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Continuing HTGR Development in the US

Framatome Family of High Temperature Gas-Cooled Reactors

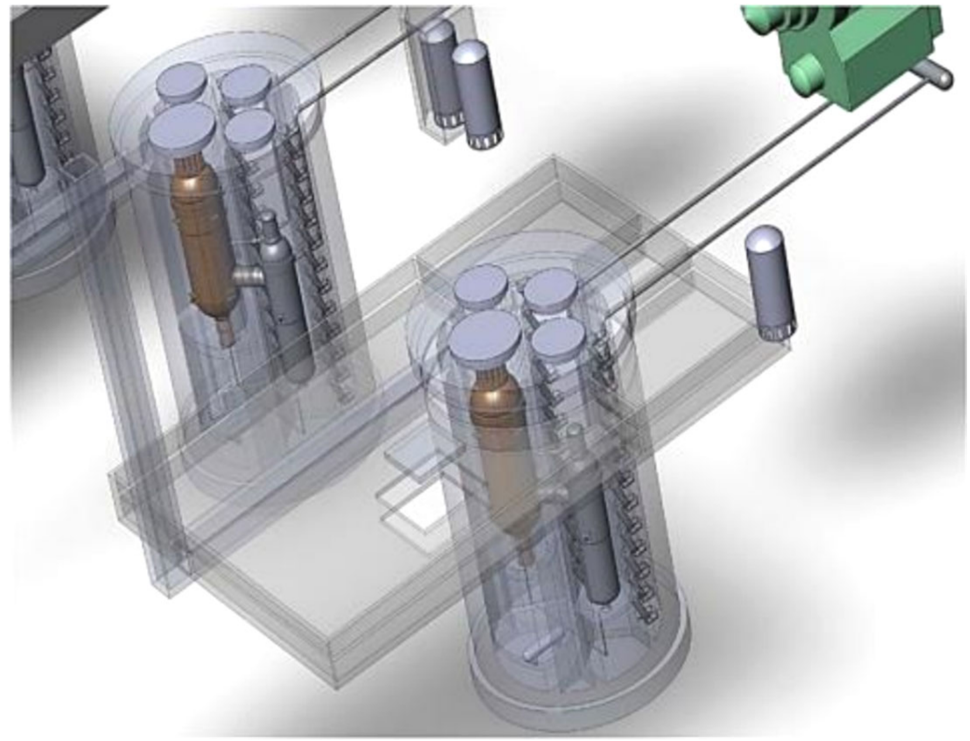
Components & Materials

NRC Advanced Reactor Materials Workshop

Dec 9-12, 2019

Topics

- Development history
- Basis for our near-term and long-term design selection
- Framatome steam cycle HTGR design
- Codes and Standards for key components



HTGR Development History

How did we get here?

- Past HTGR designs and operating experiences forms the bed rock of Framatome steam cycle HTGR design
- In 2004 Framatome launched a conceptual design project called ANTARES (V-HTGR) subsequently a family of steam cycle HTGR were conceptualized with the 625 MWt SC-HTGR as its Reference Design for commercialization

USA

X-10 Pile
1943-1963

UK

Dragon
1966-1975

USA

Peach Bottom 1
1966-1974

Germany

AVR
1967-1988

USA

Fort St. Vrain
1967-1988

Germany

THTR
1986-1989

Japan

HTTR
1998-present

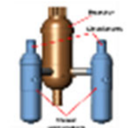
China

HTR-10
2000- Present

USA
NGNP
NGNP
2005 - 2011

China

HTR-PM
2020 Start

USA

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SC-HTGR

Other HTGR programs

- GA – Large HTGRs (1970s and 1980s)
- DOE/GA - MHTGR project (1984-1998)
- DOE/GA - GT-MHR (1991- 2000)
- DOE/CEGA NPR Project (1989 - 1995)
- South African PBMR project (1995-2011)
- Framatome ANTARES Project (2004-2008)
- Framatome SC-HTGR (2011 - present)
- X-Energy (2014 - present)

