The Advanced High-Temperature Reactor (AHTR)

Dr. Charles Forsberg (ORNL)
Dr. Per Peterson (UC-Berkeley); Dr. Paul Pickard (SNL)

Oak Ridge National Laboratory
P.O. Box 2008; Oak Ridge, TN 37831-6179
Tel: (865) 574-6783; E-mail: forsbergcw@ornl.gov

Briefing for the Department of Energy; Office of Nuclear Energy
Washington D.C.
August 13, 2003

The submitted manuscript has been authored by a contractor of the U.S. Government under contract DE-AC05-00OR22725. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes. File name: DOE.AHTR.August13.2003

The Advance High-Temperature Reactor

A Large, Passively Safe, High-Temperature Reactor for Electricity and Hydrogen Production

- Large Reactor (>2000 MW(t)) to Improve Economics
- Passive Safety Basis Retained
- High-Temperature Reactor (80% Commonality with Helium Gas-Cooled Reactors)

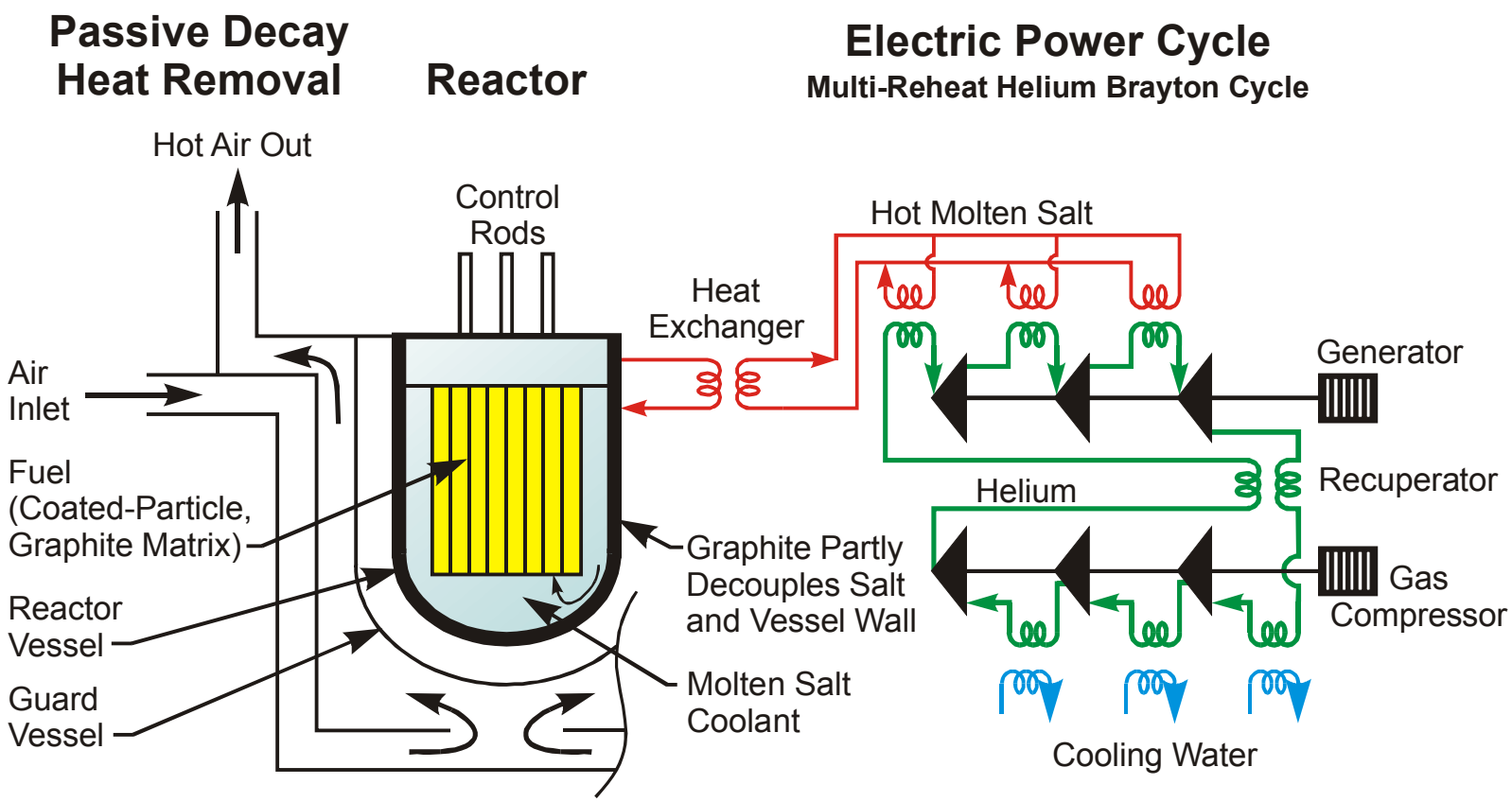
The AHTR Was Conceived During the GenIV Roadmap Activity

