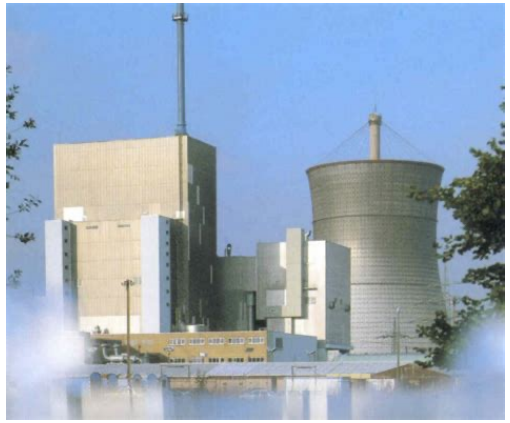
Examples of operated facilities:



Sodium cooled reactor: Superphénix, France



Molten salt reactor: MSRE, USA



High temperature reactor: THTR, Germany

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Recent changes in circumstances and demand

SMR concepts mostly not new, but

- Changed circumstances, e.g.
  - *private initiatives*
  - *energy systems with large proportions of intermittent renewable energies*
  - *climate problem being taken more seriously*
  - *increased awareness of need for security of energy supply*
- Increased demand, e.g.
  - *data centres*
  - *mining in remote locations*
  - *maritime applications*
- Innovations…







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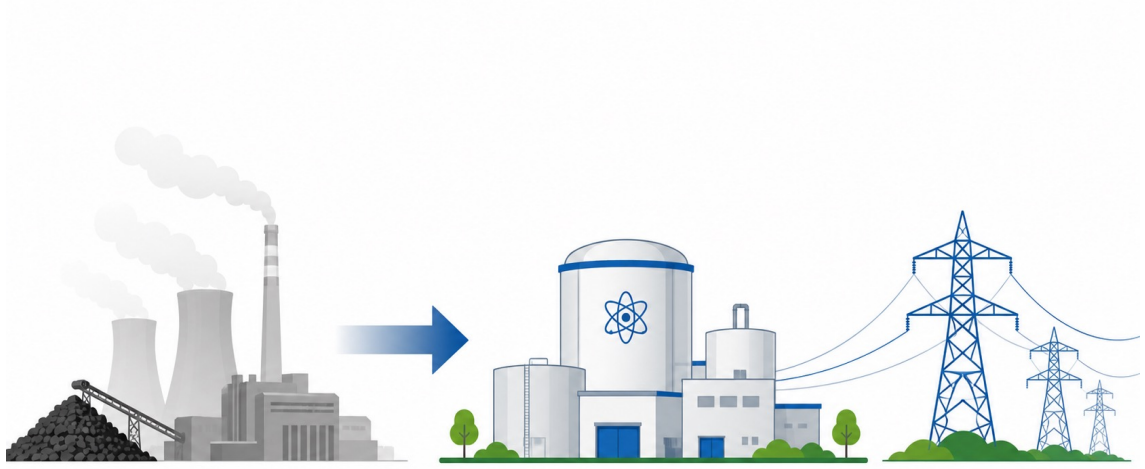
SMR applications: grid electricity and beyond

Application	Example project	Developer / partners	Main commercial logic
Coal replacement	Natrium, Kemmerer, Wyoming	TerraPower + GEH + DOE	Reuse energy workforce/site logic; firm low-carbon grid power
Off-grid power	Project Pele, INL test	BWXT / US DoD	Resilient remote power; reduce diesel logistics
Cogeneration	Long Mott / Seadrift, Texas	X-energy + Dow	Replace fossil energy assets with power and steam
Hydrogen	HTTR hydrogen demonstration	JAEA + MHI	Use high-temperature heat to increase H_2 efficiency
Process heat	HTGR-POLA, Poland	NCBJ + JAEA cooperation	Demonstrate high-temperature steam for industry
District heating	LDR-50, Finland	Steady Energy + utilities	Low-temperature heat for municipal heat networks

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Case 1 Coal replacement for on-grid power

TerraPower Natrium: Kemmerer, Wyoming, USA



Coal-to-nuclear

Developer: TerraPower / GEH

Maturity: CP issued; site work

345 MWe sodium-cooled reactor with molten-salt thermal storage, sited near a retiring coal facility.

- Strong points: uses existing grid and workforce logic; storage improves dispatchability; strong public funding signal
- Challenges: first-of-a-kind sodium fast reactor; HALEU fuel supply; licensing and cost/schedule discipline

