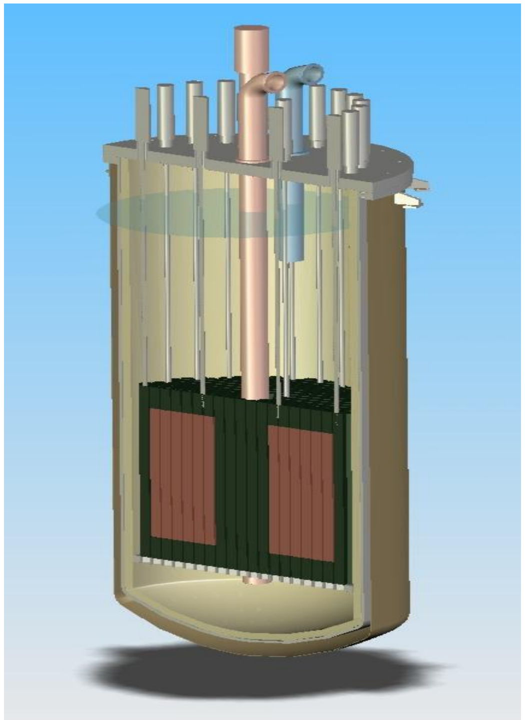
The Advanced High-Temperature Reactor (AHTR)

High-Temperature Fuel, Molten Salt Coolant, and Liquid-Metal-Reactor Plant



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OAK RIDGE NATIONAL LABORATORY

The Advanced High-Temperature Reactor

Goals:

