How Large Can Reactors Be Built Without The Possibility Of A Core-Melt Accident?

(Advanced High-Temperature Reactor)

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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
  - Passive decay heat cooling
  - Fuel to survive beyond-design-basis accidents

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)

Key Reactor Characteristics

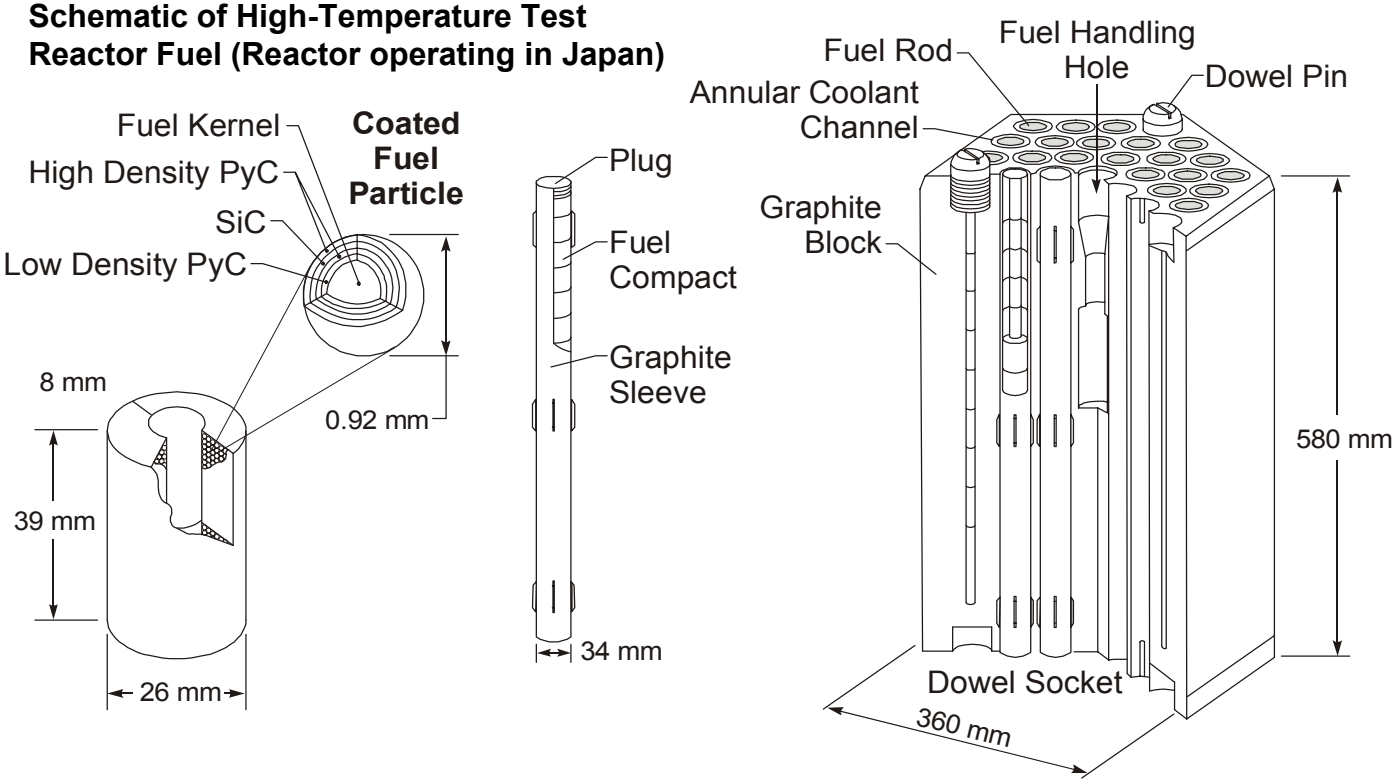
Reactor fuel

Reactor coolant

The AHTR Uses Coated-Particle Graphite Fuels

(Similar to Helium-Cooled Reactors; Failure Temperature >1600ºC)

Schematic of High-Temperature Test Reactor Fuel (Reactor operating in Japan)