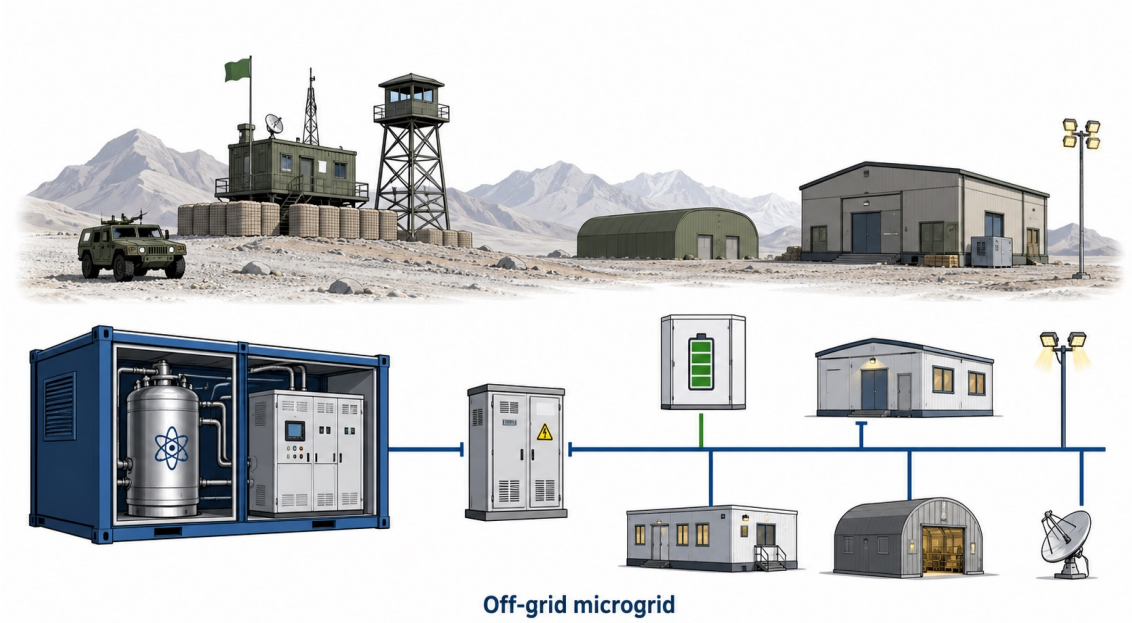
- Project is explicitly framed as a coal-to-nuclear transition near a retiring coal facility.
- NRC/DOE milestones show construction-permit progress, but operation still requires later authorization.

Start-up company

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Case 2 Off-grid power

Project Pele: transportable microreactor demonstration, Idaho National Laboratory, USA



Developer: BWXT / US DoD

Maturity: Prototype demo

Transportable high-temperature gas-cooled reactor (HTGR) prototype for resilient remote power and microgrids.

- Strong points: reduces fuel logistics for remote sites; strong mission pull; compact factory-fabricated concept
- Challenges: military-to-civil transition uncertain; safeguards/security model; licensing regime and economics at small scale

- USDOE: prototype will connect to the INL microgrid and produce roughly 1–5 MWe.
- This is a demonstrator, not yet a commercial power product.

US DoD players

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Case 3 Fossil fuel cogeneration replacement

Dow Seadrift / Long Mott Generating Station, Texas, USA



Developer: X-energy + Dow

Maturity: NRC CPA accepted

Xe-100 HTGR reactor plant intended to provide electricity and process steam for a chemical site.