High-Temperature Heat

Passive Safety

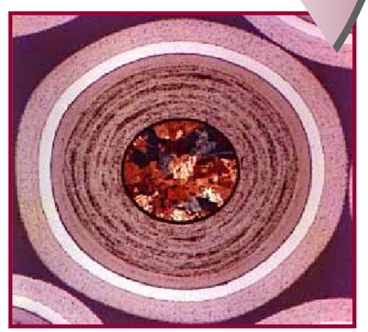
Competitive Economics

The Advanced High-Temperature Reactor

Combines Existing Technologies in a New Way

Passively Safe Pool-Type Reactor Designs

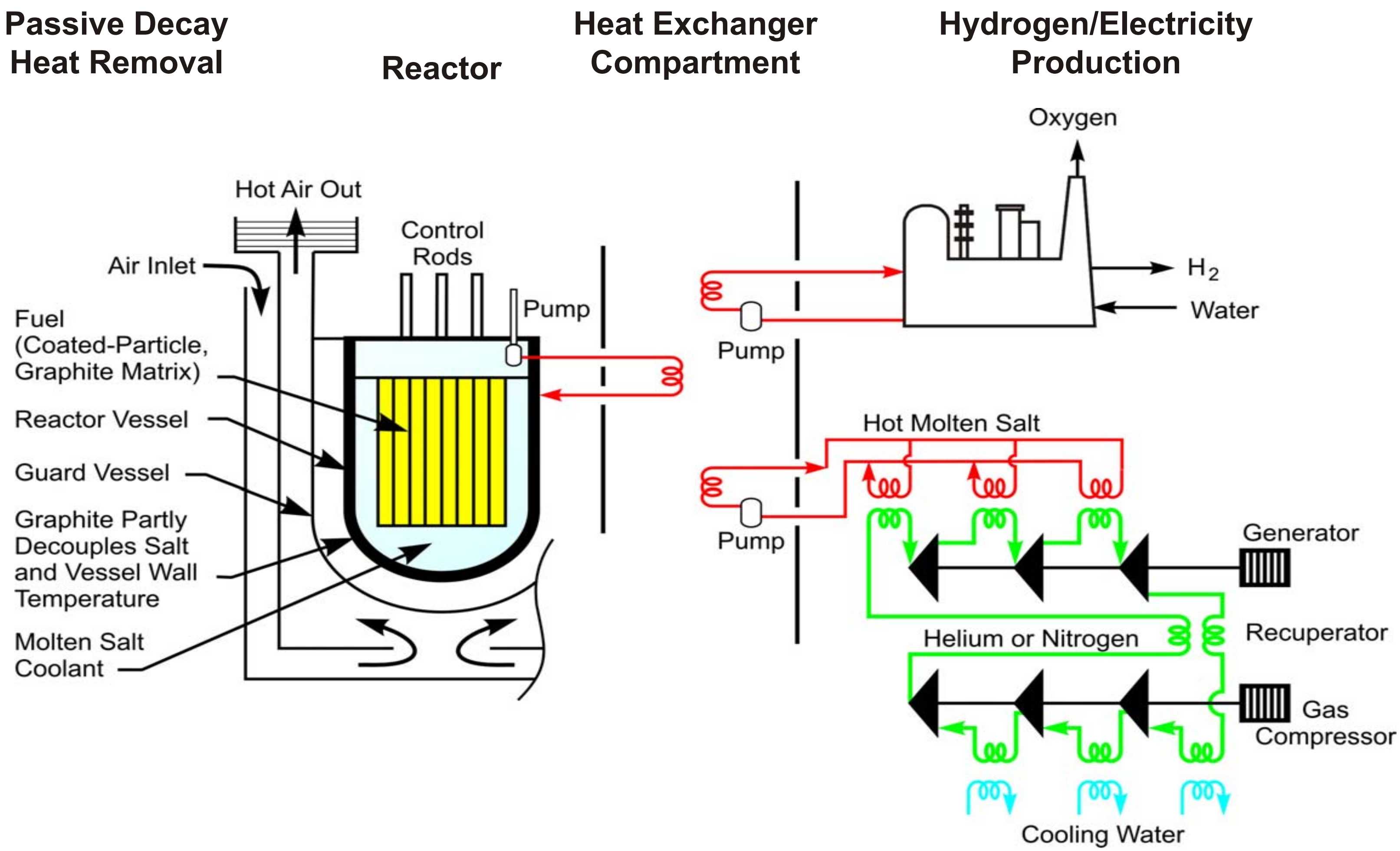
Brayton Power Cycles



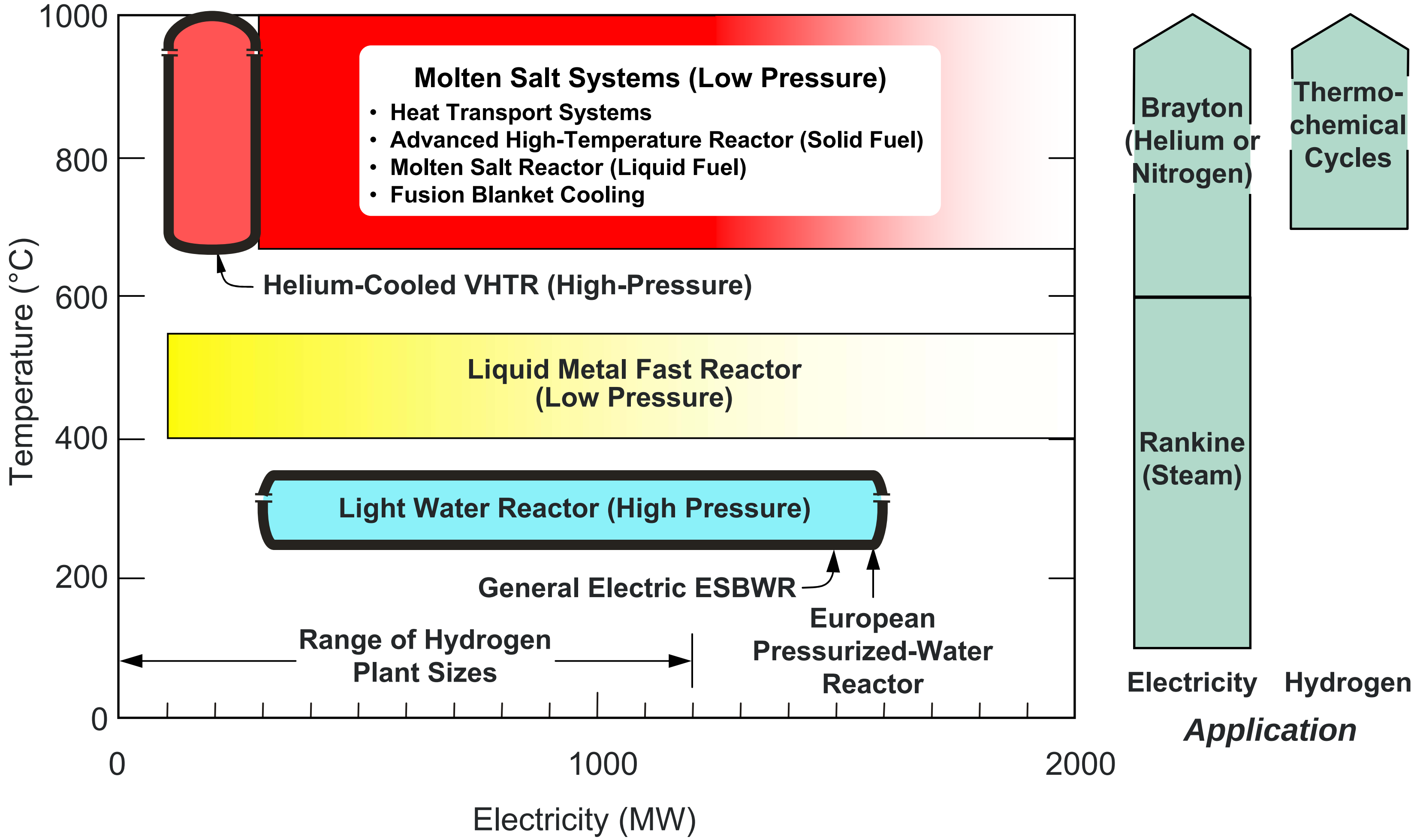
High-Temperature Coated-Particle Fuel

High-Temperature, Low-Pressure Transparent Molten-Salt Coolant

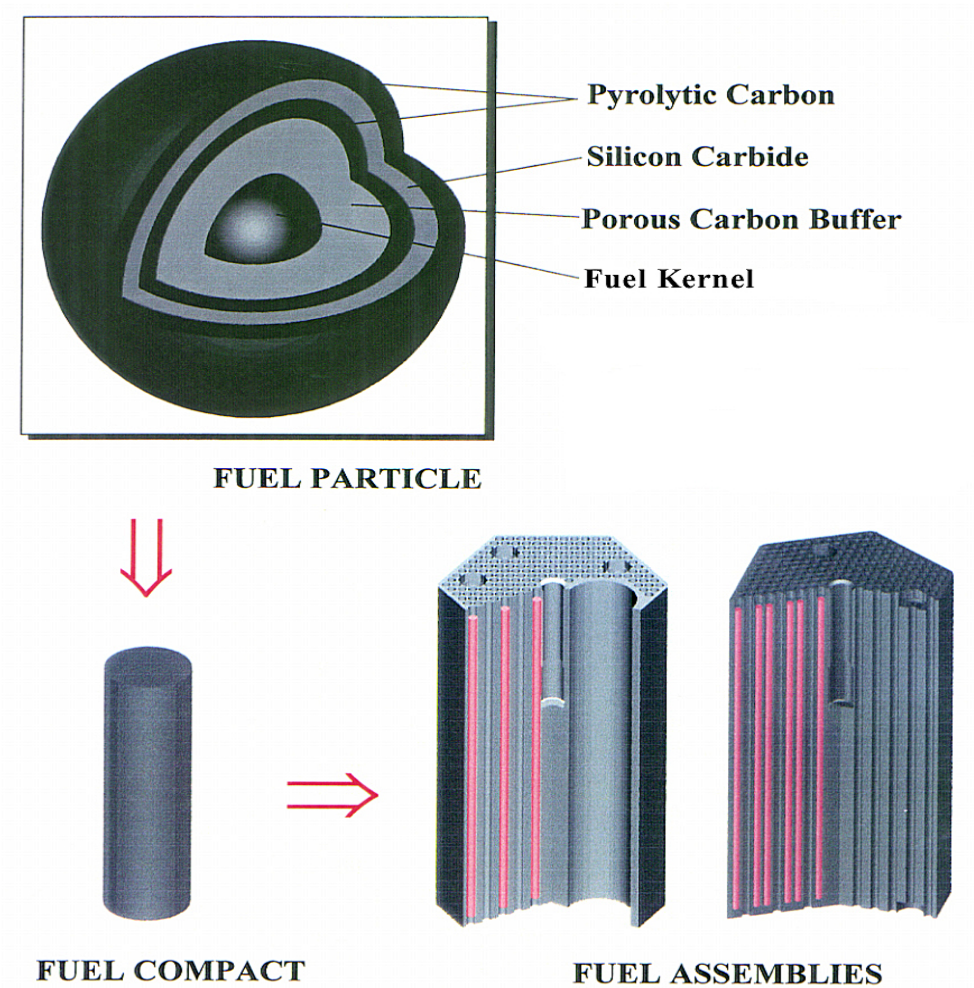
The Advanced High-Temperature Reactor



AHTR Fills the High-Temperature, High-Power Need

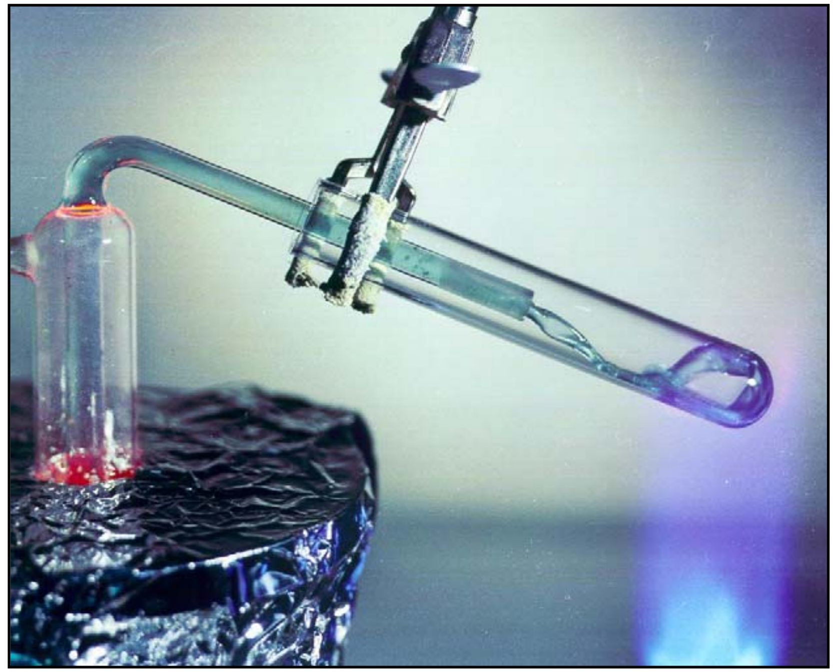


The AHTR uses Coated-Particle Graphite-Matrix Fuel Elements



- **Same fuel as used in gas-cooled high-temperature reactors**
- **Peak operating temperature: 1250ºC**
- **Failure temperature exceeds 1600ºC**
- **Graphite blocks provide neutron moderation and heat transfer to coolant**

Two Coolants have been Demonstrated to be Compatible with Graphite Materials and High-Temperature Operations



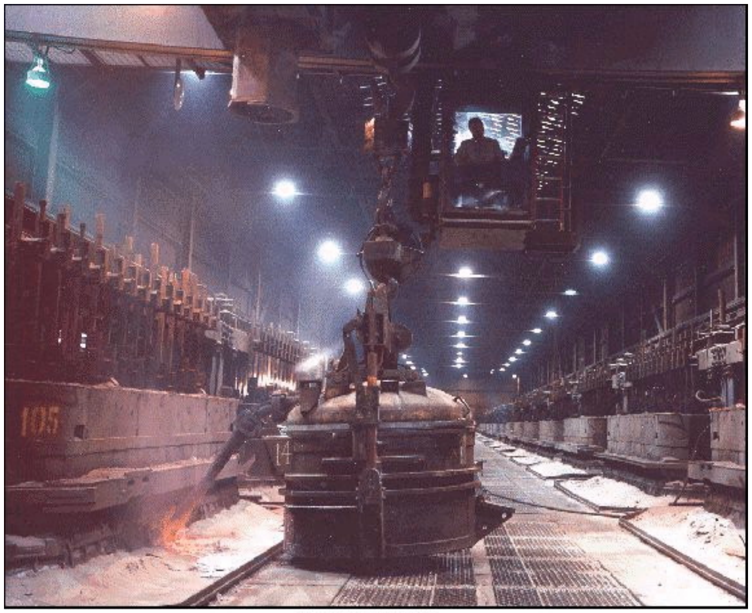
Helium

(High Pressure/Transparent)

Molten Fluoride Salts

(Low Pressure/Transparent)

Molten-Fluoride Salts have been used in Industrial and Nuclear Applications

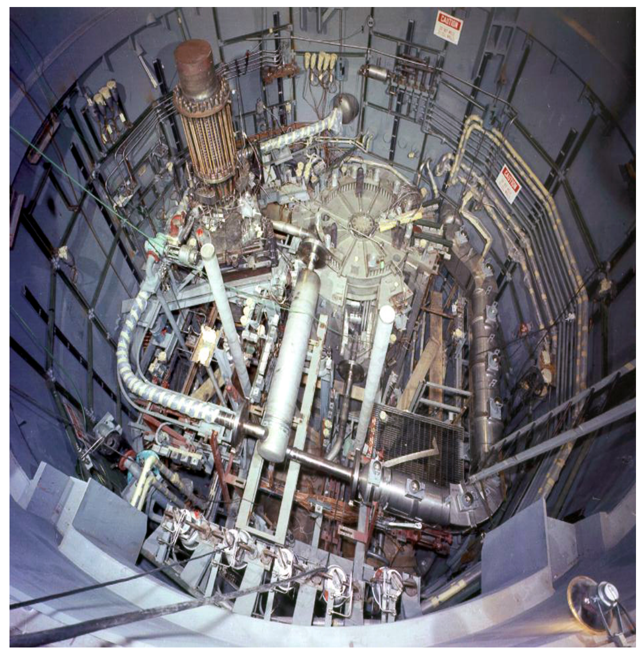


Tapping aluminum

Aluminum is tapped from a Kitimat Works electrolytic-reduction cell into a steel vessel called a crucible. The crucible holds approximately 4,000 kg of aluminum and is used to transfer the molten aluminum to the furnaces in the casting department.

