International Developments

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Introduction

Strong interest in SMR worldwide, dynamic

HTGR has one of the highest TRL of all SMR

Test reactors – prototypes – new designs

HTGR are competing in a number of countries

Main Countries	Intl. Orgs.
China	IAEA
Japan	OECD-NEA
US	GIF
Canada	
UK	
EU	

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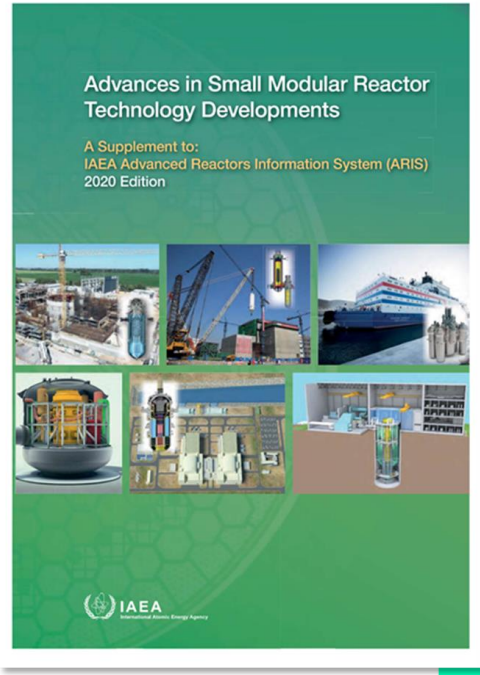
▶ Test reactors

DRAGON, U.K. 20 MW 1963-76 | Peach Bottom, US 200 MWth 1967-74 | AVR, Germany 15 MWe 1967-88 | HTR-10, China 10 MWth since 2000 | HTTR, Japan 30 MWth since 1998

▶ Industrial prototypes

Fort Saint-Vrain, US 300 MWe, 1976-89

THTR, Germany 300 MWe, 1986-89



China

HTR-10:
Running since 2000, used also for district heating
Based on German pebble bed technology

HTR-PM:
2 x 250 MWth, start-up in 2021,
cold commissioning completed,
initially for electricity, cogeneration later,
H2 production processes,
standards/codes for design and licensing

HTR-PM600:
6 x 250 MWth design, 3 utilities interested,
suitable for inland sites (dry cooling)

Japan

High Temperature Test Reactor HTTR:

Running since 1998, 30 MWth prismatic block design

Little affected by 2011 earthquake

Restart after post-Fukushima updates in 2021

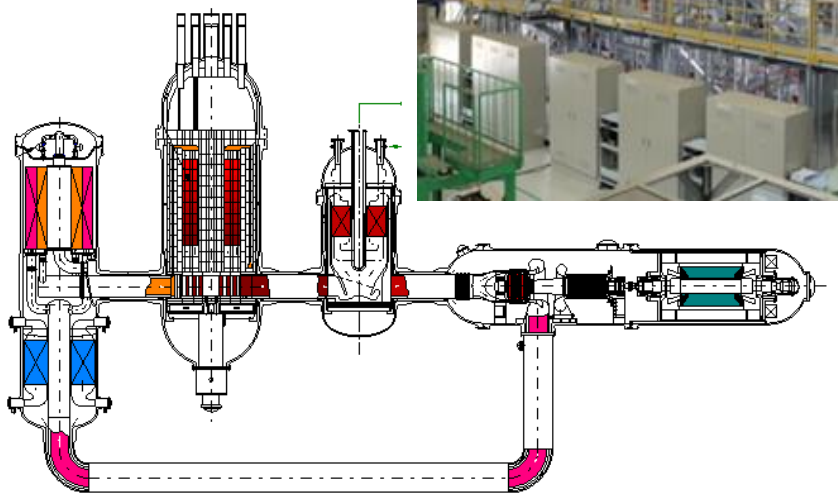
Safety demonstrations envisaged to prove passive heat removal capability