- Concept developers
  - Charles Forsberg (ORNL)
  - Per Peterson (U. of California-Berkeley)
  - Paul Pickard (SNL)
- AHTR combines 5 established technologies
  - Molten salt coolant (1960s)
  - Gas-cooled reactor coated-particle fuel (1970s)
  - S-PRISM/MHTGR passive safety (1980s)
  - Helium Brayton power cycle (1990s)
  - Corrosion control in clean salts (1960s forward)

High-Temperature Reactors

	AHTR	*VHTR (Helium)*
Fuel	Coated Particle	Coated Particle
Neutronics	Epithermal	Epithermal
Power Cycle	Helium Brayton	Helium Brayton
Safety System	Passive	Passive
Coolant	*Molten Salt*	*Helium*
Pressure	Atmospheric	High Pressure
Power Level	2400 MW(t)	600 MW(t)

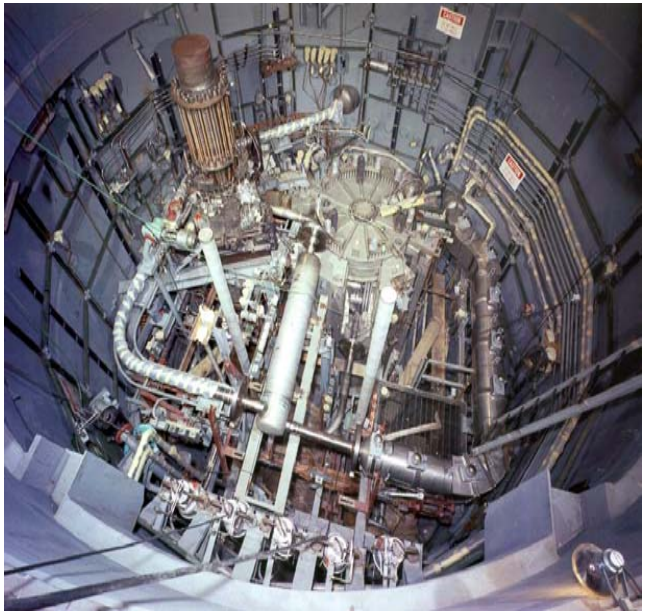
The Advanced High Temperature Reactor Concept