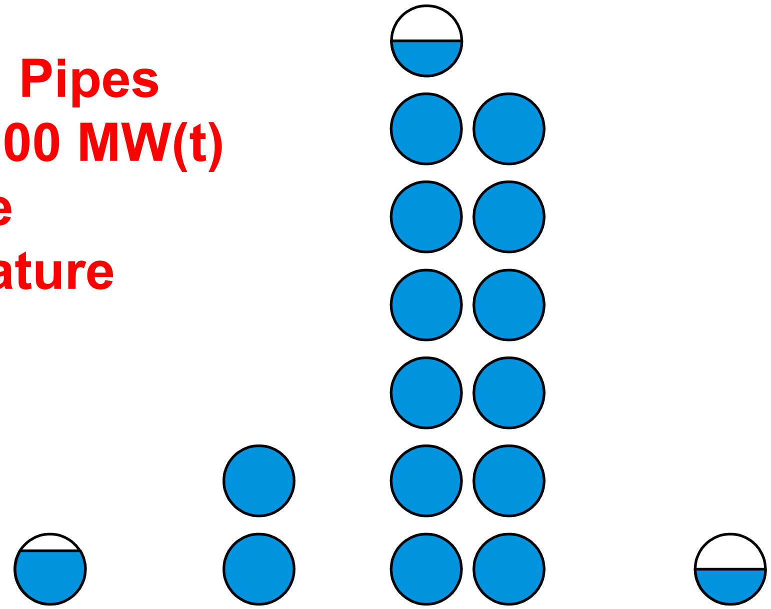
Molten Fluoride Salts Are Used to Make Aluminum in Graphite Baths at 1000°C

Molten Fluoride Salts Were Used in Molten Salt Reactors with Fuel in Coolant (AHTR Uses Clean Salt and Solid Fuel)



Molten Salts have Superior Capabilities for the Transport of Heat

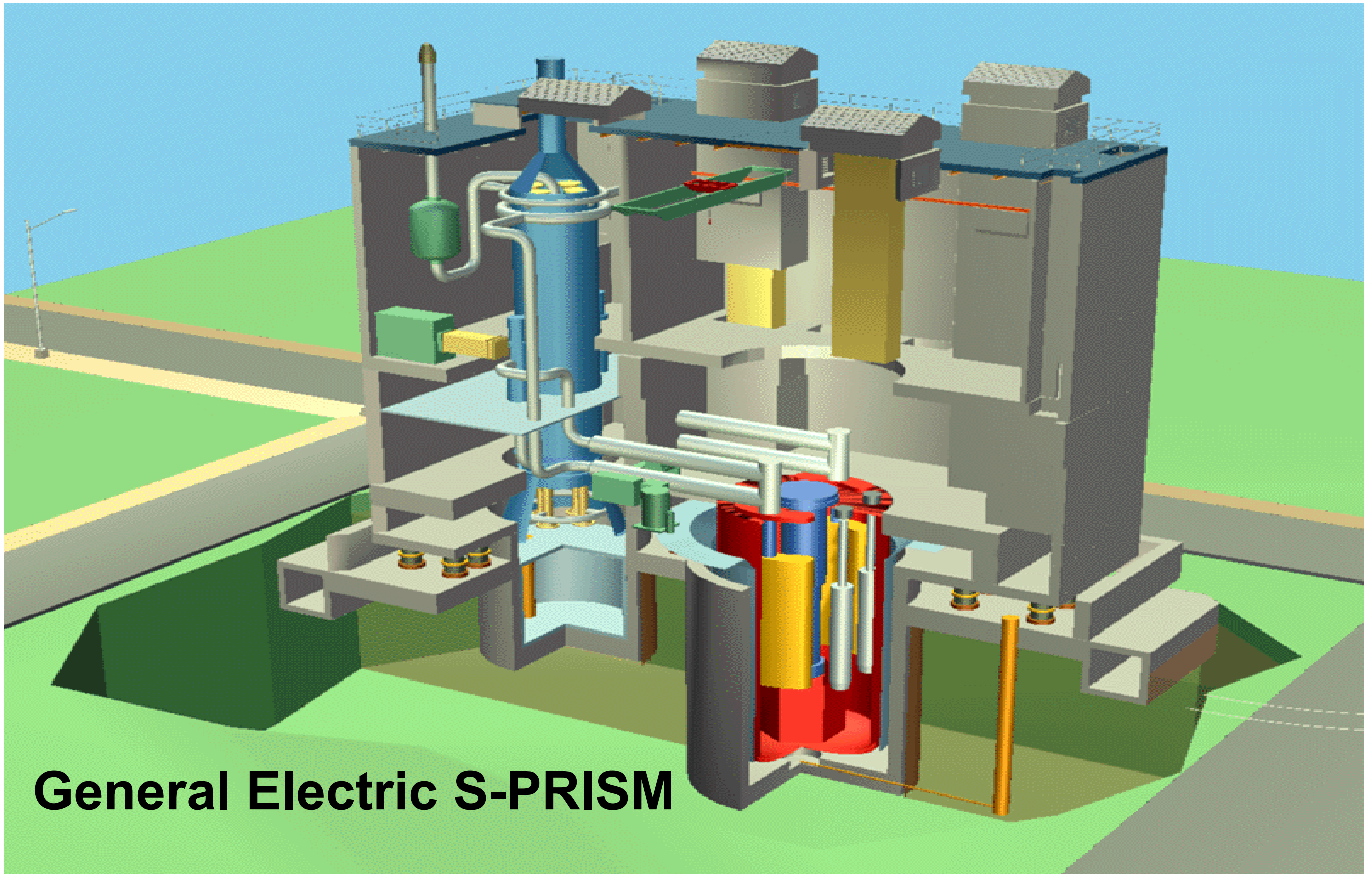
Number of 1-m-diam. Pipes Needed to Transport 1000 MW(t) with 100ºC Rise in Coolant Temperature



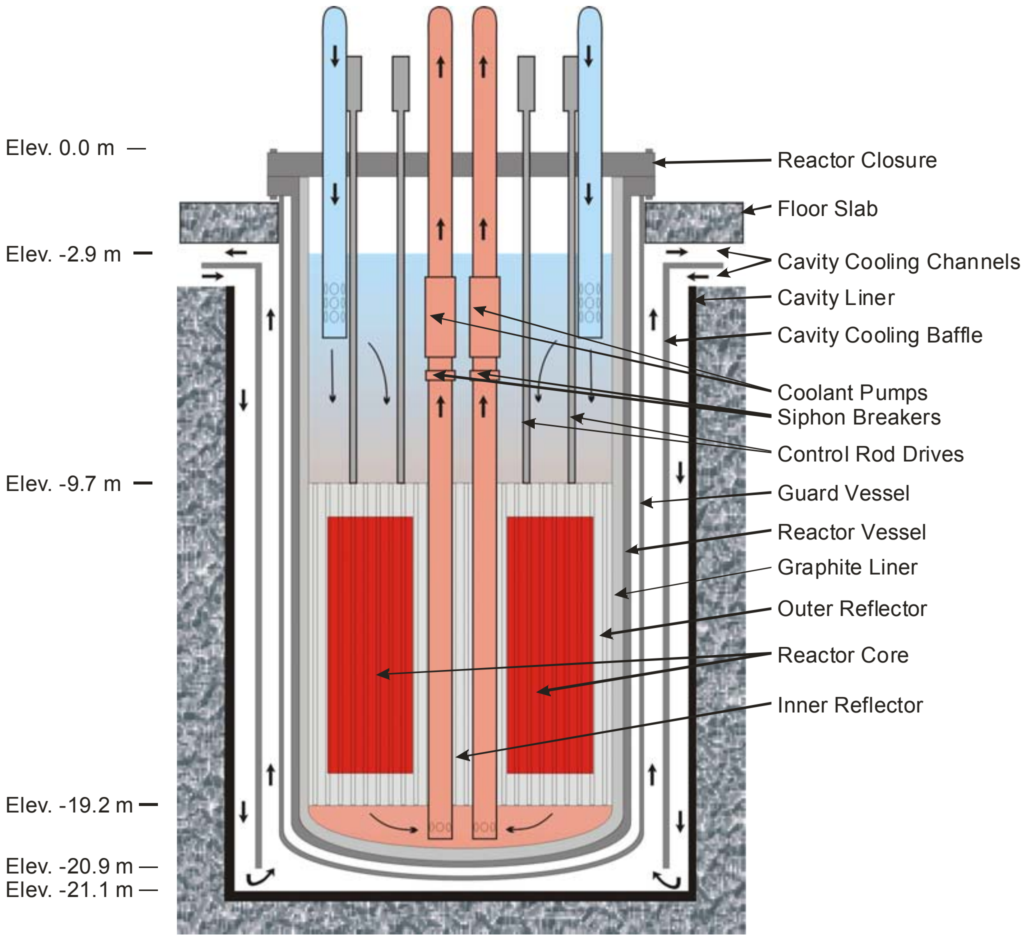
	Water (PWR)	Sodium (LMR)	Helium	Molten Salt
Pressure (MPa)	15.5	0.69	7.07	0.69
Outlet Temp (ºC)	320	540	1000	1000
Coolant Velocity (m/s)	6	6	75	6

Proposed AHTR Facility Layouts are Based on Sodium-Cooled Fast Reactors

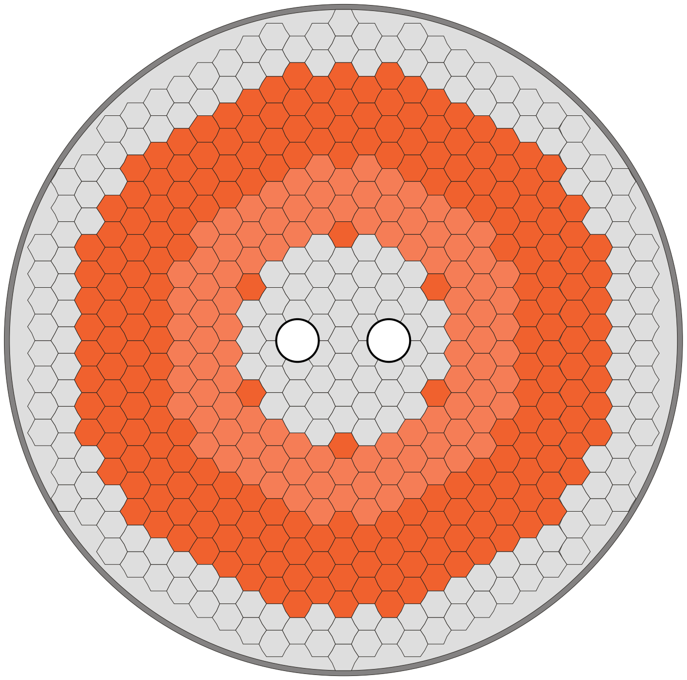
Low Pressure, High Temperature, Liquid Cooled