Component design and manufacturing

World leader in H2 production with Sulfur-Iodine process

Ultra-safe concept with minimized waste

Commercial plant design GTHTR300



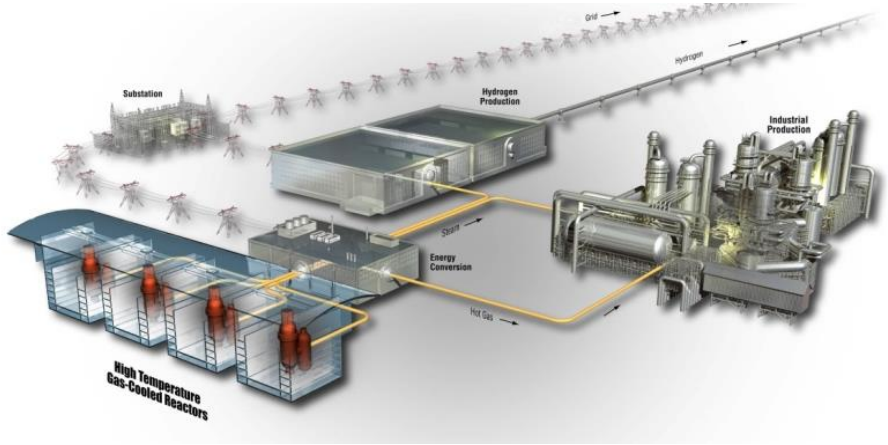
United States of America

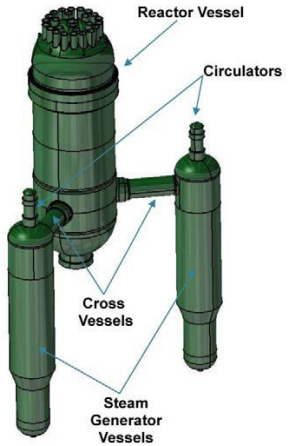
Peach Bottom and Fort St. Vrain reactors

NGNP Industry Alliance

R&D for licensing, studies on economics, | deployment and siting, benefits

Framatome Inc. (SC-HTGR, ANTARES)





DoD and DoE efforts towards development/demonstration/deployment

Cost-shared partnerships with industry

For military or remote sites + mobile reactors

Process heat, cogeneration, Hybrid Energy Systems

Licensing incl. of TRISO fuel, Design Code adaptation (include Alloy 617)

- USNC, MMR-5 construction project at Chalk River, Canada
- X-energy (Xe-100, Xe Mobile, TRISOx) demo project at Idaho National Laboratory
- HolosGen (13 MWe "quad core" in shipping container)

Canada

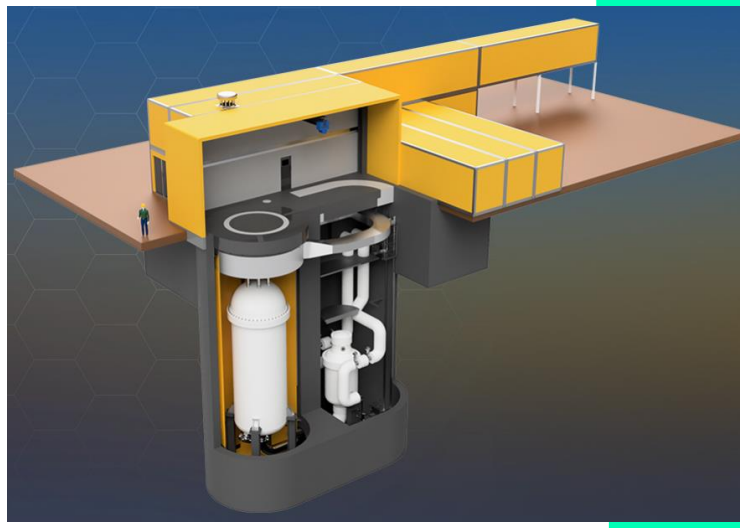
Interest in SMR, Ontario, New Brunswick, Saskatchewan

www.smrroadmap.ca

Mining, tar sands, remote locations, emission reduction

Regulator engaged with 11 vendors in
"pre-licensing vendor design review"