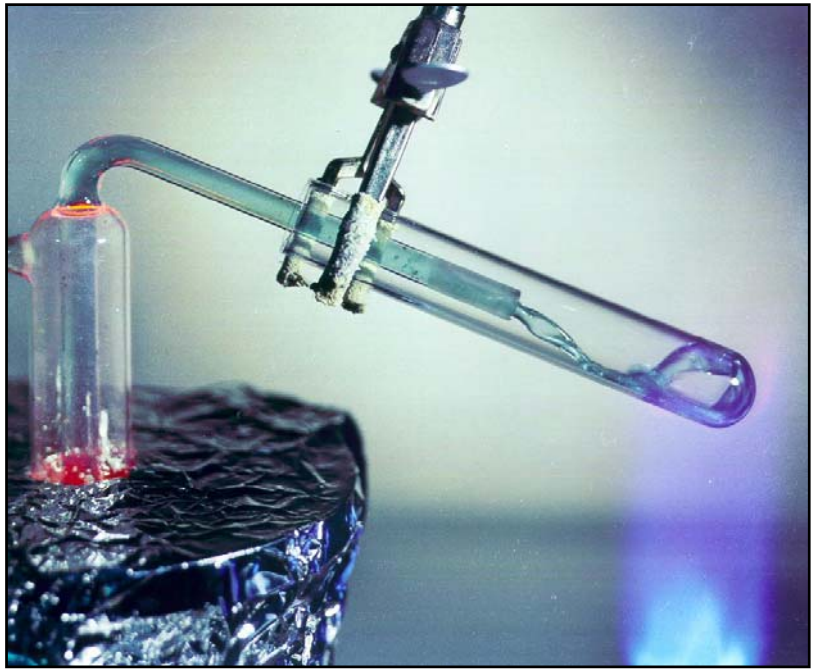


Why Molten Salt Coolants?
Good Heat Transfer, Low Pressure Operation, and In-Service Inspection

Potential Uses Include the AHTR, Heat Transfer Loops Between Reactor and Hydrogen Production Plants, and Fusion Energy Plants)

