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GAIN Innovative Materials Research
High-Temperature Gas-Cooled Reactors

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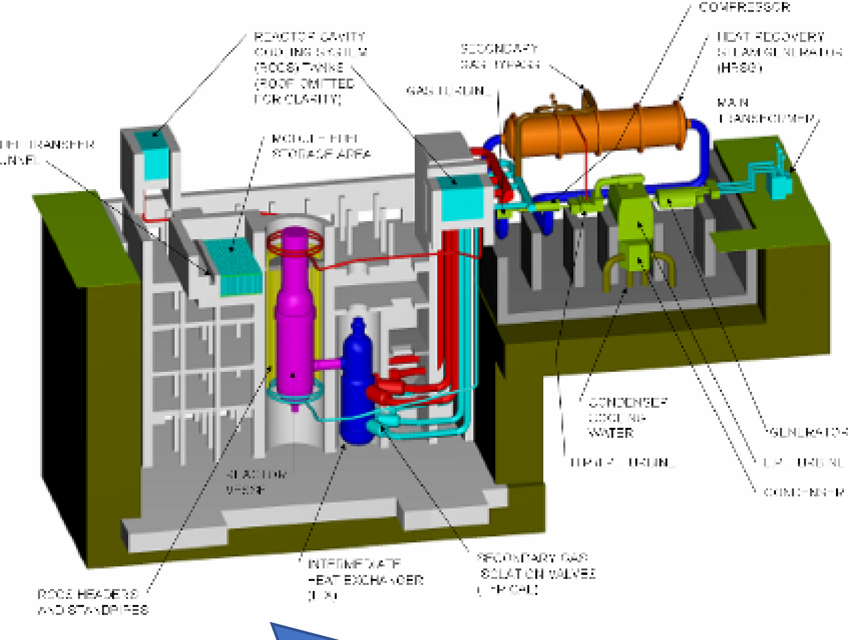
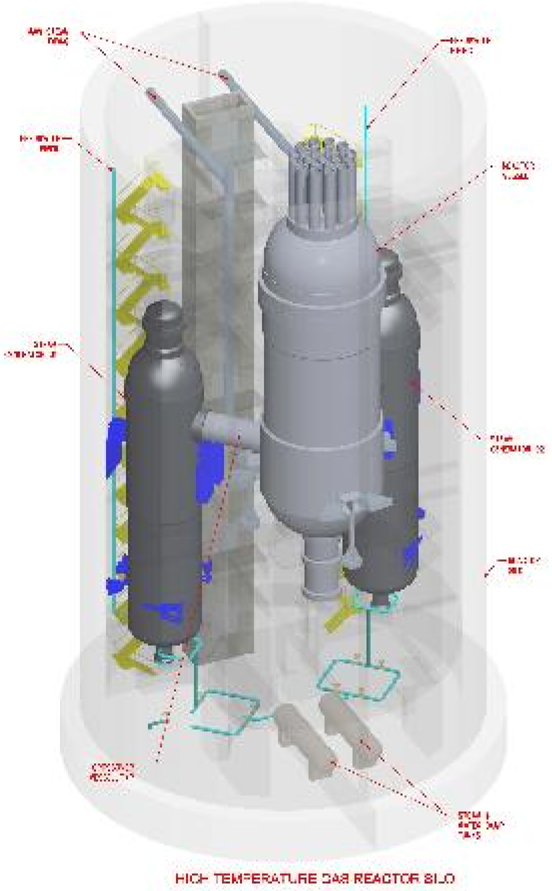
Topics – Material Challenges





- **Steam Cycle HTGR**
- **Very High Temperature Gas-cooled Reactor**

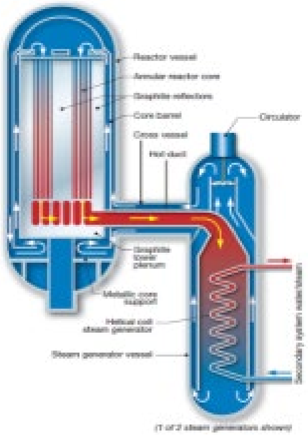
Framatome History of HTGR Development

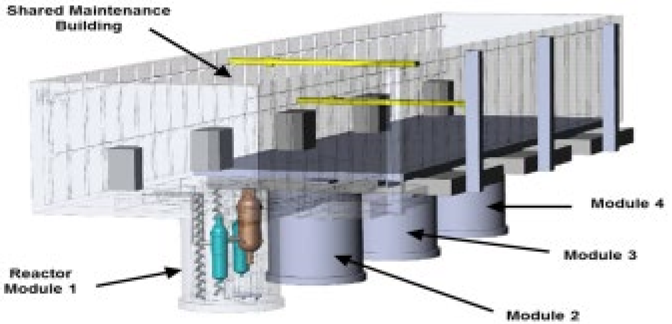
- **1960s, 70s, and 80s**
  - Framatome GmbH – Pebble Bed HTGRs
    - AVR – 46 MWth test reactor
    - THTR – 750 MWth cogeneration reactor
    - HTR-Module – 200 MWth (beginning of modular HTGR development)
- **1990s and early 2000s**
  - GT-MHR – 600 MWth prismatic core, Brayton Cycle.
  - Collaboration with Russian Federation and General Atomics
- **Mid to Late 2000s**
  - **ANTARES** Project - 600 MWth prismatic core, Indirect cycle with combined cycle gas turbine generation
  - **US DOE NGNP** project - Modified ANTARES design
- **Late 2000s to Present**
  - **Steam Cycle – HTGR reference plant**
    - **4 x 625 MWth, prismatic core, cogeneration of high temperature process steam and electricity**
    - **Optimized for passive safety and lowest cost of energy**
  - Scalability of reference concept provides variants for smaller markets (all use the same fuel)