Supporting R&D (e.g. H2 production, materials, safety, economics)



Strong response to siting invitation for SMR demonstration
at Chalk River

2 HTGR designs involved:

- StarCore: 36 MWth (Stage 2 "Due Diligence")
- Global First Power (Ontario Power Generation + USNC):
  15 MWth MMR-5 (Stage 3 "Negotiations of Land Arrangements and Other Contracts")
  signed host agreement 20 Nov 2020

United Kingdom

Advanced Modular Reactor (AMR) Feasibility and Development (F&D) project

Technology development towards commercial deployment.

HTGR competitor in Phase 1: U-Battery ~£10m

+ projects on materials and manufacturing, supply chain, fuel and fuel recycling, safety and efficiency, codes and data

U-Battery (10 MWth prismatic block design by Manchester University and TU Delft)

Urenco, supported by Jacobs, Kinectrics, Cavendish Nuclear, Rolls Royce, National Nuclear Laboratory, Nuclear AMRC, BWXT and Mammoet

Targets UK and Canadian market

Engaged with Canadian regulator

European Union

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Legacy in Germany: AVR, THTR pebble bed HTR

1980-1990: former industrial programs on reactor and nuclear process applications

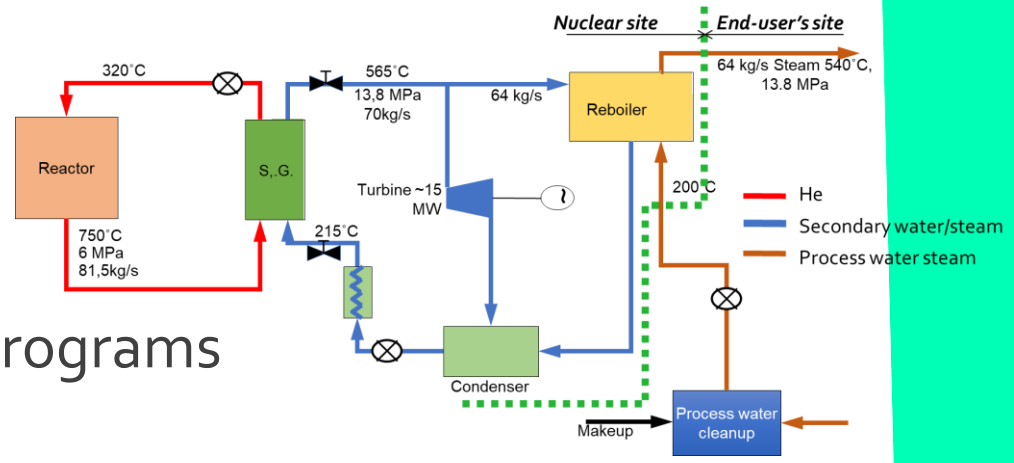
Since 2000: several Euratom technology projects, engagement with stakeholders

Several national projects

Member of GIF, contributions to Materials, Graphite, Fuel, Codes,
H2 production, safety and licensing, process heat applications…

Political division about nuclear and nuclear innovation for climate change mitigation

Brain drain is a risk



Nevertheless:

- Several new (nuclear and non-nuclear) H2 production programs
- Several SMR start-ups (not only on HTGR)
- GEMINI+ project in cooperation with US, JA, KR, in support to new developments in PL

Others

South Korea:
active in GIF, anti-nuclear government has cut budget, H2 production for steel industry

Australia:
active in GIF, positive developments for nuclear in Australia

South Africa:
active in GIF, PBMR (terminated in 2010), STL, some equipment (fuel, component qualification) at NECSA, electricity, heat, H2, and economics at universities

Indonesia:
BATAN: Small 10 MWth test reactor, phase 2 depending on financing (Russia), host of HTR 2021 conference

Saudi Arabia:
Cogeneration, desalination, district A/C, agreement with China

IAEA

Vast documentation on technologies, fuel, codes etc.