MSRE Intermediate Heat Transfer Loop Used Clean Salt

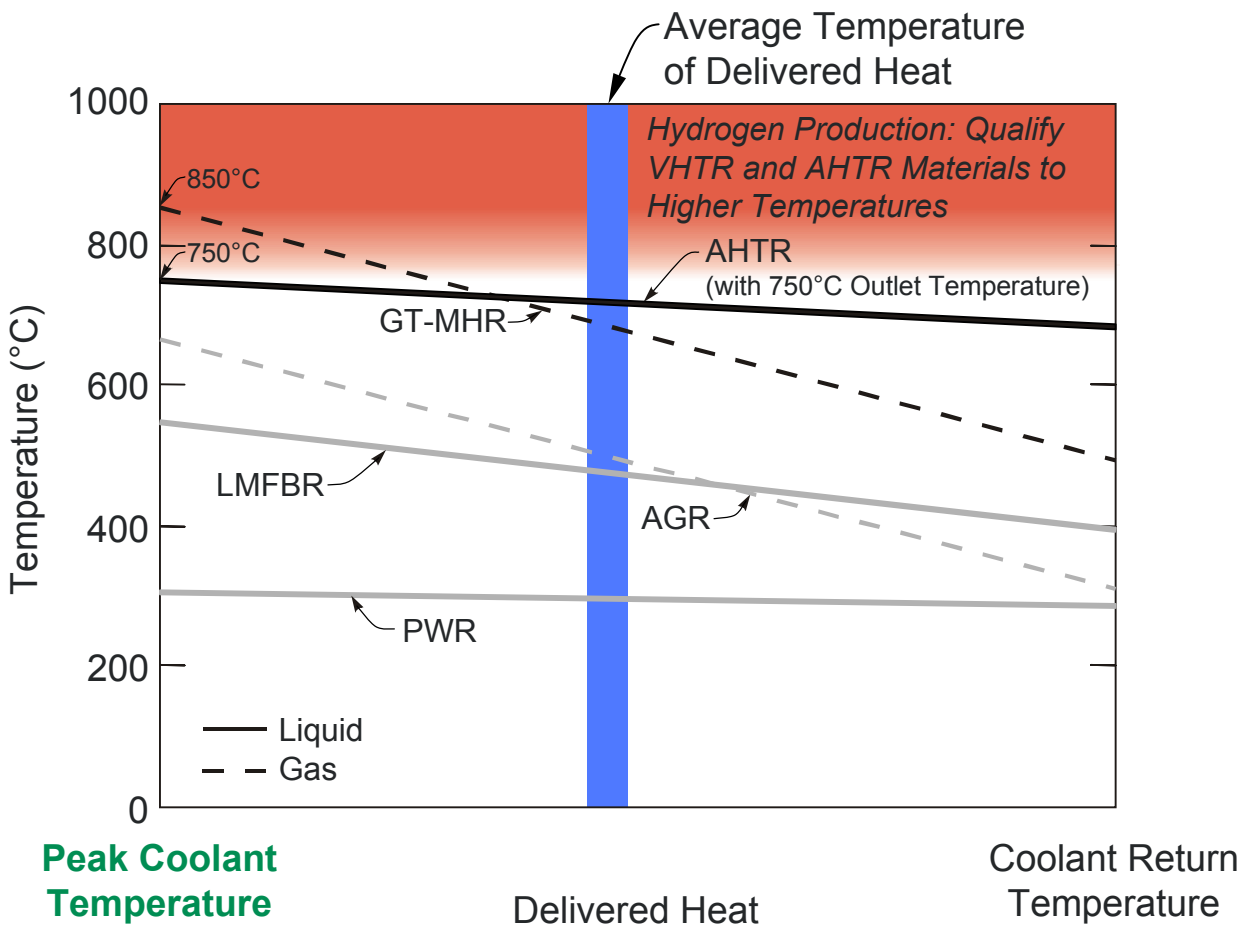




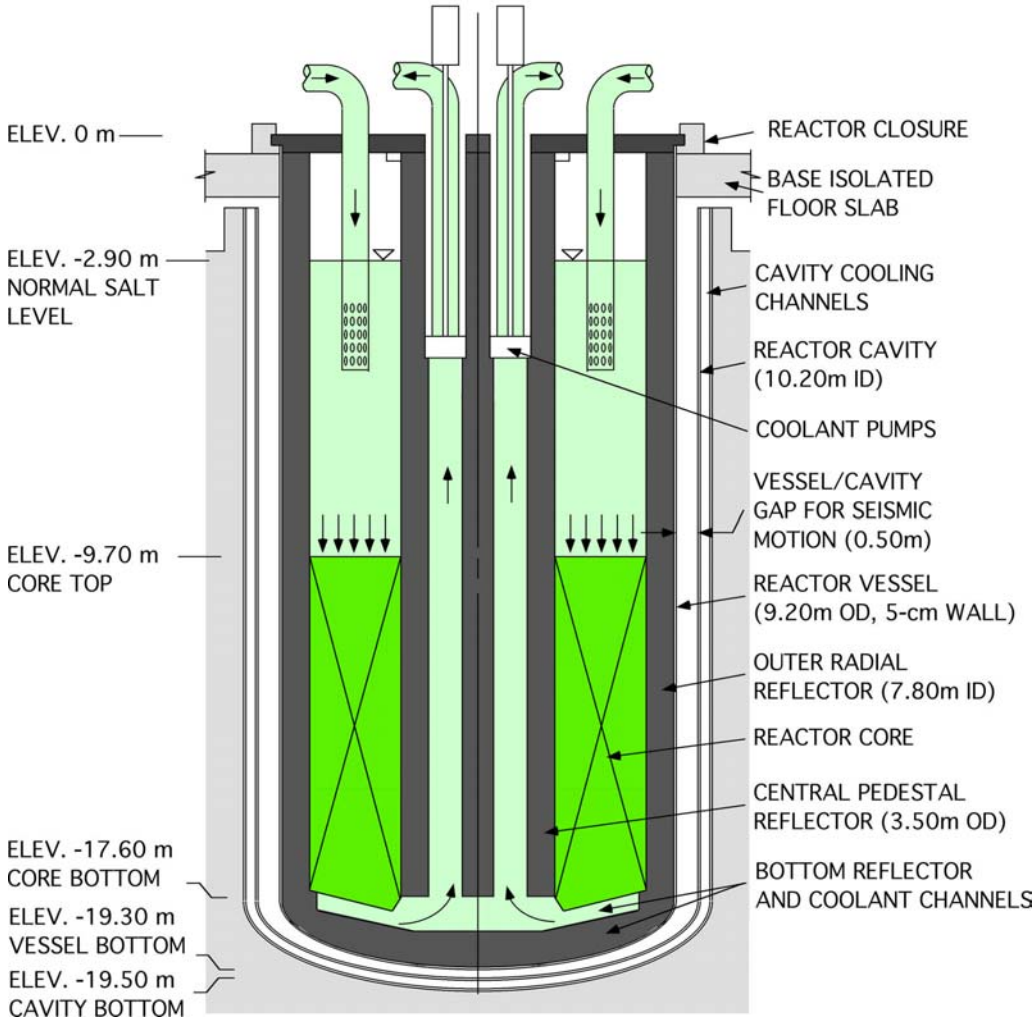
What Are The Materials Issues?