625 MWth reference
315 MWth single SG
180 MWth EU steam only
54 MWth remote site
10 MWth Micro-HTGR
7 MWth mobile micro HTGR

Framatome 625 MWt SC-HTGR
A modular High Temperature Gas-cooled Reactor

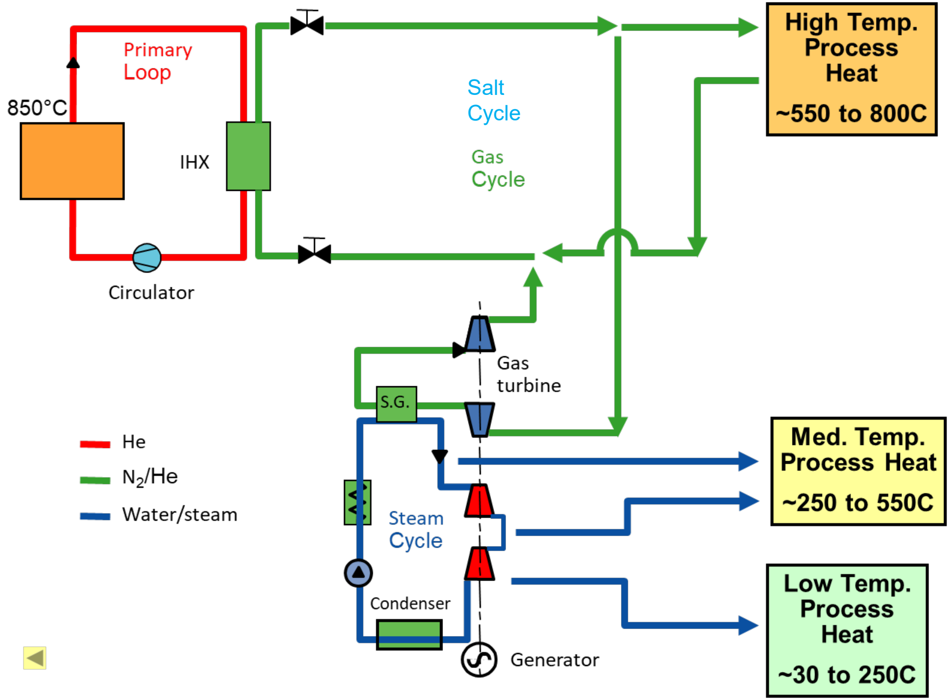
- **Net electric output 272 MWe / module**
  - **In all electricity mode (43.5% net)**
- **Reactor temperatures**
  - **Core inlet/outlet: 325°C / 750°C**
  - **Process steam: 566°C**
- **Reasons for selection**
  - **High temp steam satisfies most process heat needs - today**
  - **Minimized technical risks to allow completion of the FOAK demo plant in early 2030s**
  - **Prismatic HTGR has lowest unit cost**
  - **Excellent safety characteristics**
    - Safety does not require AC power
    - Safety does not require reactor coolant
    - Safety does not require operator action
  - **Excellent investment risk profile**
    - Plant can be restarted after any Design Basis Accident
  - **Provides path for improving technology incrementally for future higher temperature process heat needs and industrial scale hydrogen generation**





Framatome 600 MWt V-HTGR
A modular Very High Temperature Gas-cooled Reactor

- **Net electric output 290 MWe / module**
  - **In all electricity mode (48.5% net)**
- **Reactor temperatures**
  - **Core inlet/outlet: 400°C / 850°C**
  - **Process Heat: 800°C**
- **Reasons for selection**
  - **Very high temp heat most process heat needs**
  - **Prismatic HTGR has lowest unit cost**
  - **Excellent safety characteristics**
    - Safety does not require AC power
    - Safety does not require reactor coolant
    - Safety does not require operator action
  - **Excellent investment risk profile**
    - Plant can be restarted after any Design Basis Accident