AHTR 9.0-m Vessel Allows 2400-MW(t) Core

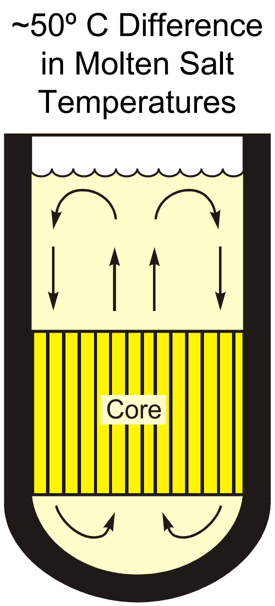


102 GT-MHR fuel columns
222 Additional fuel columns
324 Total fuel columns

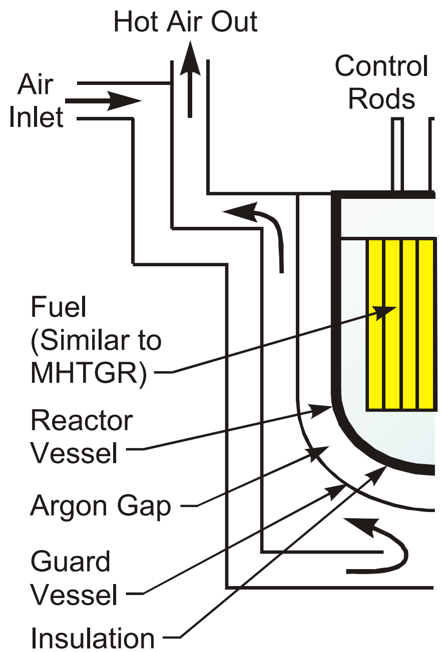


Power density = 8.3 MW/m^3
(26% larger than 600-MW GT-MHR)

Decay Heat is Transferred to the Reactor Vessel and then to the Environment



Decay Heat from Core to Vessel Liner



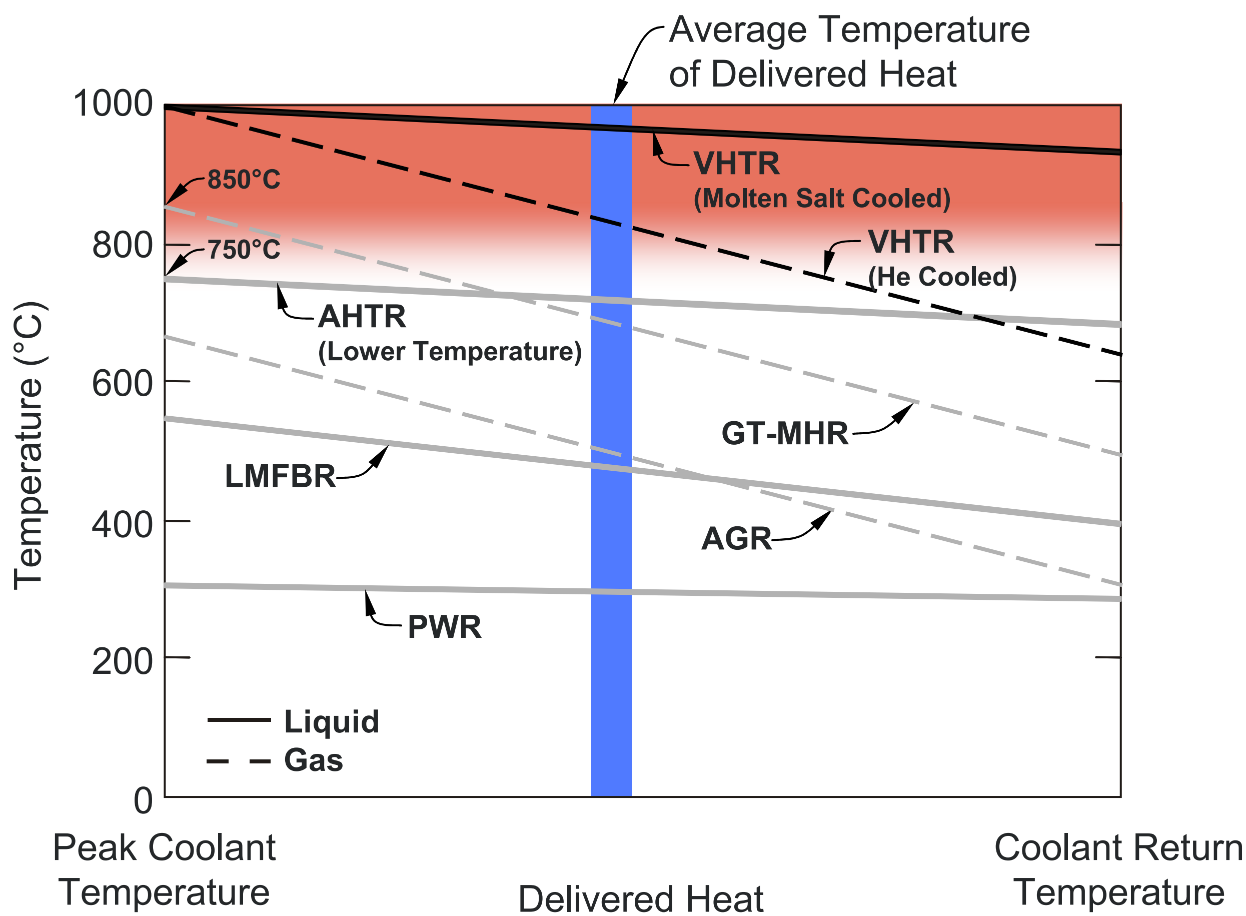
Decay Heat from Vessel to Environment

- Similar to GE S-PRISM (LMR)
- Liquid transfers heat from fuel to wall with small temperature drop (~50ºC)
- Argon gap: Reactor to guard vessel
  - Heat transfer: $\sim T^4$
  - Thermal switch mechanism
- Heat rejection: Vessel temperature dependent
  - LMR: 500–550ºC [~1000 MW(t)]
  - AHTR: 750ºC [~2400 MW(t)]
- Other decay heat cooling options

Power Production

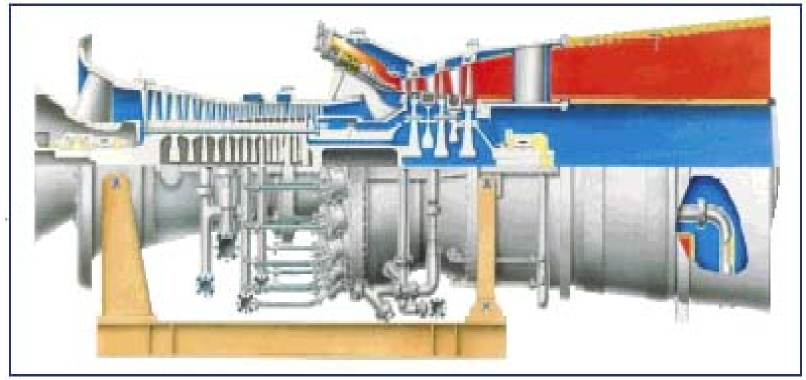
The AHTR Power Plant Efficiency is Higher than the Comparable Gas-Cooled Reactor

Higher-Temperature Delivered Heat for the Same Peak Temperature

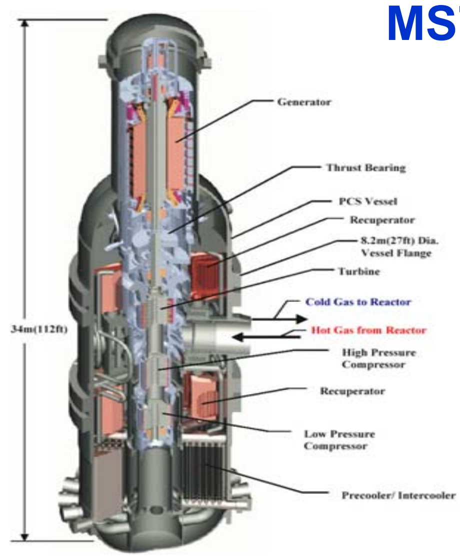


Closed Nitrogen or Helium Brayton Cycle for Electricity Production

- **Same turbine technology as existing natural-gas-fired turbines (but closed cycle, not open cycle)**
  - **Lower temperatures than current commercial units**
  - **For 2400 MW(t) AHTR**
    - **1145 MW(e) if peak molten salt temperature 800ºC**
    - **1300 MW(e) if peak molten salt temperature 1000ºC**
- **Choice of horizontal or vertical (GT-MHR) systems**
- **Helium Brayton cycle is a longer term option**



