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

Other HTGR programs

- GA – Large HTGRs (1970s and 1980s)
- DOE/GA - MHTGR project (1984-1998)
- 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

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Rational for Selection of SC-HTGR

HTGR Process Heat Price versus Module and Plant Rating

- At 3000 MWe Plant Rating:
  - Electricity Generation: 1025 MWe
  - Steam Supply: 890 MWe
  - This ratio is carried down to lowest plant rating for the 200 and 600 MWe module.

Debt ratio: 80%
IRR: 10%
Term: 20 year
Interest: 8%
Tax Rate: 38.9%

Plant Rating, MWe: 0 500 1000 1500 2000 2500 3000 3500
Process Heat Price, $/MMBtu: 0 5.00 10.00 15.00 20.00 25.00

200 MWe Pebble Bed Reactor Modules
600 MWe Prismatic Block Reactor Modules
**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
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, 21/4- 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