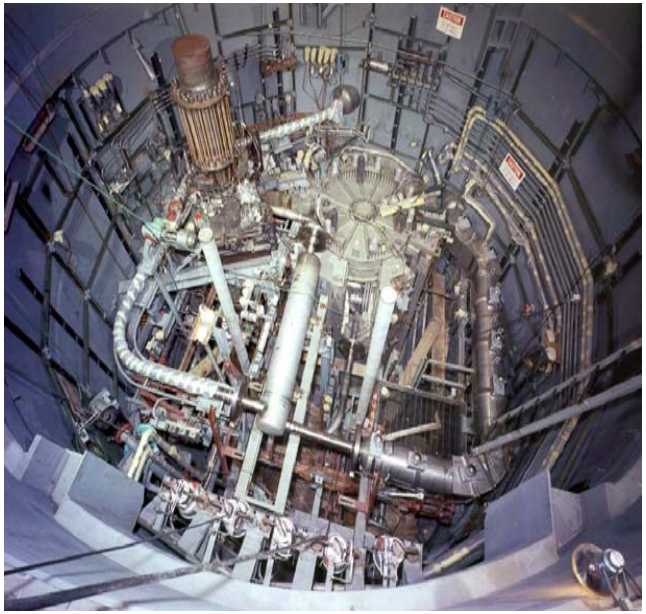


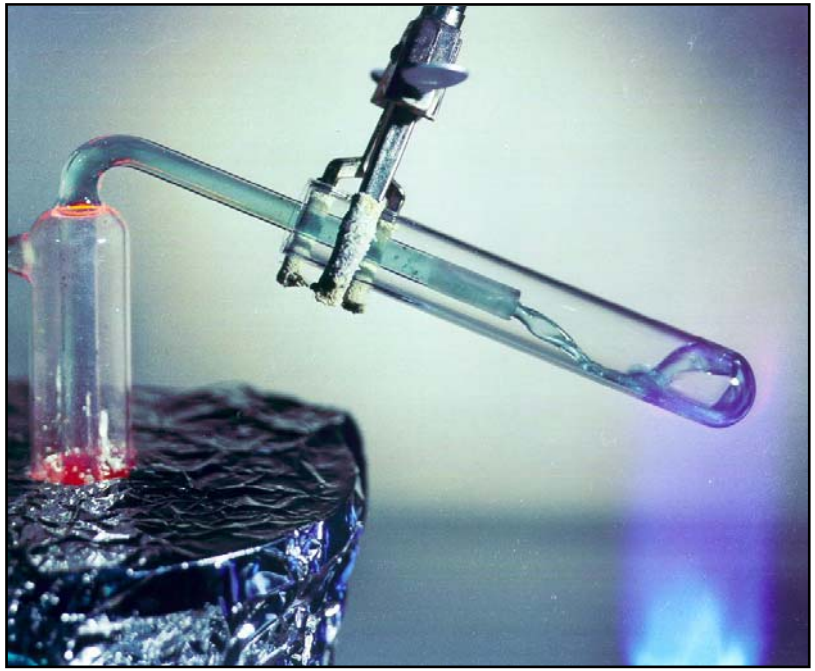
Fuel Compact **Fuel Rod** **Fuel Block**

The AHTR Uses A Molten Salt Coolant

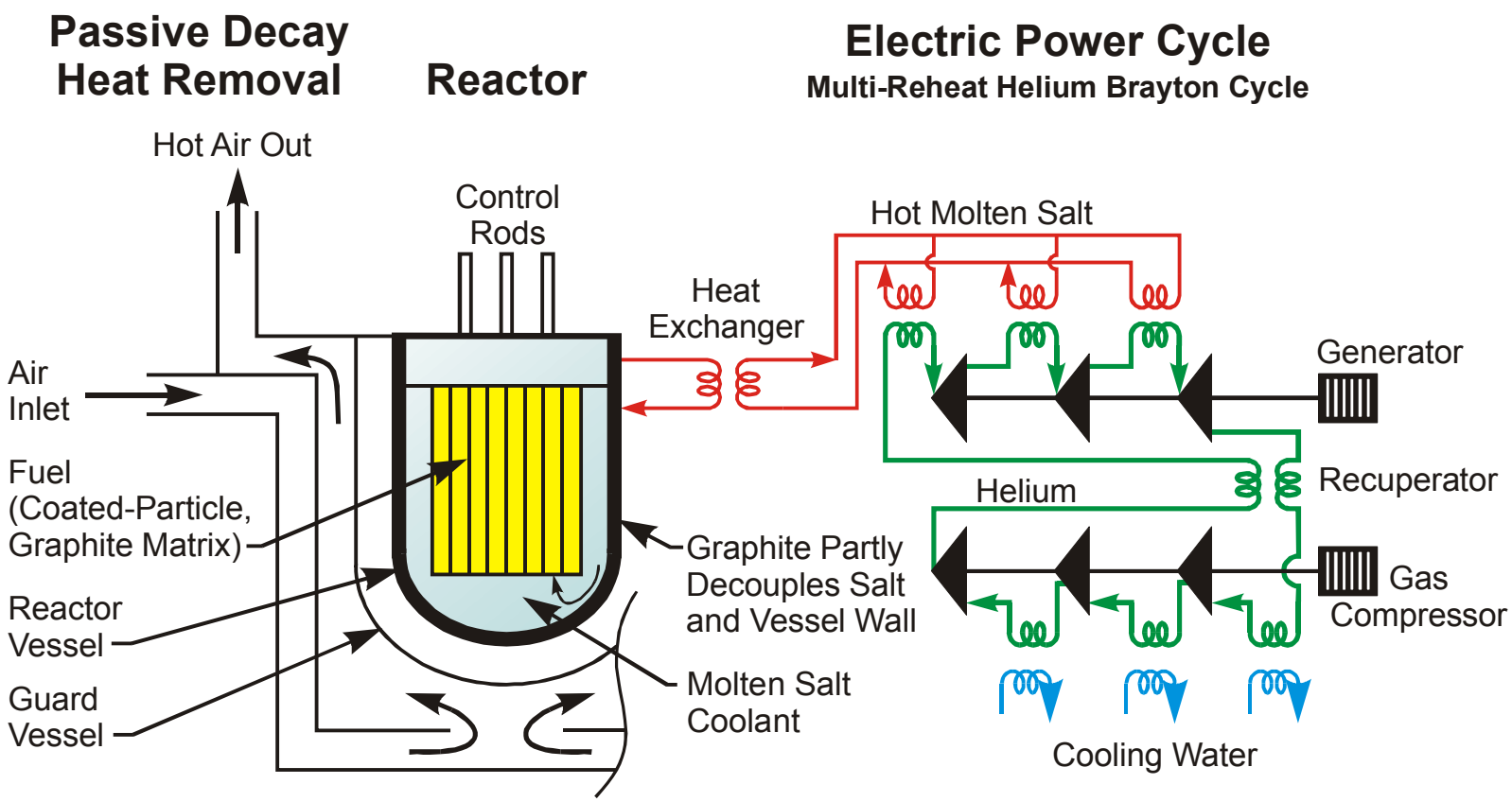
Good Heat Transfer, Low Pressure Operation, In-Service Inspection, and Boiling Point ~1400ºC