Recovery of German legacy

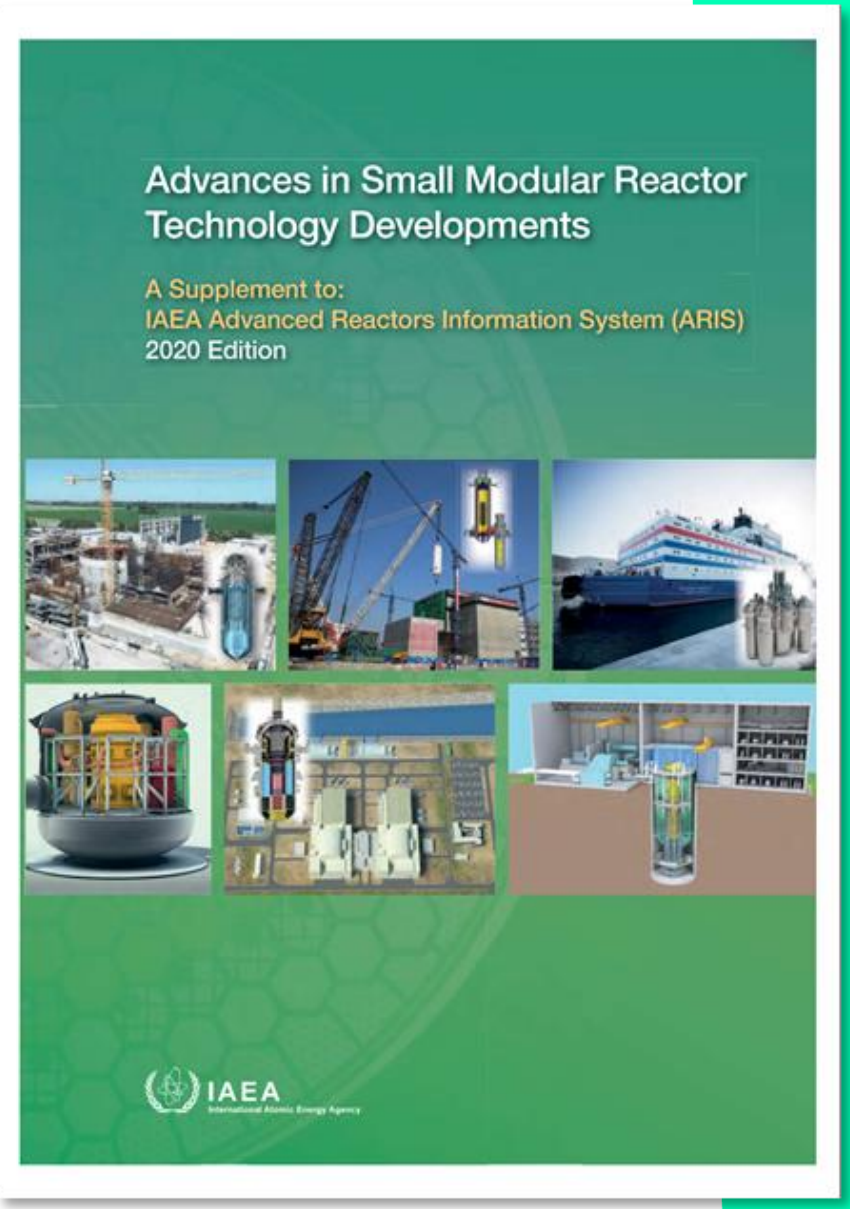
Technical meetings, CRPs and TECDOCs on

- Non-electric applications in industry
- Hydrogen production

Techno-economic assessment

Safety and Licensing

Updated SMR booklet



OECD-NEA

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- Techno-economic and market analyses
- Safety and licensing (WGSAR)
- Nuclear Innovation 2050
- IFNEC International Framework for Nuclear Energy Cooperation (Infrastructure Development Working Group), Workshop held
  14 Sept. 2019 in Warsaw on “Nuclear Energy Beyond Electricity”
- Technical Secretariat to Generation IV International Forum
- Round Table event on SMR 2019