- Strong points: real industrial offtaker; replaces aging fossil assets; power and steam value streams
- Challenges: interface with chemical plant operations; FOAK licensing; financial return threshold and construction risk

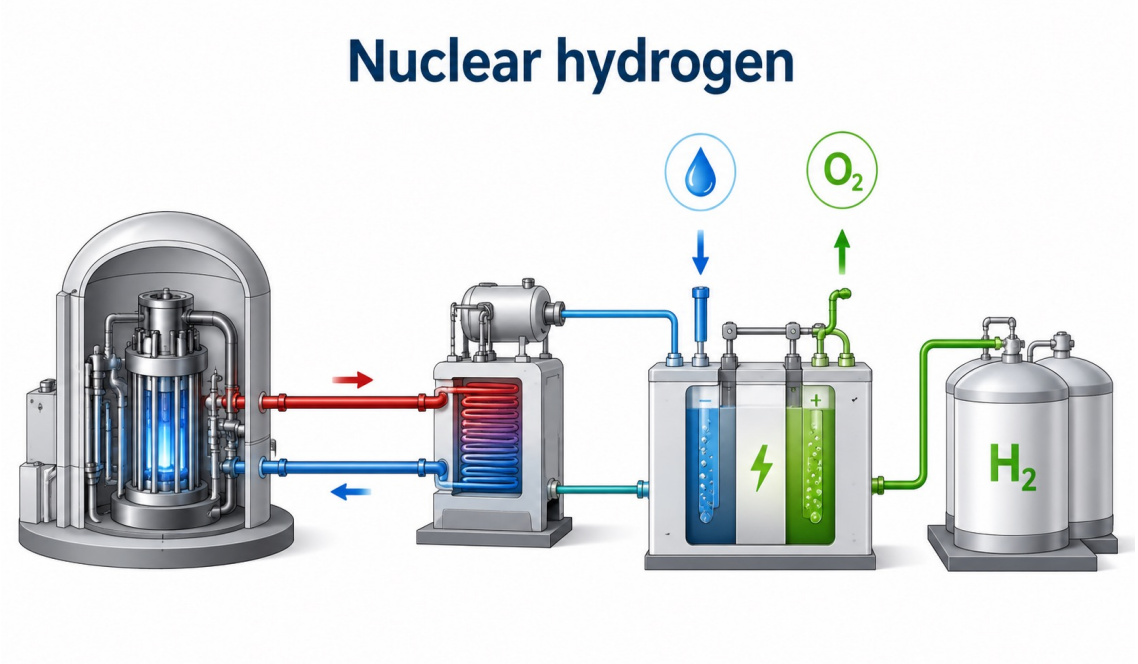
- Dow and X-energy submitted the construction permit application for Seadrift in 2025.
- First SMR plant to power a chemical facility.

Start-up company

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Case 4 Hydrogen production

HTTR hydrogen demonstration, Japan



Developer: JAEA + MHI

Maturity: Regulatory review

Use HTGR heat to connect to hydrogen production equipment and demonstrate low-carbon H_2 production.

- Strong points: high-temperature heat improves efficiency; supports steel/chemical decarbonisation; strong national R&D base
- Challenges: hydrogen market and offtake are still developing; coupling nuclear heat to chemical plant adds safety/licensing complexity

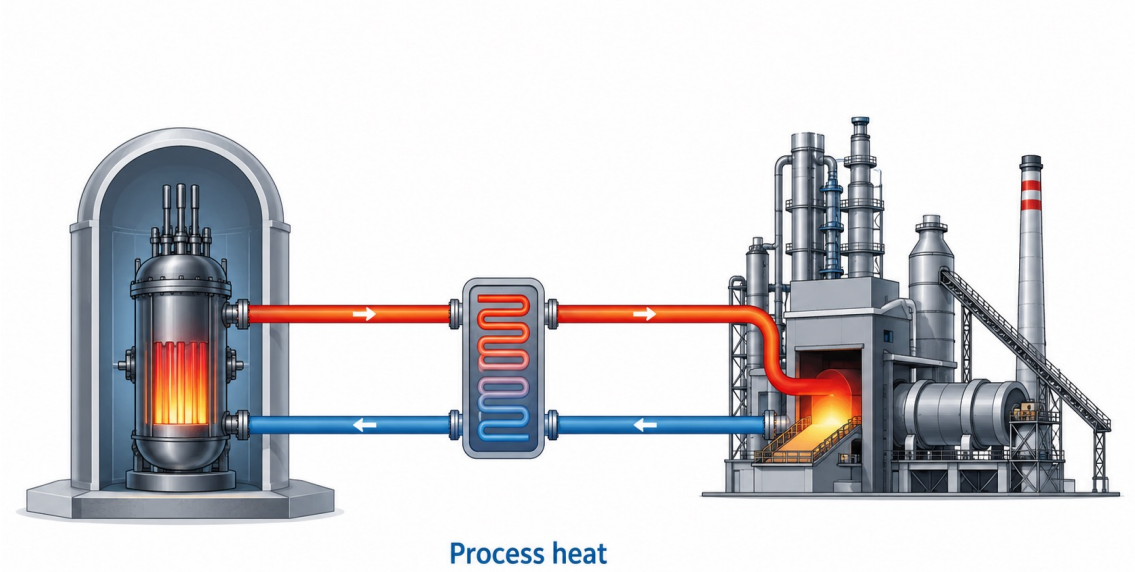
- JAEA operates HTTR 30 MWth test reactor since 1999
- JAEA submitted an application in 2025 to connect HTTR to a hydrogen production facility.
- MHI is developing a demonstration HTGR for hydrogen production, aiming at late-2030s operation for a demo reactor.