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Materials of Construction

√ Available Now
√ Requires development & codification

• Fuel (UCO kernel TRISO coated particle)	AGR irradiation data and NRC topical
• Core Graphite (SGL-Carbon NBG-17, Toyo-110)	AGC characterization, ASME Sec. III Div. 5
• Vessel Systems (SA-508/533) / (9Cr-1Mo)	ASME Section III, (no cladding required)
• Reactor Internals (Alloy 800H, Graphite)	ASME Section III Div. 5
• Steam Generator (Alloy 800H, 2.25Cr-1Mo)	Helical coil tubes (He-to-steam), TEMA
• Intermediate Heat Exchanger (Ceramic)	Helium to Molten Salt, TEMA
• Instrumentation and Controls	IEEE Standard (analog or digital)
• Decay Heat Removal (RCCS)	Steel panels (ASME Section III)
• Circulator (submerged motor, magnetic bearings)	ASME Section III (housing)
• Reactor Building (concrete)	ACI standard
• Refueling Machine	Semi-automated refueling

Process Heat

HTGRs can generate heat at higher temperatures necessary for certain industrial processes

Potential to Displace Fossil Fuels

HTGR technology is the near-term energy source capable of displacing the use of fossil fuels for high-temperature process heat and/or electricity generation while emitting almost no CO_2.

- Process heat and electricity can be supplied for petrochemical refining, chemical processes and extraction, upgrading of bitumen from oil sand and shale, replacing or supplementing premium fossil fuels.
- Low CO_2 emissions enable premium fossil fuels to be used as feedstock for higher-value products, such as chemicals and synthetic fuels that add multiples of gross returns instead of simply burning as fuel.

Near-Term Market Potential

- North America/USA:

  250-500°C = 75,000MWt (or 150-300 reactors)
- Mostly Petroleum products:

  500-700°C = 65,000MWt (or 130-260 reactors) (Petroleum + Ammonia). Easily achievable today.

Allows flexibility of operation, switching between electricity and process heat

Cogeneration of Electricity, Steam, Heat

HTSE, Thermo-Chemical Hydrogen -- >>>>>>>
Production, Coal Gasification -- >>>>>>>>>>>>

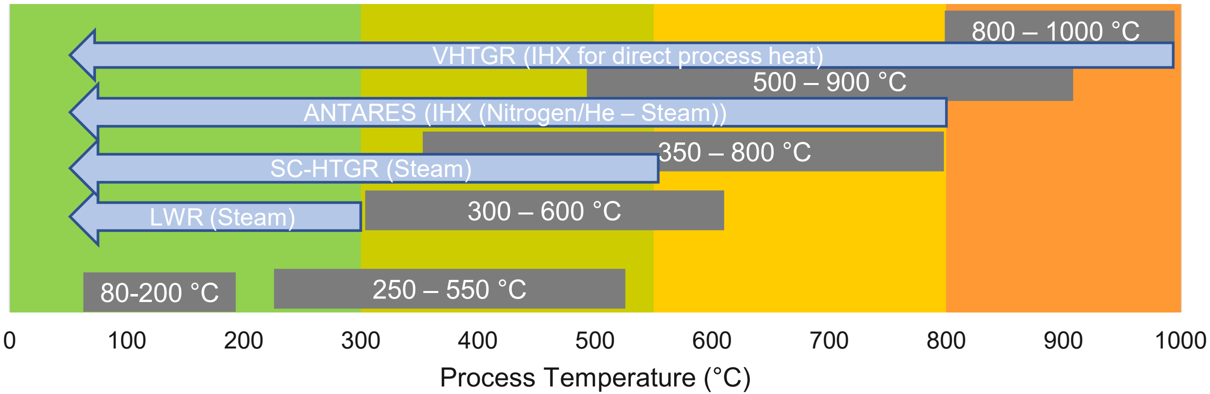
Steam Reforming of Natural Gas Biomass -- >>
Hydrothermal Gasification -- >>>>>>>>>>>>>>

Oil Shale & Oil Sand Processing -- >>>>>>>>>

Petroleum Refining -- >>>>>>>>>>>>>>>>>>>>

Ethanol Concentration, Seawater -- >>>>>>>>>
Desalination, District Heating -- >>>>>>>>>>

Temperatures required for various industrial processes



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SC-HTGR is Optimized to Provide Maximum Benefit to the Overall Energy Mix in the Near-Term

- Process steam market exists now
  - Largest segment of the process heat market
  - Depends entirely on fossil fuels
  - Requires no modification of existing chemical plants to use high temperature steam from SC-HTGR
- Market for direct very high temperature heat is longer-term
  - Smaller than high temperature steam market
  - More fragmented – requires customized interface for different applications
  - Existing chemical processes require further development for integration with heat from very high temperature reactor
- Reactor technology similar between steam cycle HTGR and VHTR
  - Largest VHTR challenge is high temperature energy transfer interface
- Focusing on steam cycle HTGR provides best short-term and long-term solution
  - Partitioning risk between HTGR and VHTR projects reduces risk for each project

Required Development	SC-HTGR	Future VHTGR
Fuel Qualification	X	
HTR Siting	X	
HTR Licensing	X	
Process Interface Issues	X	
Safety Case Validation	X	
Very High Temperature Materials (metals, ceramics)		X
IHX Development (gas or salt)		X
Very High Temperature Process Interface		X

Questions

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