- Metal alloys have been developed for molten-salt industrial service to 750ºC
  - Metals are non-reactive (noble) in contact with clean salts
- ORNL LDRD test loop evaluating corrosion resistance to higher temperatures
- Salt is compatible with graphite to >1200 ºC

AHTR Lowers Peak Coolant Temperatures



Conceptual 2400 MW(t) AHTR Design



- **Transportable vessel**
  - **Same size as S-PRISM 1000 MW(t) vessel**
  - **Similar size to 600 MW(t) GT-MHR reactor vessel**
- **Down-flow molten salt**
- **MHTGR annular core**

Passive Safety

Decay Heat to the Reactor Vessel Wall With Silo Cooling

Same approach as Modular High-Temperature Gas-Cooled Reactors and the General Electric Sodium-Cooled Modular S-PRISM

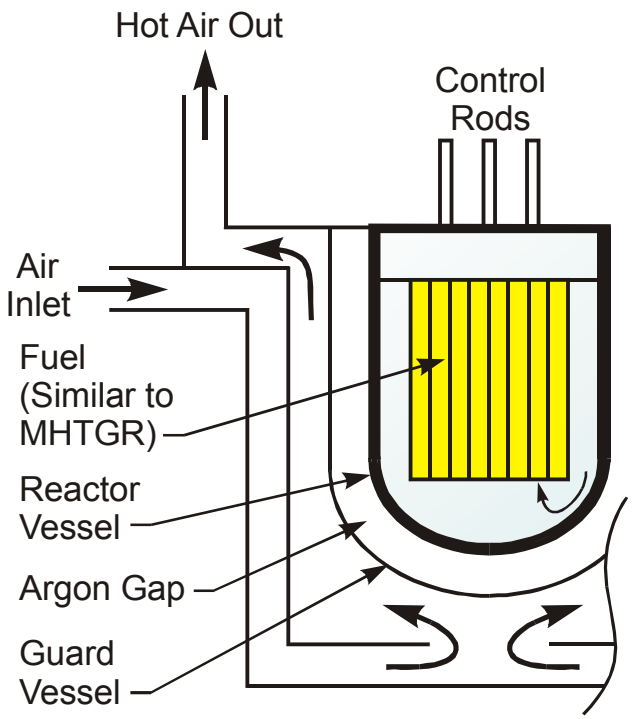
However

Molten Salt Allows Larger Reactor Sizes

In an Emergency, Decay Heat is Transferred to the Reactor Vessel and Then to the Environment