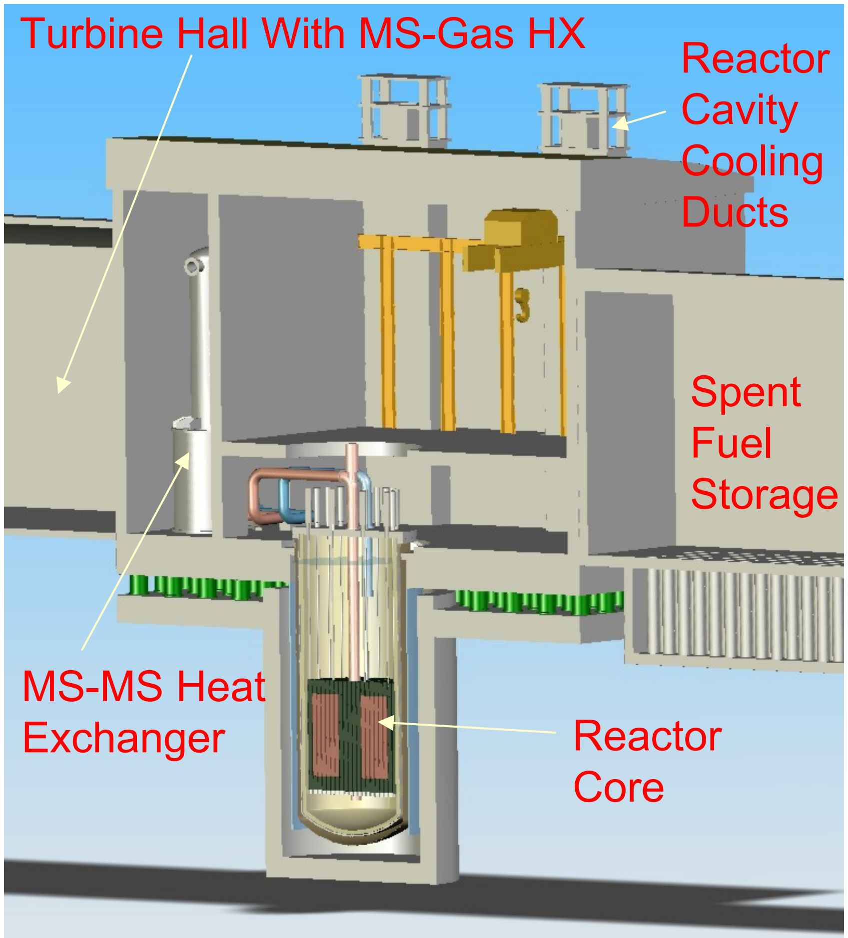
GE Power Systems MS7001FB



General Atomics GT-MHR Power Conversion Unit (Russian Design)

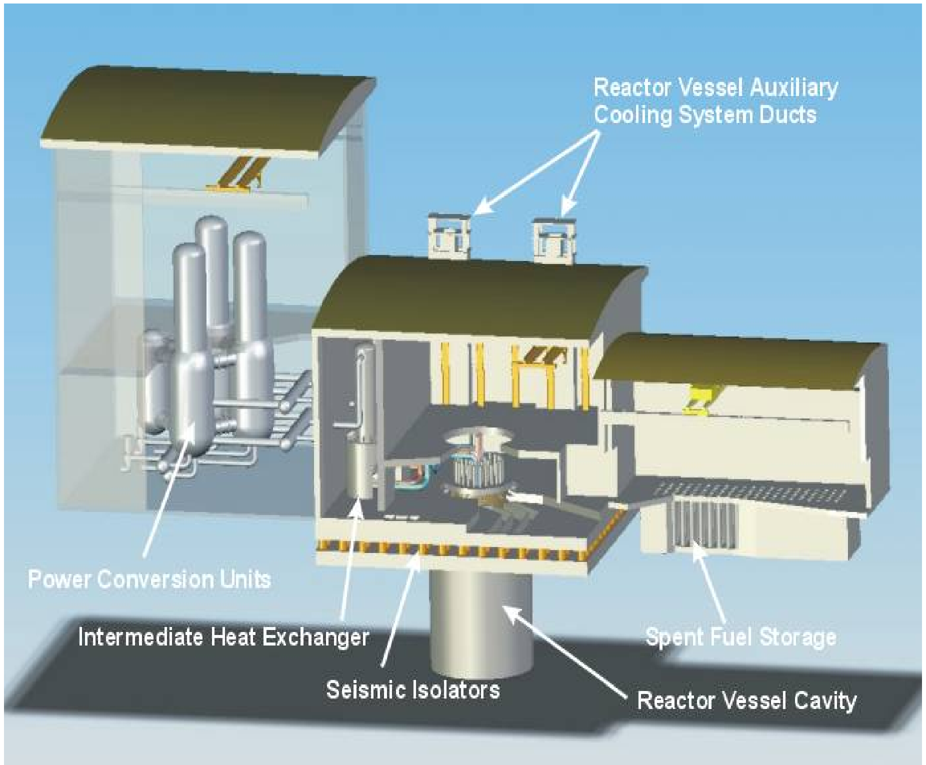
Economics

2400-MW(t) AHTR Nuclear Island is Similar in Size to the 1000-MW(t) GE S-PRISM



- **Differences from S-PRISM facility layout:**
  - **No SNF storage in vessel**
  - **No heat exchanger inside vessel**
  - **Molten salt-to-gas heat exchanger in turbine hall**
- **Same vessel size (low pressure)**
  - **Space for 2400-MW(t) AHTR core with low power density**
- **Similar equipment size**
  - **Molten salt volumetric heat capacity greater than that for sodium**
- **Higher-capacity decay heat removal system**
  - **750ºC vessel under accident conditions for nominal 1000ºC salt exit temperature**
- **Higher electrical output**
  - **S-PRISM: 380 MW(e)**
  - **AHTR: >1200 MW(e)**

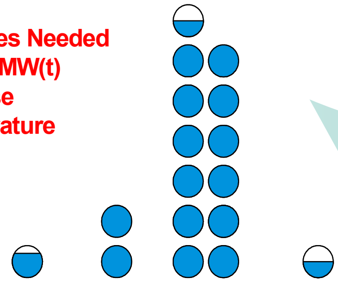
The Preliminary Economic Analysis Indicates Capital Costs of 50 to 60% per kW(e) Relative to S-PRISM and MHTGRs



- **Economics of scale**
  - **2400 MW(t) vs 600 to 1000 MW(t)**
  - **1300 MW(e) vs 300 to 380 MW(e)**
- **Passive safety in a large reactor**
  - **Liquid heat transport inside reactor vessel**
  - **Higher temperature (750ºC) vessel increases heat rejection**
- **Higher efficiency multi-reheat Brayton cycle**
- **No high-pressure vessel**

AHTR Projected Economics Are Superior to Large Sodium-Cooled Reactors

Number of 1-m-dia. Pipes Needed
To Transport 1000 MW(t)
With 100ºC Rise
In Coolant Temperature



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Pressure (MPa)	15.5	0.69	7.07	0.69
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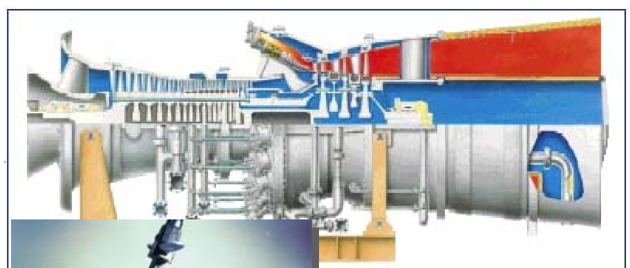
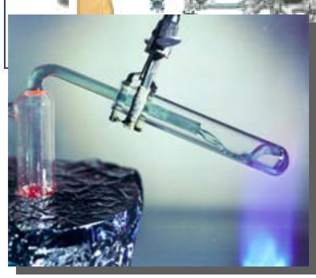
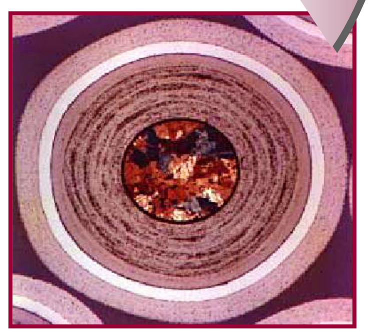
Smaller Equipment, Higher Volumetric Heat Capacity