Gen IV International Forum

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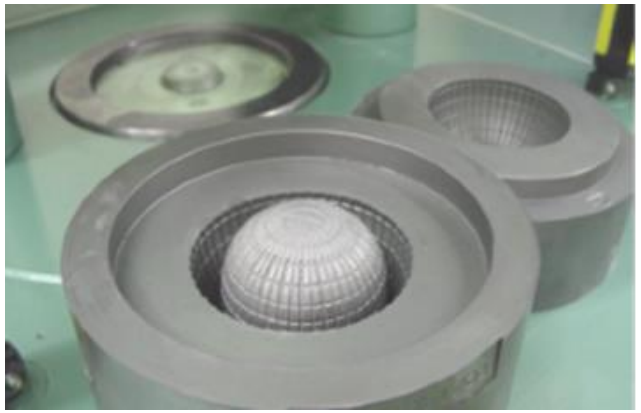
https://www.gen-4.org/gif/jcms/c_84279/webinars

4 Active VHTR Projects: "pre-competitive"



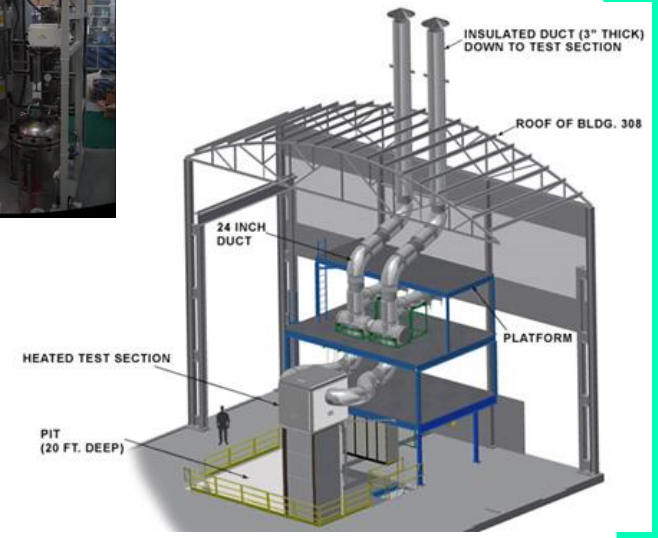
1. **Materials:**

Graphite, Metals, Ceramics: corrosion, joining, irradiations;

2. **Fuel:**

Fabrication, characterization, qualification (irradiation, PIE, safety tests), waste management;

3. **Hydrogen Production:**
    1. Iodine-Sulfur (850°C)
    2. Copper-Chlorine (530°C)
    3. High T electrolysis (650°C)



4. **Computer Tools for Design and Licensing:**

Thermal-hydraulic analysis (CFD)
Neutronics and nuclear cross-section data
Radioisotope chemistry and transport
Reactor and plant dynamics

Ten Take-away messages

- Several industrialized countries are investing in SMR
- Existing pre-competitive R&D cooperation is highly productive, but not enough
- China has taken the lead for HTGR, several Western countries intend to catch up
- European countries have collaborated on HTGR technology for 20 years
- HTGR vendors are no longer nationally, but mostly internationally operating companies
- HTGR Technology has reached a degree of maturity that allows taking the next step towards demonstration and deployment
- The near-term market for process steam is very big
- Industry also needs CO_2-free H_2 production technology
- Renewables and nuclear electricity alone are insufficient to meet emission targets in highly industrialized countries with limited potential for renewables
- What are the lessons from similar projects (OECD: DRAGON/HALDEN, JHR, ITER)? Can they serve to develop national or multi-national demonstration projects?