Passive Decay Heat Removal

Reactor

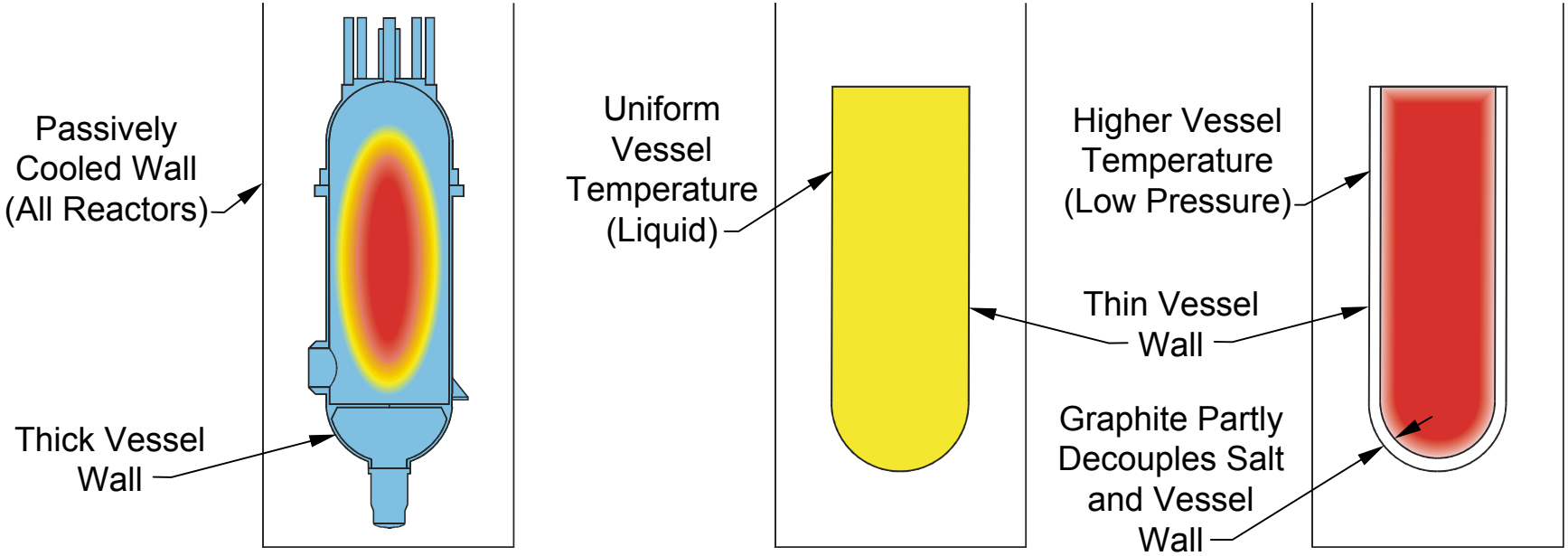


Decay-Heat Cooling System Characteristics

- Similar to GE S-PRISM (LMR)
- Argon Gap
  - Heat Transfer ~T^4
  - Thermal Switch Mechanism
- Heat Rejection: Temperature Dependent
  - LMR: 500-550°C [~1000 Mw(t)]
  - AHTR: 750-1000°C [>2000 Mw(t)]
- High Heat Capacity
  - Molten Salt and Graphite
  - High Temperature (Limited-Insulation of Vessel from Hot Salt)

Evolution of Passive Decay Heat Removal Systems in Similar Size Vessels Enables Design of Larger Reactors

Reactor	MHTGR	S-Prism	AHTR
Coolant	Helium	Sodium	Molten Salt
Power	600 MW(t)	1000 MW(t)	>2000 MW(t)
Limitation	Conduction	Sodium Boiling Point	Vessel



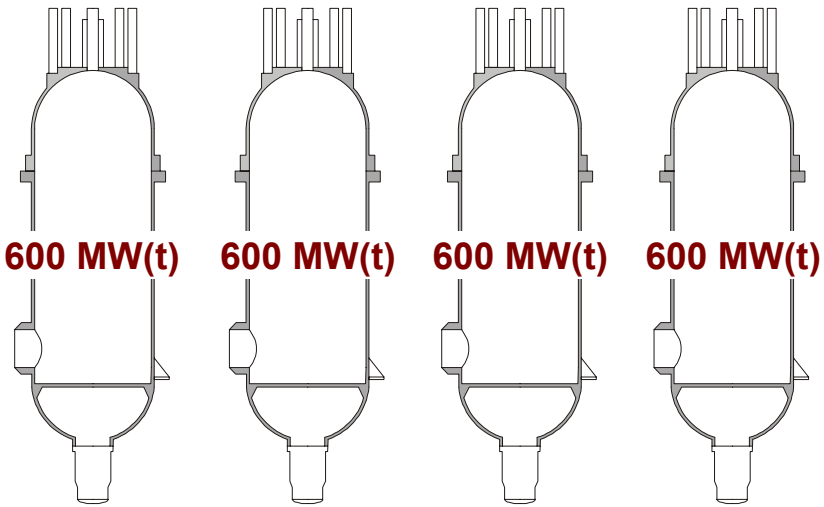
Economics

Larger Reactors Have the Potential for Lower Capital and Operating Costs

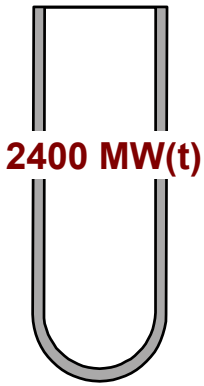
Molten Salt Preferred for Heat Transfer From Any Reactor to Hydrogen Plant