No Liquid-Metal / Water Reactions



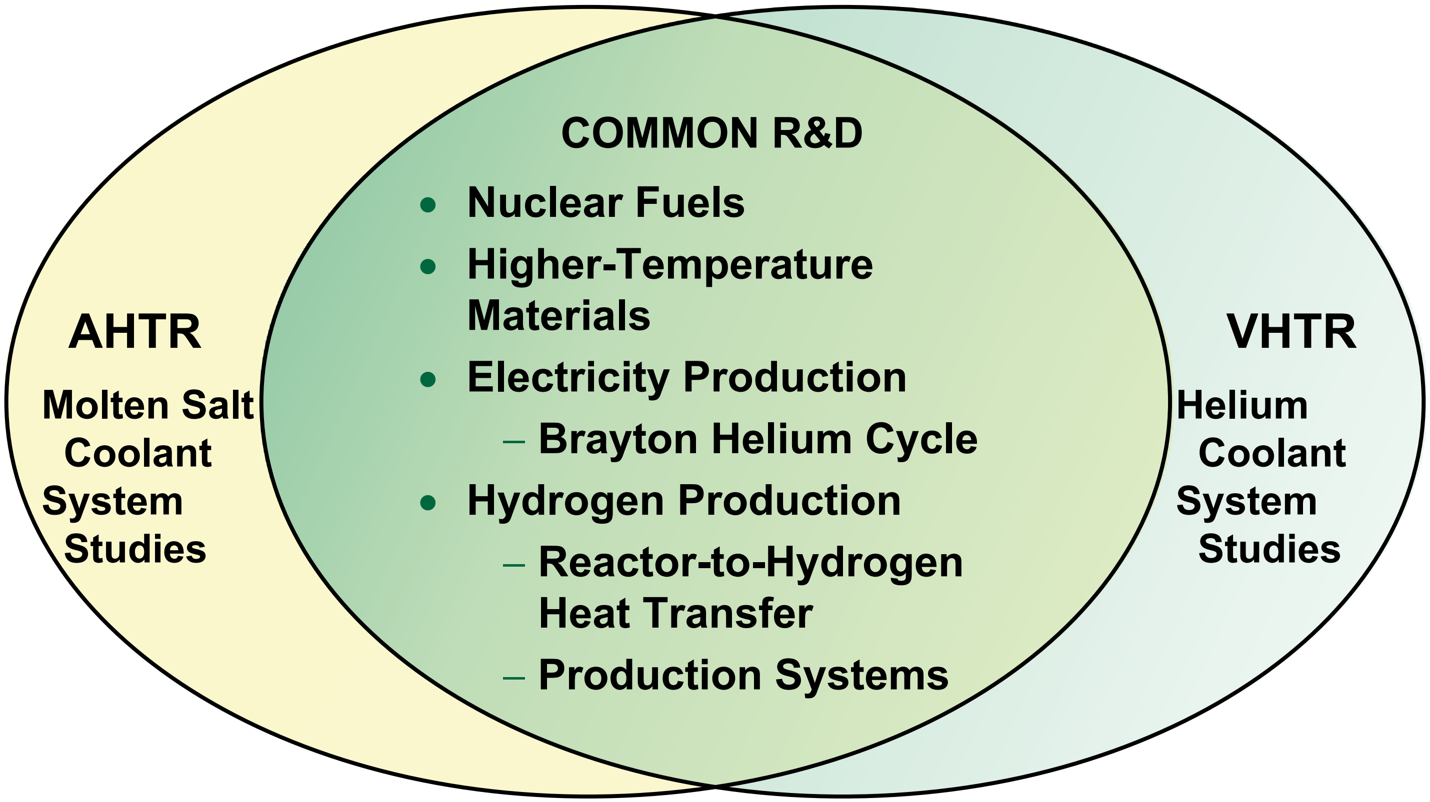
Higher Thermal Efficiency

(50% versus 40%)

Easier Inspection With Transparent Coolant

Research and Development

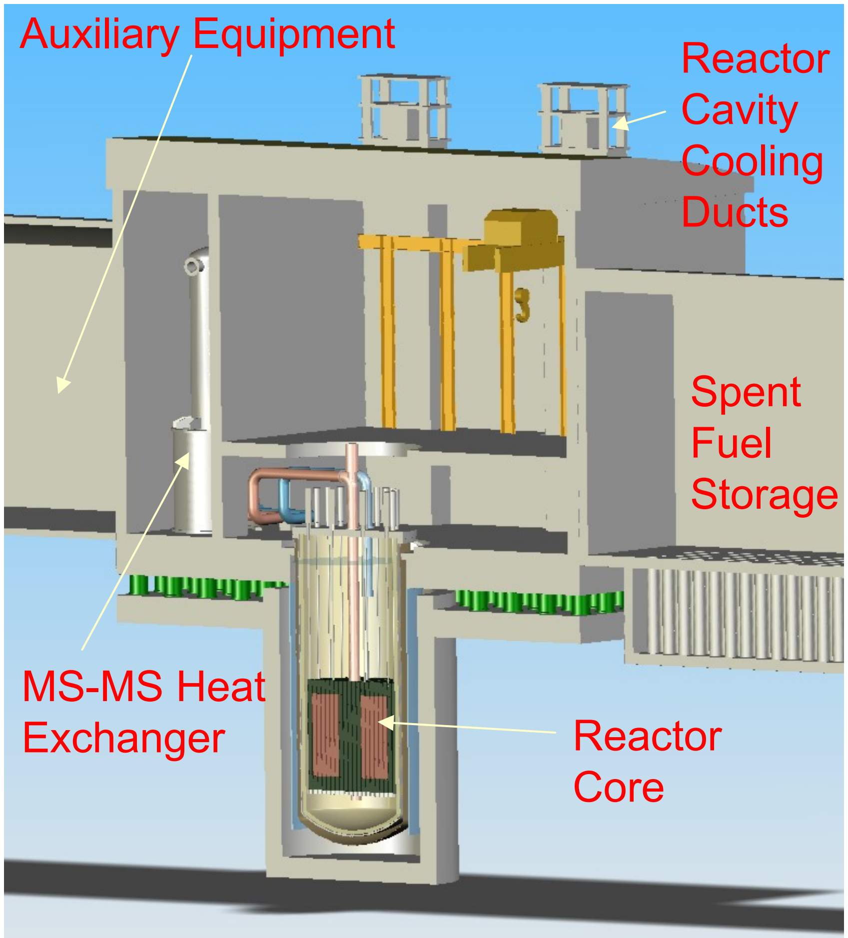
The R&D Requirements for the AHTR and the Helium-Cooled VHTR have Much in Common



AHTR Research and Development Challenges

- ***New reactor concept with associated uncertainties***
- **No qualified materials of construction if operating temperatures are above 750ºC**
- **Reactor core design**
  - **Salt selection (several options)**
  - **Neutronics**
- **Refueling temperatures 350 to 500ºC (avoid salt freezing)**

Conclusions: Advanced High-Temperature Reactor

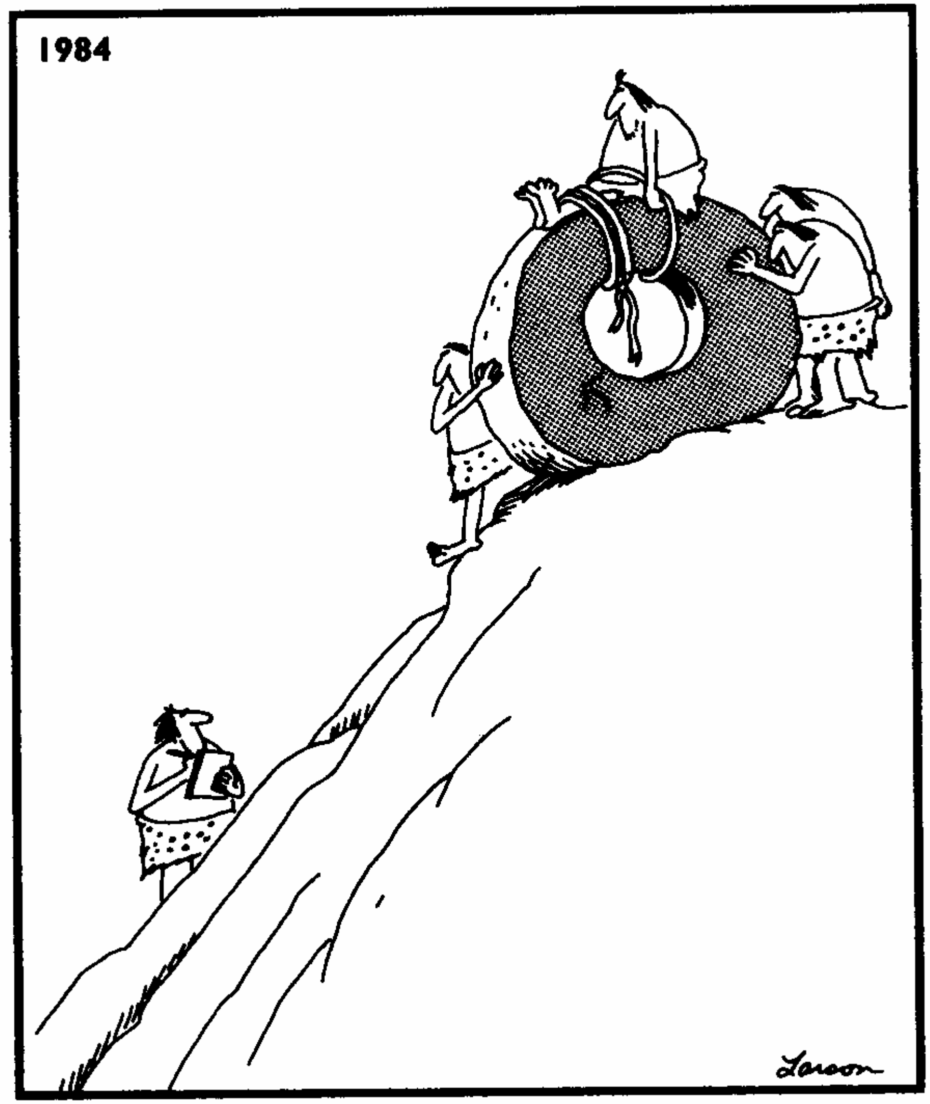


- **New reactor concept**
- **Gas-cooled-type reactor fuel**
- **Molten-salt low-pressure coolant**
- **Liquid-metal fast-reactor plant design**
- **Potentially superior economics**
- **Significant R&D needs**

Backup
Backup
Backup

The AHTR:

A good idea that still needs some work

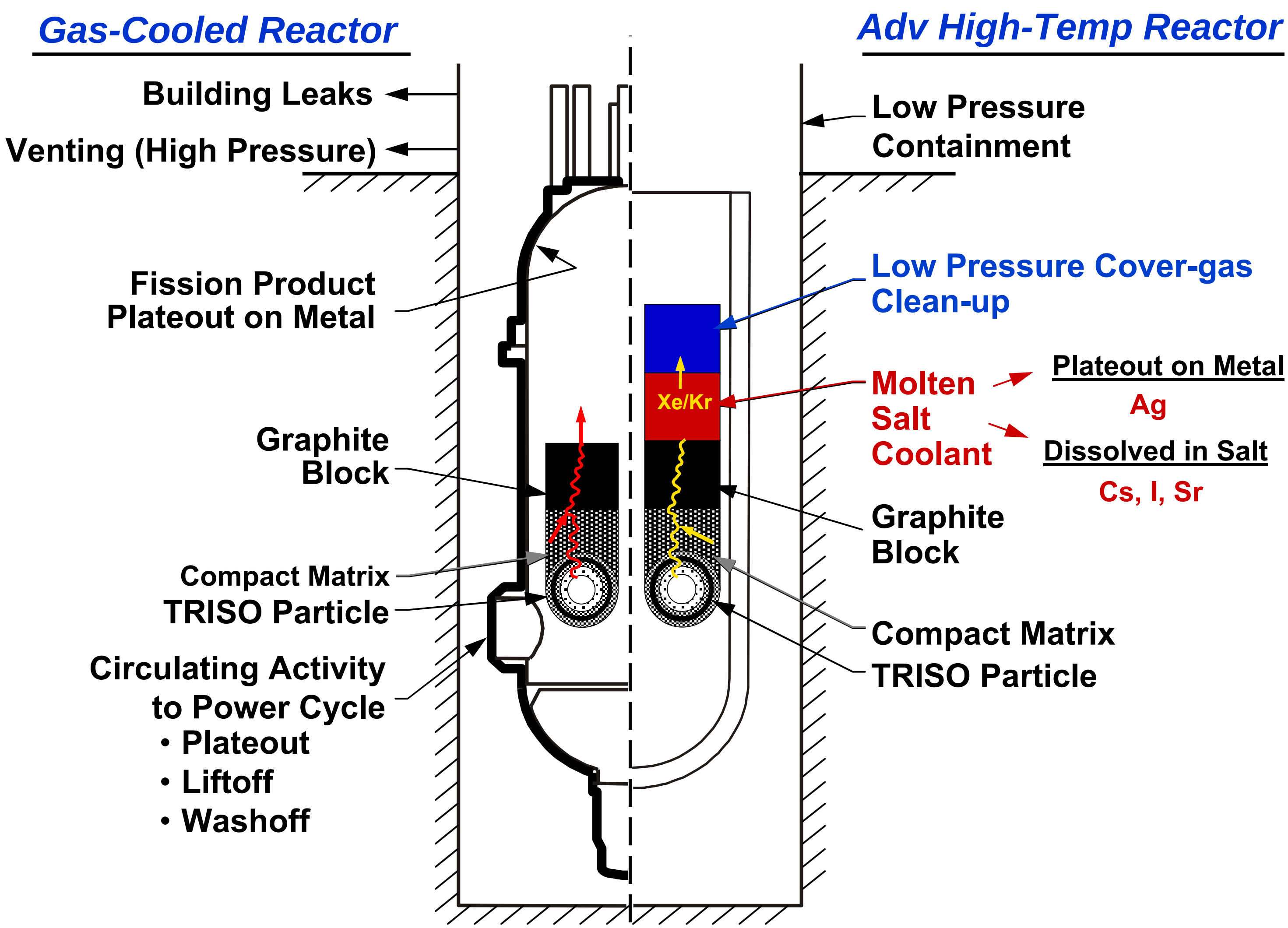


The AHTR is not a Molten Salt Reactor

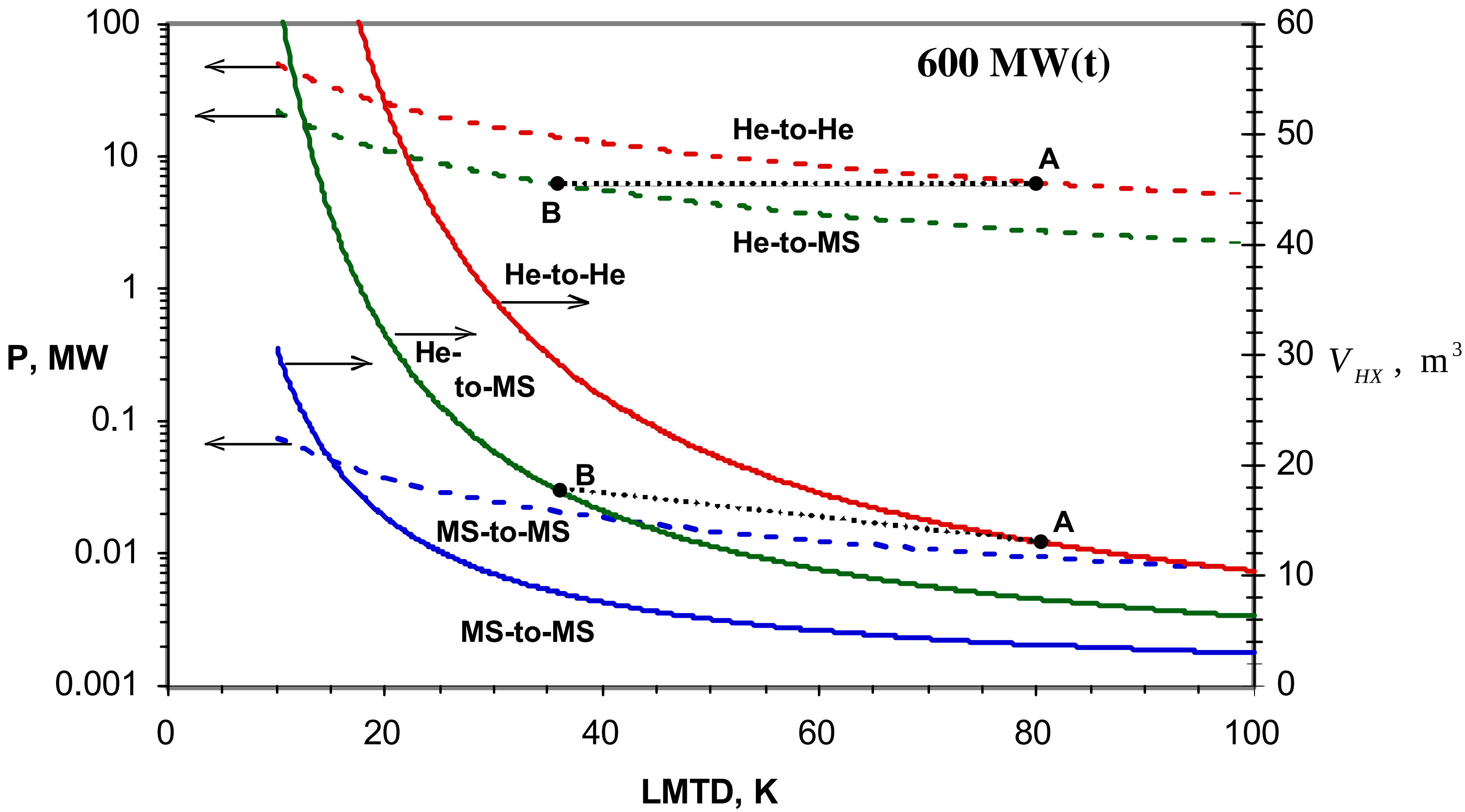
Cooled with a Clean Molten Salt, No Fuel in Salt

- **MSR programs operated test loops for hundreds of thousands of hours**
- **MSR programs developed code-qualified alloys of construction to 750°C**
- **Experience showed major efforts required to develop materials for molten *fuel* salt (high concentrations of fission products and actinides in salt)**
- **Experience showed low corrosion rates with clean salts (similar to experience with other coolants)**