Research institute

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Case 5 Process heat for industry

HTGR-POLA HTGR concept, Poland



Developer: NCBJ + partners

Maturity: Concept/design

30 MWth high-temperature demonstrator aimed at industrial steam and later scale-up for chemical/petrochemical sectors.

- Strong points: targets hard-to-electrify heat; national R&D ownership; platform for industrial coupling and licensing learning
- Challenges: not yet an industrial plant; user-site integration and safety case still to be proven; requires long-term industrial offtake

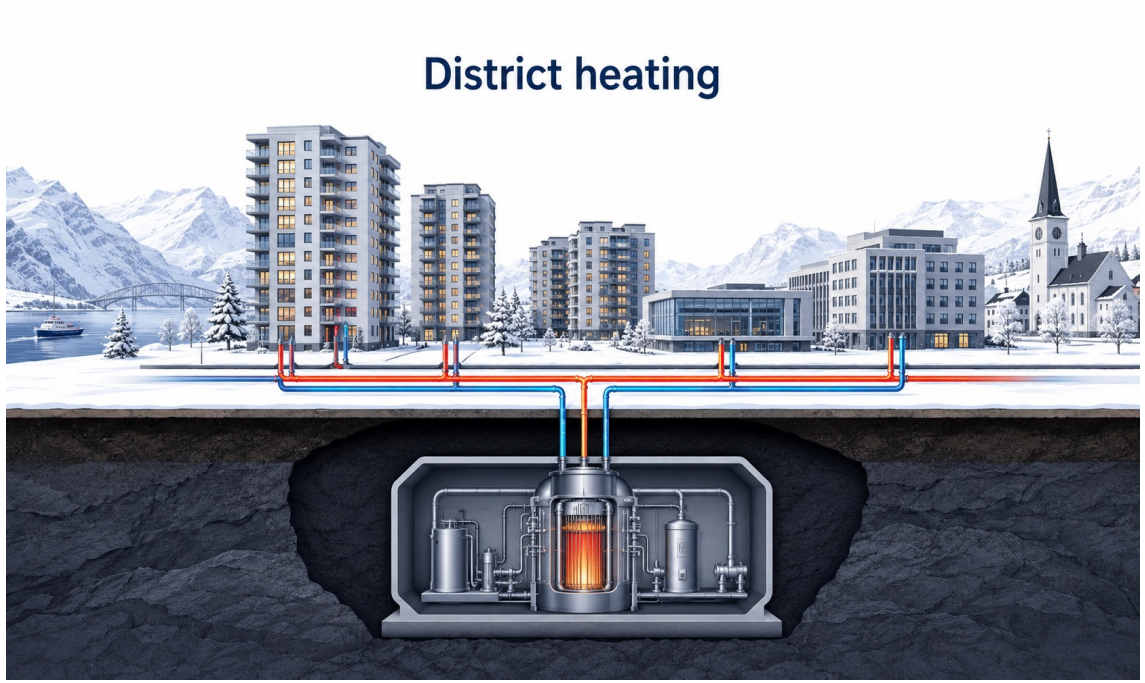
- NCBJ describes HTGR-POLA as a technology demonstrator that could later scale to about 180 MWth.
- The concept is targeted at industrial heat for chemical, petrochemical, heating and other sectors.