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
- **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 heat recovery steam generator
  - **US DOE NGNP** project - Modified ANTARES design
- **Late 2000s to present** (North America)
  - **Steam Cycle HTGR** – 4x625 MWth, prismatic core cogeneration of process steam and electricity
  - **Five scaled variances** of the reference plant (All use the same fuel and the same fuel block.)
    - **315 MWth** single SG,
    - **180 MWth** EU steam only,
    - **54 MWth** remote site,
    - **7 MWth** mobile, SCO
    - **kW-Scale Rx** FOB

Same fuel/fuel block, scaled components, custom interface to grid and or end user

Basis for SC-HTGR Selection & Foundation for Future V-HTGR Markets

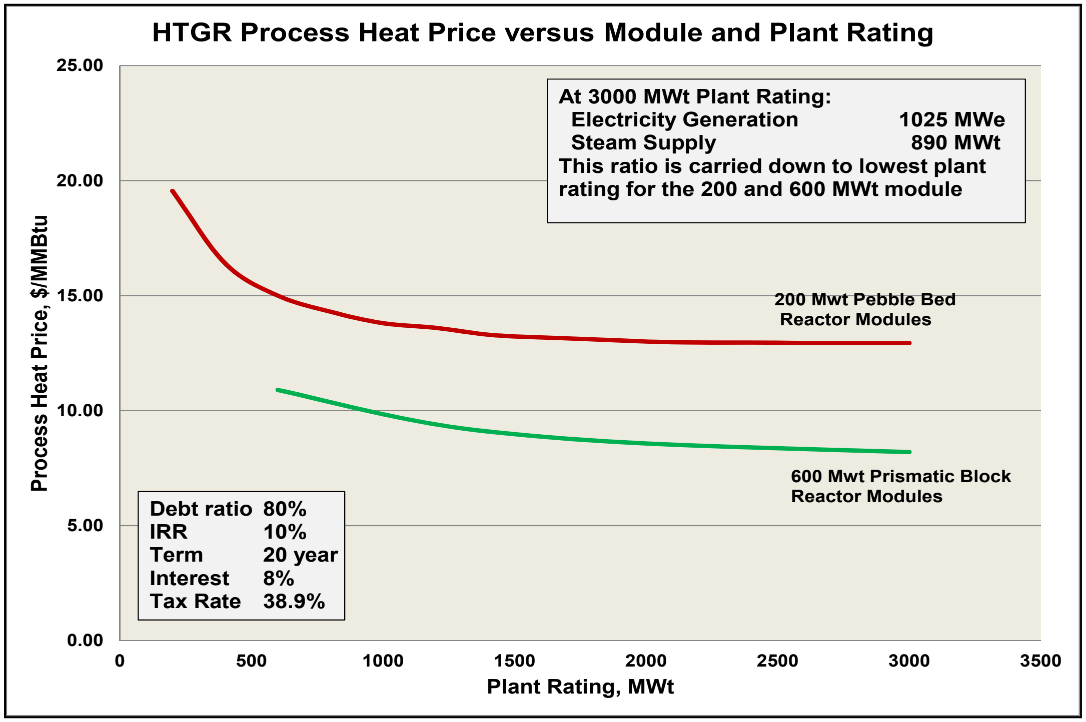
Market for direct very high temperature heat is longer-term

- 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 V-HTGR**
  - **Largest VHTR challenge is high temperature energy transfer interface**
- **Focusing on steam cycle HTGR now provides best short-term and long-term solution**
  - **Maximum benefit for energy markets as soon as possible**
  - **Partitioning risk between HTGR and VHTR projects reduces risk for each project**

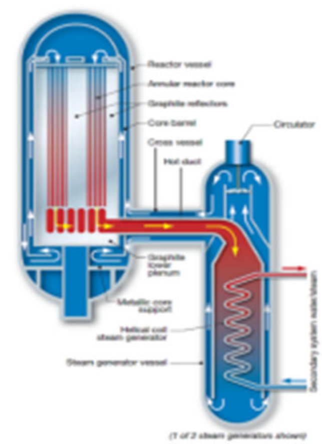
Required Development	SC-HTGR	Future V-HTGR
Fuel Qualification	X	
HTR Siting	X	
HTR Licensing	X	
Process Interface Issues	X	
Safety Case Validation	X	
Very High Temperature Materials (metals, ceramics)		X
IHX Development		X
Very High Temperature Process Interface		X