Equipment Comparisons Suggest AHTR Capital Cost Per MW(t) Is Less Than a Modular Reactor

Pressure Vessels For 2400 MW(t) of HTGRs



Low-Pressure Vessel For 2400 MW(t) of ATGR



Simple scaling laws estimate AHTR per kilowatt capital costs at 60% of a Modular High Temperature Gas-Cooled Reactor

Potential for Better Economics Than Light-Water Reactors

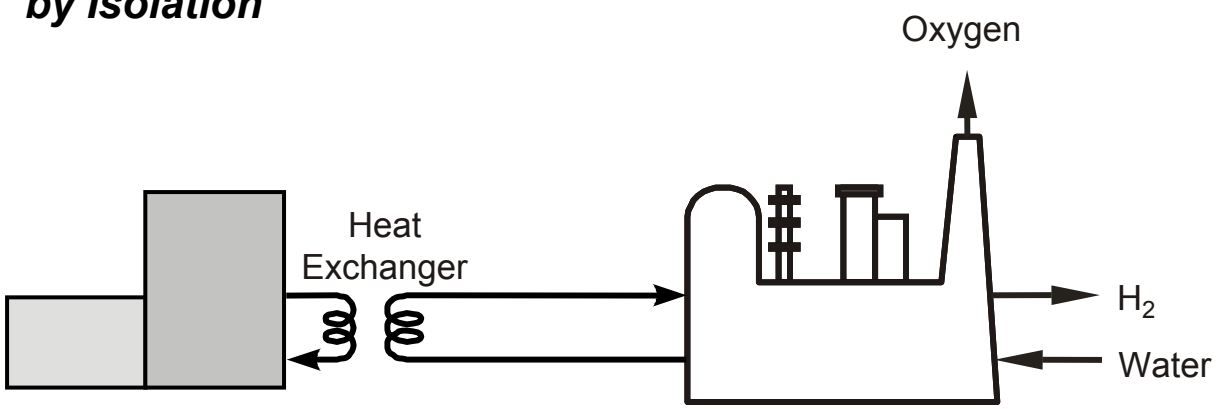
- Potential economic advantages of AHTR
  - Higher thermal-electric efficiency (50% versus 33%)
    - Fuel savings
    - Smaller secondary systems
  - Brayton helium cycle (Smaller than steam turbine)
  - Low pressure containment
- But no definitive economic comparison
  - LWR technology is significantly different; thus, simple scaling comparisons can not be made

Molten Salts Preferred For Transfer of Heat From Reactor to Physically-Separated Hydrogen Production Facility

(1970s German Studies)

Nuclear Safety by Isolation

Hydrogen Safety by Dilution



Loop Heat Transfer Comparison
[50 MW(t)]