Research institute

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Case 6 District heating

Steady Energy LDR-50: municipal heat networks, Finland



Developer: Steady Energy + utilities

Maturity: Pilot / pre-commercial

50 MWth low-temperature reactor concept designed for underground siting and heat-only district heating service.

- Strong points: simpler heat-only product; close to urban heat loads; utility partners; avoids electricity market exposure
- Challenges: public acceptance near cities; heat-network economics; licensing of a new heat-only nuclear category

- Steady Energy presents the LDR-50 as a 50 MW thermal district-heating SMR.
- Recent reporting describes a pilot in Finland and commercial plants envisioned in the 2030s.

Start-up company

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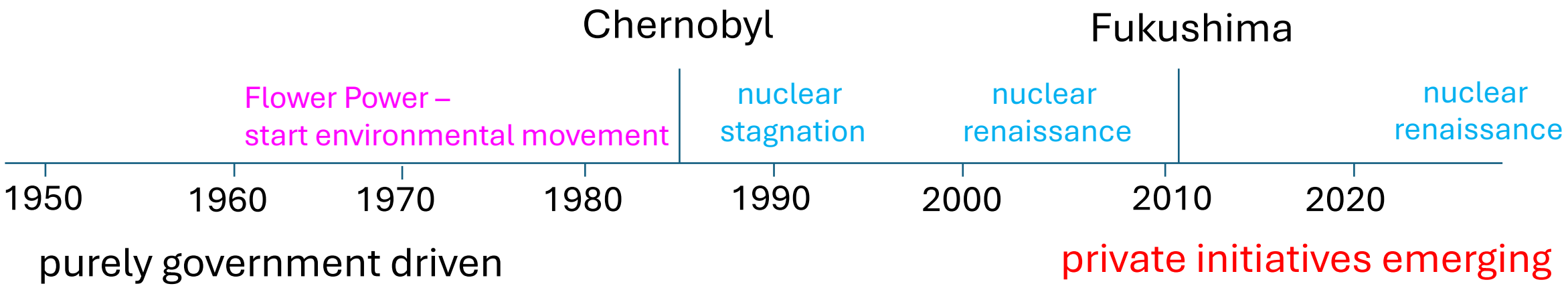
Non-traditional SMR development patterns

- Anchor customer first: projects succeed only when a credible offtaker needs reliable low-carbon energy.
- Technology follows the heat requirement: LWR-type SMRs fit electricity/low-temperature heat; HTGRs target steam, hydrogen and industry.
- Demonstration is as much commercial as technical: contract structures, licensing interfaces and operations models are being tested.
- Co-location is attractive but creates new interfaces: industrial hazards, security, emergency planning, grid/heat network integration.
- Public support is often decisive in pilot projects: grants, cost-sharing, government sites, defence needs or municipal decarbonisation.

Key message:
non-traditional applications change the buyer, business case and licensing interfaces.

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Timeline of nuclear sector development

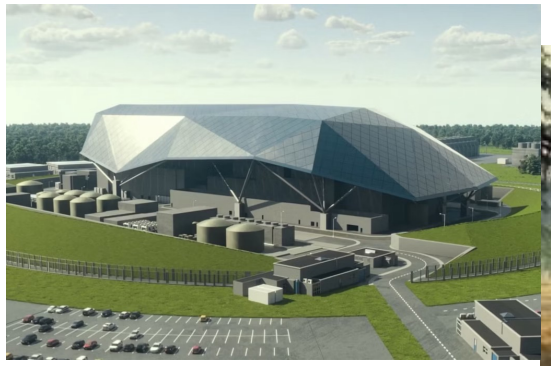


- Private start-up companies offering Small Modular Reactors
- Traditional nuclear vendors followed

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Small Modular Reactor – company examples

- Small LWR:
  - Based on current large LWR technology
- Other types:
  - High temperature reactors
  - Liquid metal cooled reactors
  - Reactors with liquid fuel
- Microreactors: <30 MWth



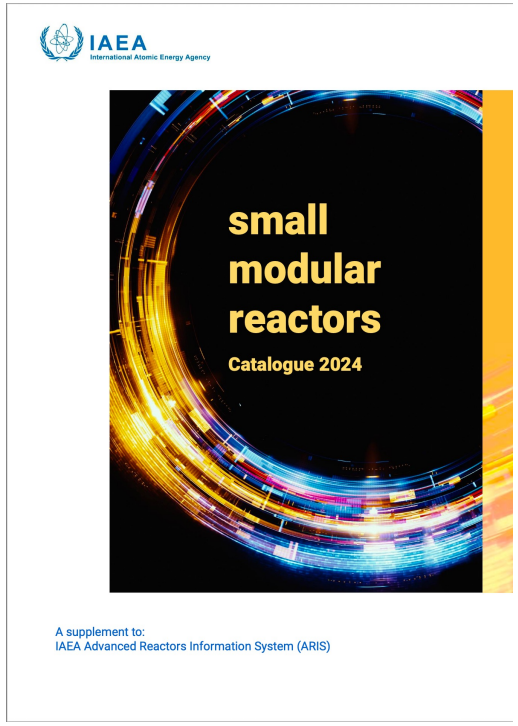




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SMR: information and communication