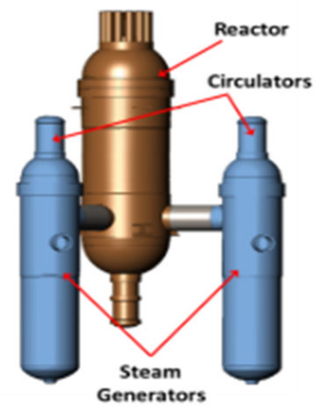
Rational for Selection of SC-HTGR

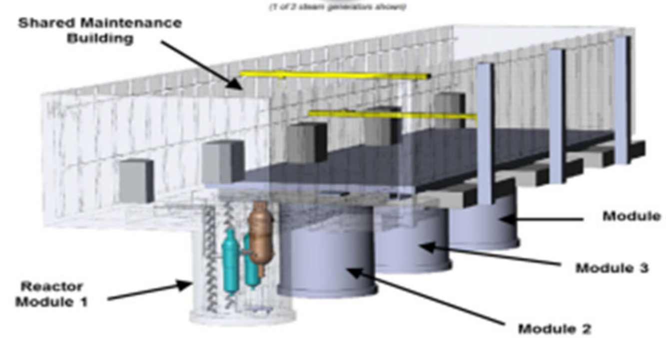


Framatome 625 MWt SC-HTGR
A modular High Temperature Gas-cooled Reactor

- Net electric output 272 MWe / module
  - In all electricity mode
- Reactor temperatures
  - Core inlet/outlet: 325°C / 750°C
  - Process steam: 560°C
- Reasons for selection
  - Cost and safety advantage to LWRs -- higher efficiency, expanded market, higher burnup, eliminate multiple safety systems including S-R AC power, eliminate evacuation requirements
  - Lowest unit cost
  - Satisfies most process heat needs
  - Provides test bed for improving technology incrementally for future higher temperature and Hydrogen cycles
  - Intrinsically safe-passive heat removal
  - Minimized technical risks to allow completion of the demo plant in early 2030s







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Codes and Standards

- The HTGR reactor design will be governed by hundreds of codes and standards.
- Most will be of little consequence; since they govern routine design, fabrication, construction, and installation activities
  - Heat exchanger design standards for air blast heat exchangers which we will simply order out of a catalog
  - Relevant standards which the NRC would be most interested are various ASME, IEEE, ACI standards
  - These standards will be invoked for major parts of the nuclear island, e.g. ASME B&PV Sect III , Div. 5, but they include many others

Codes and Standards (cont'd)

- Section III Div. 5 includes graphite and other high temperature materials
- It provides higher temperature rules for some conventional materials
- The value of the graphite section of Div. 5 remains to be seen, since they have never actually been applied in practice to the design of an actual reactor
- We believe they are usable and beneficial beyond the laboratory context
- The parts for metallic materials will be useful to us and essential for our next generation of HTGRs and V-HTGR
- Good progress has already been made on Div. 5, being reviewed for endorsement by the NRC

Typical Standards we intend to use

• Fuel (UCO kernel TRISO coated particle)	AGR qual/data and NRC topical
• Core Graphite (Toyo-110, SGL-Carbon NBG-17)	ASME Section III Div. 5
• Vessels (SA-508/533)	ASME Section III
• Reactor Internals (Alloy 800H, SiC-SiC, Graphite)	TBD - Section III Div. 5
• SGs (Alloy 800H, $2^{1/4}$- Cr, dissimilar welds)	TEMA
• Instrumentation and Controls	IEEE Standard (Analog or Digital)
• RCCS (Stainless Steel)	ASME Section III
• Valves	TBD - ASME Section III
• Circulator	TBD - ASME Section III
• Reactor Silo (concrete)	ACI standard
• Refueling Machine	TBD - robotics and elevator standards

Questions