The AHTR Offers Enhanced Fission Product Retention



Molten-Salts Superior to Gases in Intermediate Heat Exchangers



Optimized Compact Off-set Strip-Fin IHX

Hydrogen Production

The AHTR may Enable Nuclear-Hydrogen Production

Hydrogen production requires high-temperature (800 to 850ºC) heat

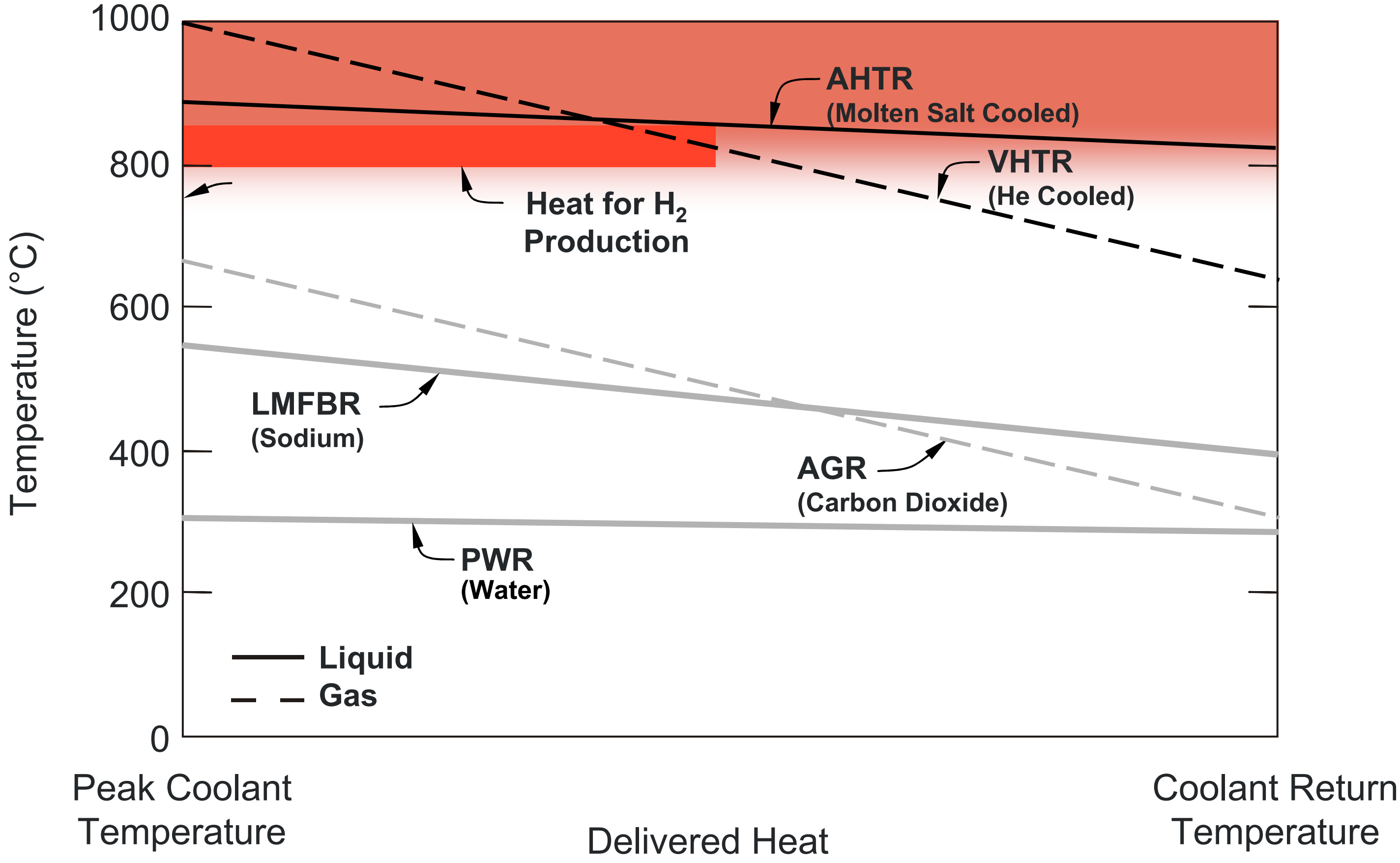
Reactor temperatures must be higher to transport heat to the hydrogen production plant

Reactor temperatures are at the limits of practical design and available materials of construction

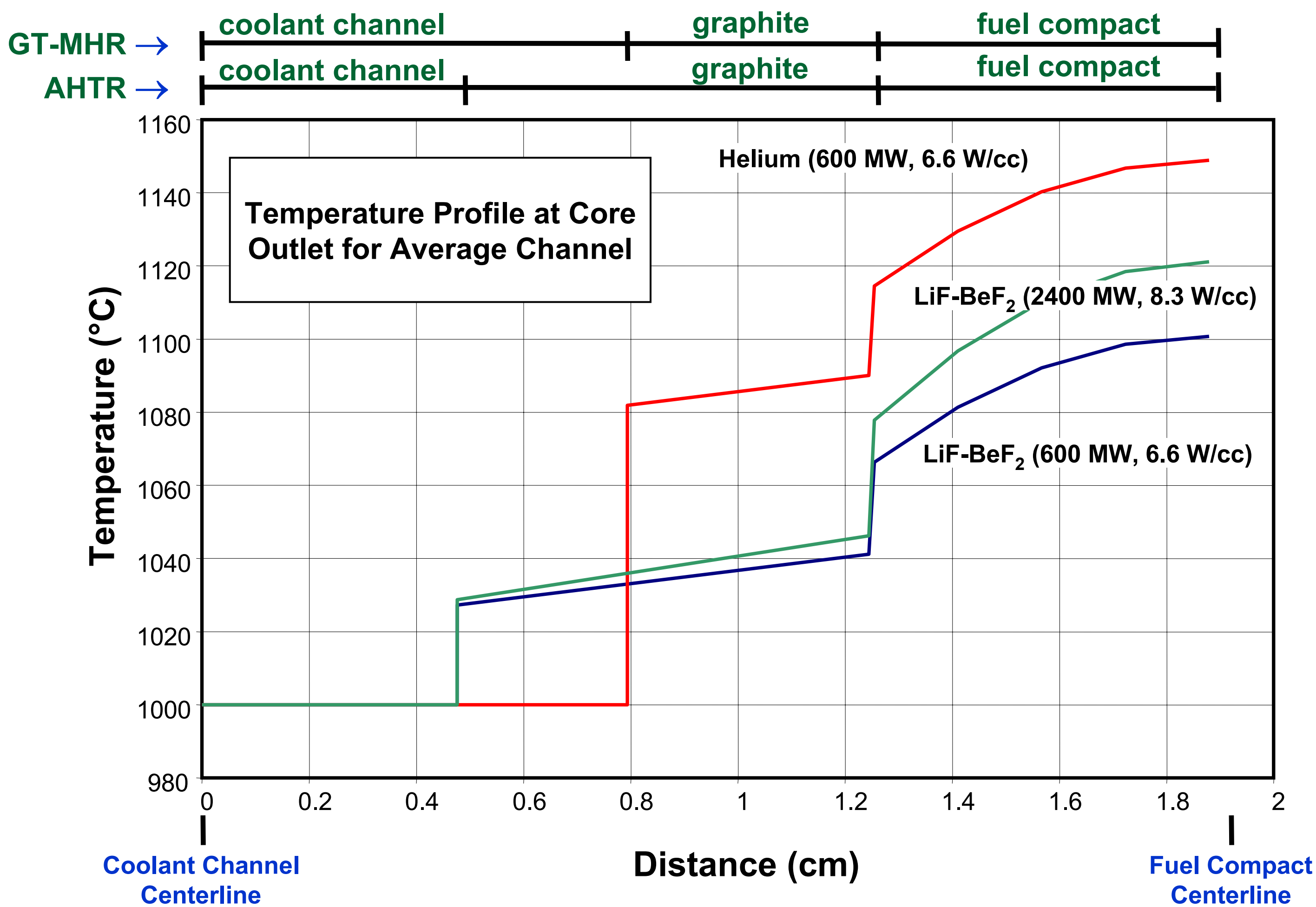
The liquid-cooled AHTR reduces peak reactor temperatures 100 to 200ºC relative to gas-cooled reactors to reduce engineering challenges

Liquid Cooling Lowers Peak Coolant Temperature *for Heat Delivered at Any Given Temperature*

The Hydrogen Production Requirement is not a 1000ºC, Its Delivery of Large Amounts of Heat Above Some Lower Temperature

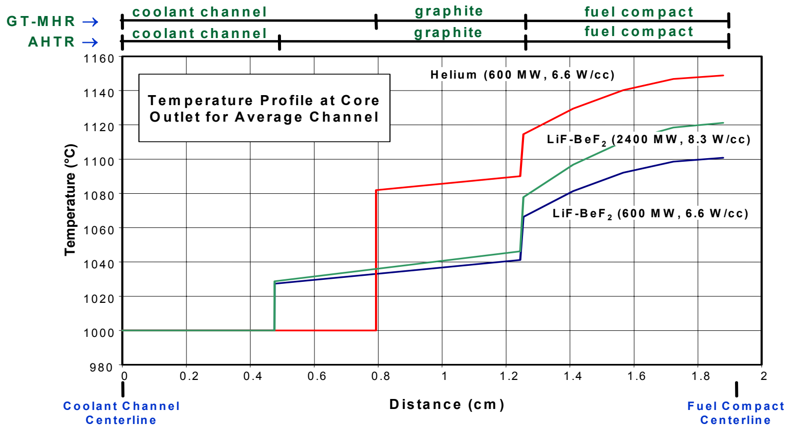


Molten-Salt Coolants Yield Lower Fuel Temperatures than Gas Coolants



Similar Reductions In Temperature Drops Across All Heat Exchangers

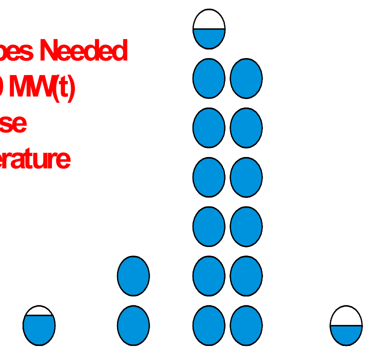
AHTR Peak Temperatures are Significantly Lower than Gas-Cooled Reactors for Heat Delivered at the Same Temperatures*



←Better Heat Transfer

Number of 1-m-dia. Pipes Needed To Transport 1000 MW(t) With 100°C Rise In Coolant Temperature

Better Transport of Heat→



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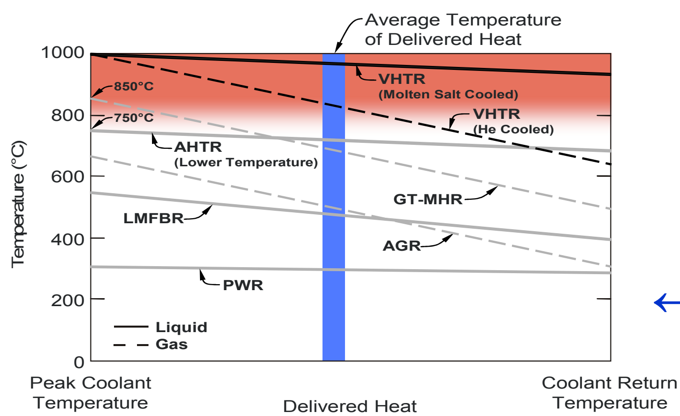

←Heat Delivered at Higher Temperatures

***Critical for Hydrogen Production**

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