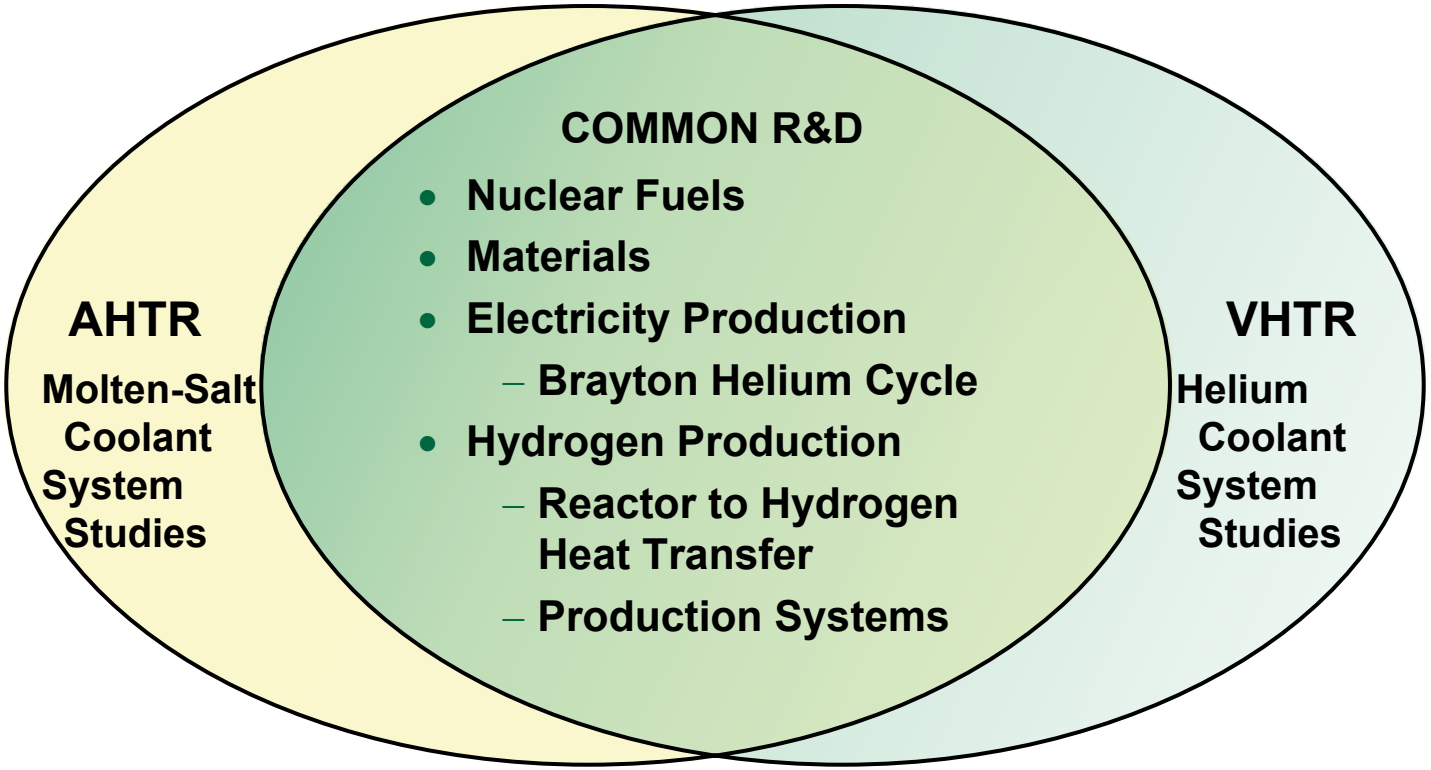
Characteristic	Salt	Helium
Pressure (bar)	1	70
Velocity (m/s)	4	40
Temperature Drop (°C)	200	200
Pipe Diameter (m)	0.25	1.2
Relative Pumping Power	1	45

Technical Status

Shares Many R&D Issues with VHTR

Some Unique Issues

The R&D Requirements for the Molten-Salt-Cooled AHTR and Helium-Cooled VHTR Have Much In Common



AHTR R&D Requirements

- Conceptual design and safety basis studies needed
  - Initially to 750ºC
  - Higher temperature designs
- System studies
  - Decay heat cooling systems
  - System tradeoffs
  - Economics
- Core design (neutronics, thermal hydraulics, structural)
- Choice of Materials

Research Partnerships

- Potential international support
  - French and European interest in:
    - Molten salt reactors
    - Hydrogen production
  - French National Assembly Report
- Connections to other programs
  - Hydrogen from nuclear energy (heat transfer loop for hydrogen plant isolation)
  - Fusion (molten-salt blanket and materials)
  - International interest in transmutation

Conclusions

- AHTR goals
  - Improve economics with larger high-temperature reactor
  - Same passive safety basis as modular reactors
  - Commonality with helium-cooled high-temperature reactors
- Technology foundation based on
  - Modular high-temperature gas-cooled reactors
  - Molten salt experience (Industrial and reactor)
- New reactor concept
  - Shares many R&D issues with VHTR
  - Several AHTR specific issues
- Strengthens basis for high-temperature reactors
- Several potential partners (France, Fusion)