- Technical information on reactor designs is commercially sensitive → available to limited extent
- Much marketing effort
- Reliable information sources: IAEA and OECD NEA Catalogues





Online databases:

NEA Small Modular Reactor Digital Dashboard:

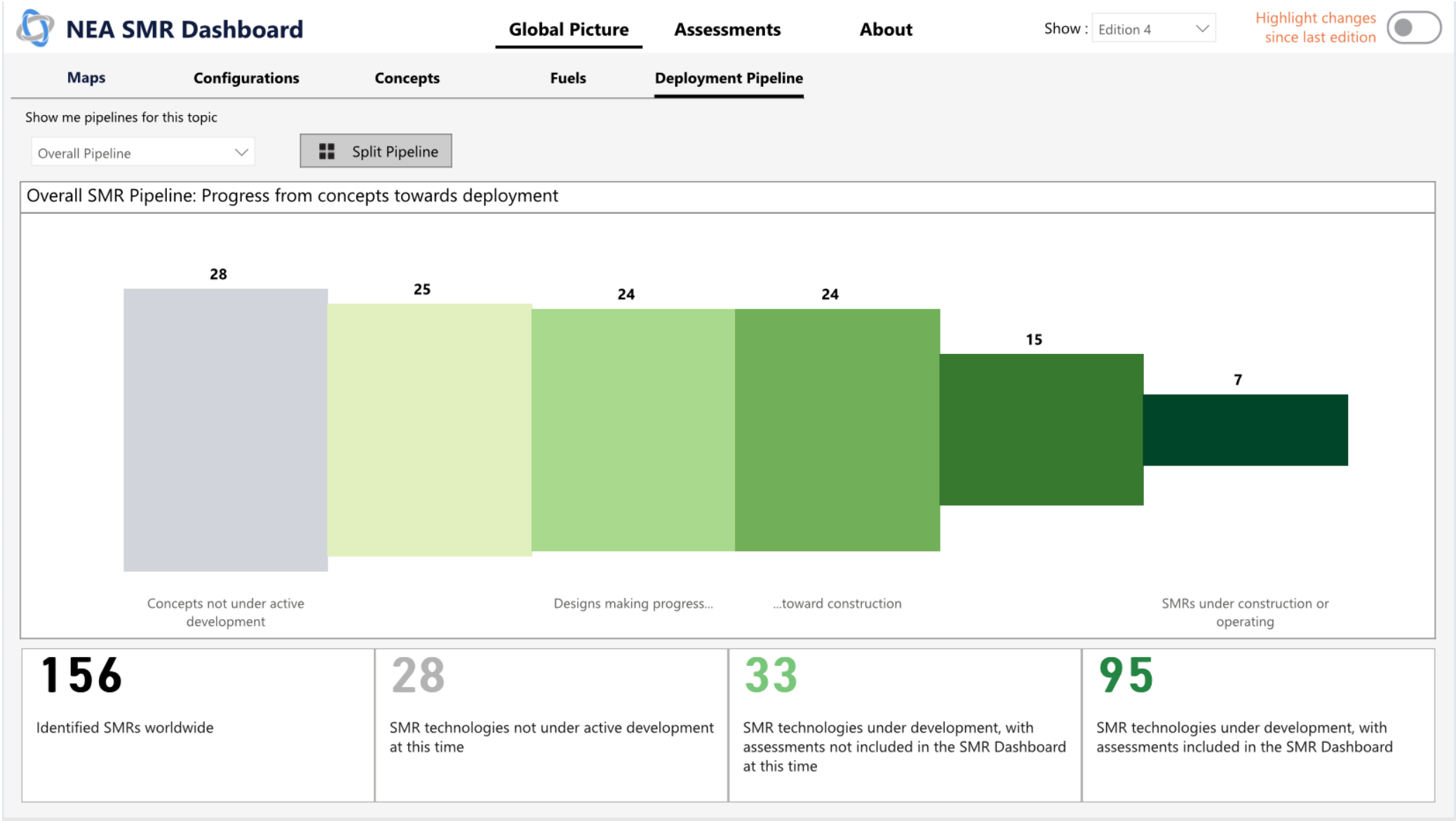
https://oecd-nea.org/jcms/pl_107879/nea-small-modular-reactor-digital-dashboard

IAEA Advanced Reactor Information System:

https://aris.iaea.org

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Small Modular Reactor – development status in the world

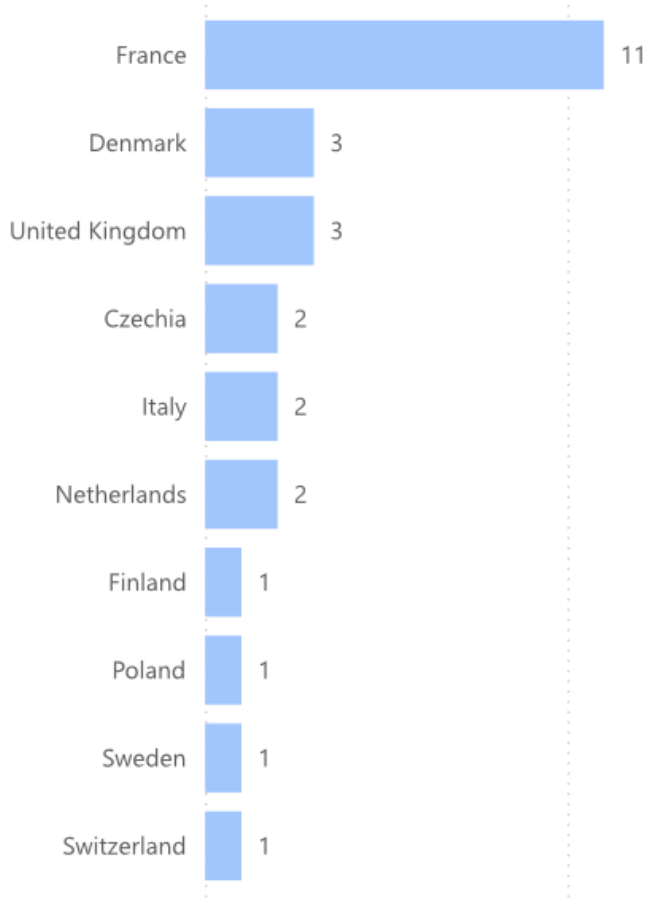


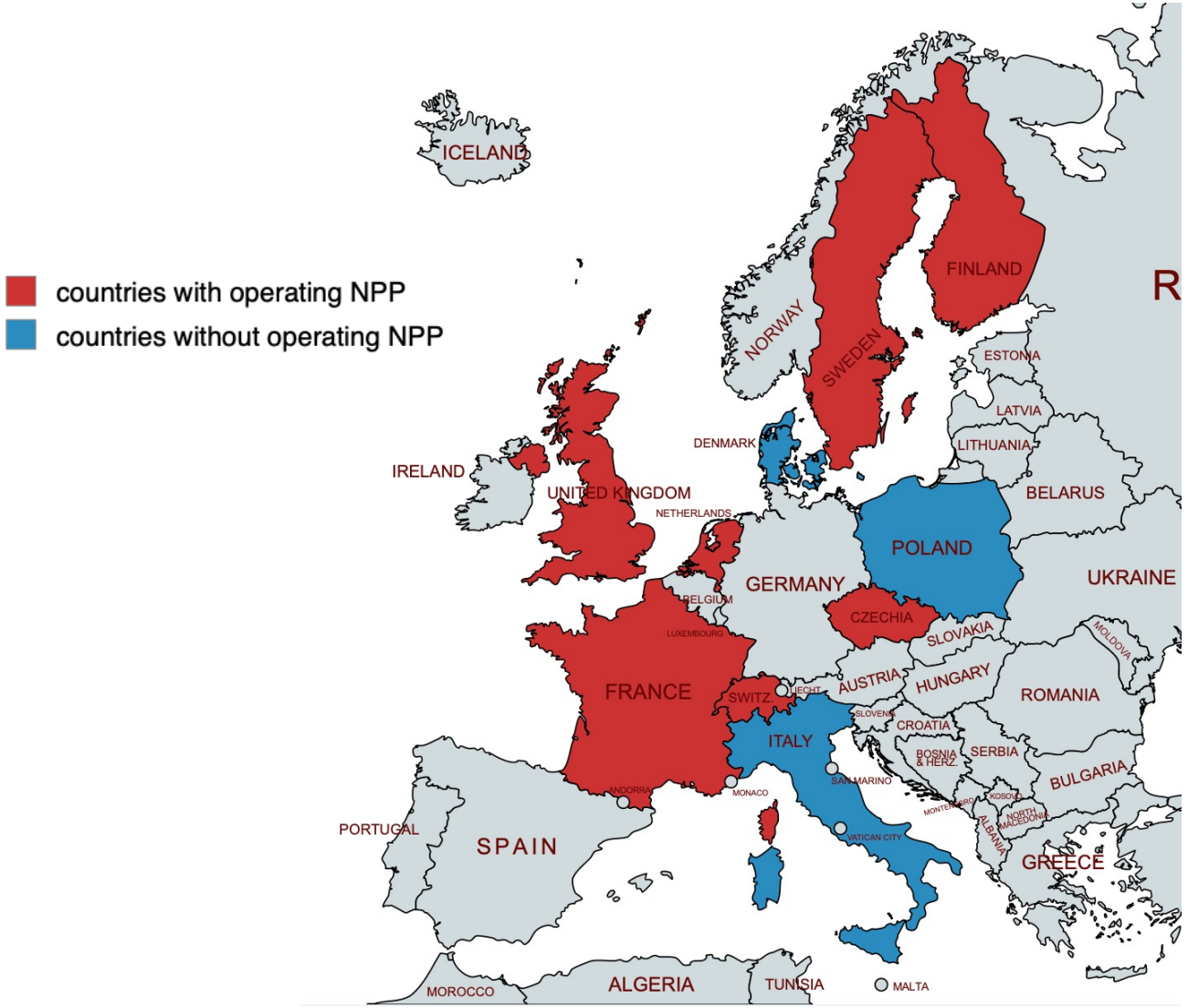
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Status
8.10.2026

Small Modular Reactor – development initiatives in Europe

- Number of SMR designs per country in Europe





Source: NEA Digital SMR Dashboard

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Update SMR in SEE countries since SEE Energy Outlook 2024

Country	Main developments since 2024	Current status
Greece	In 2026, the government expressed interest in exploring SMRs, including regional cooperation and potential maritime applications.	Policy exploration; no announced domestic SMR project.
Bulgaria	Bulgarian Energy Holding signed a 2024 agreement with GE Hitachi to explore BWRX-300 technology; government interest continued in 2025.	Technology assessment and cooperation.
Hungary	2025 agreements explored up to ten BWRX-300 units and, separately, Holtec SMR-300 and Rolls Royce SMR technology.	Multiple technology partnerships; no confirmed construction.
Romania	Doicești six-module NuScale project completed engineering work and received a conditional final investment decision in February 2026.	Advanced development; financing, licensing and conditions outstanding.
Serbia	Removed its nuclear construction moratorium in 2024; an EDF-led preliminary nuclear study was completed in 2025 and presented in 2026.	National nuclear programme development; no SMR selected.
Slovenia	Sate utility GEN energija began SMR pre-feasibility work in 2025 and launched formal feasibility-study procurement in 2026.	Feasibility and possible site assessment.
Turkey	Outlined an ambition for 5 GW of SMR capacity by 2050; a US-supported deployment roadmap agreement followed in September 2026.	National planning; no confirmed SMR construction.

Announced partnerships and targets are not construction commitments.

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Key takeaways

1. Formal SMR definition: any reactor under 300 MWe
2. SMR can be distinguished into 4 main type categories: water-cooled, gas-cooled, metal-cooled and with liquid fuel
3. Startup companies emerged as a new player category
4. The OECD NEA SMR Dashboard is a useful resource to monitor progress
    * 4 SMRs are in operation
    * 3 SMRs are under construction
5. In recent years, most SEE countries have stepped up their SMR engagement.



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