MSRE Intermediate Heat Transfer Loop Used Clean Salt

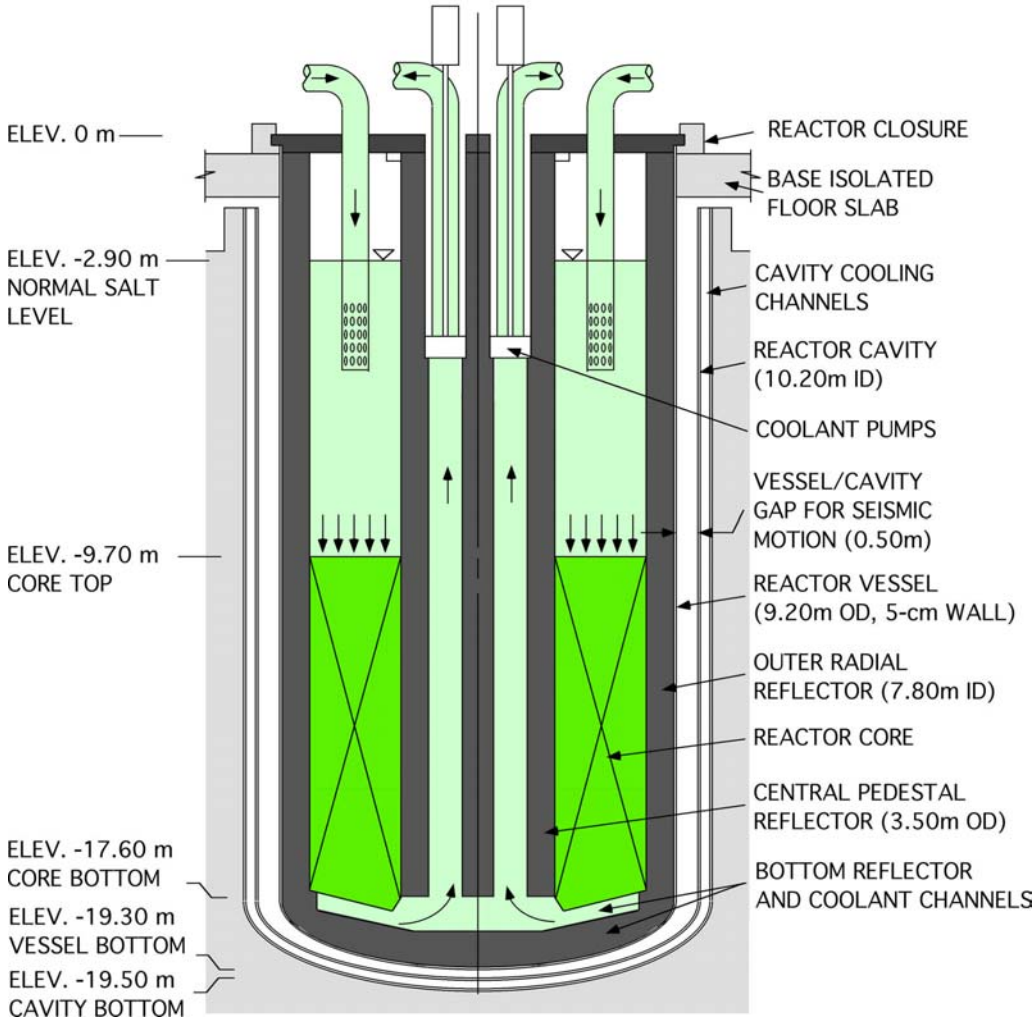




The Advanced High Temperature Reactor

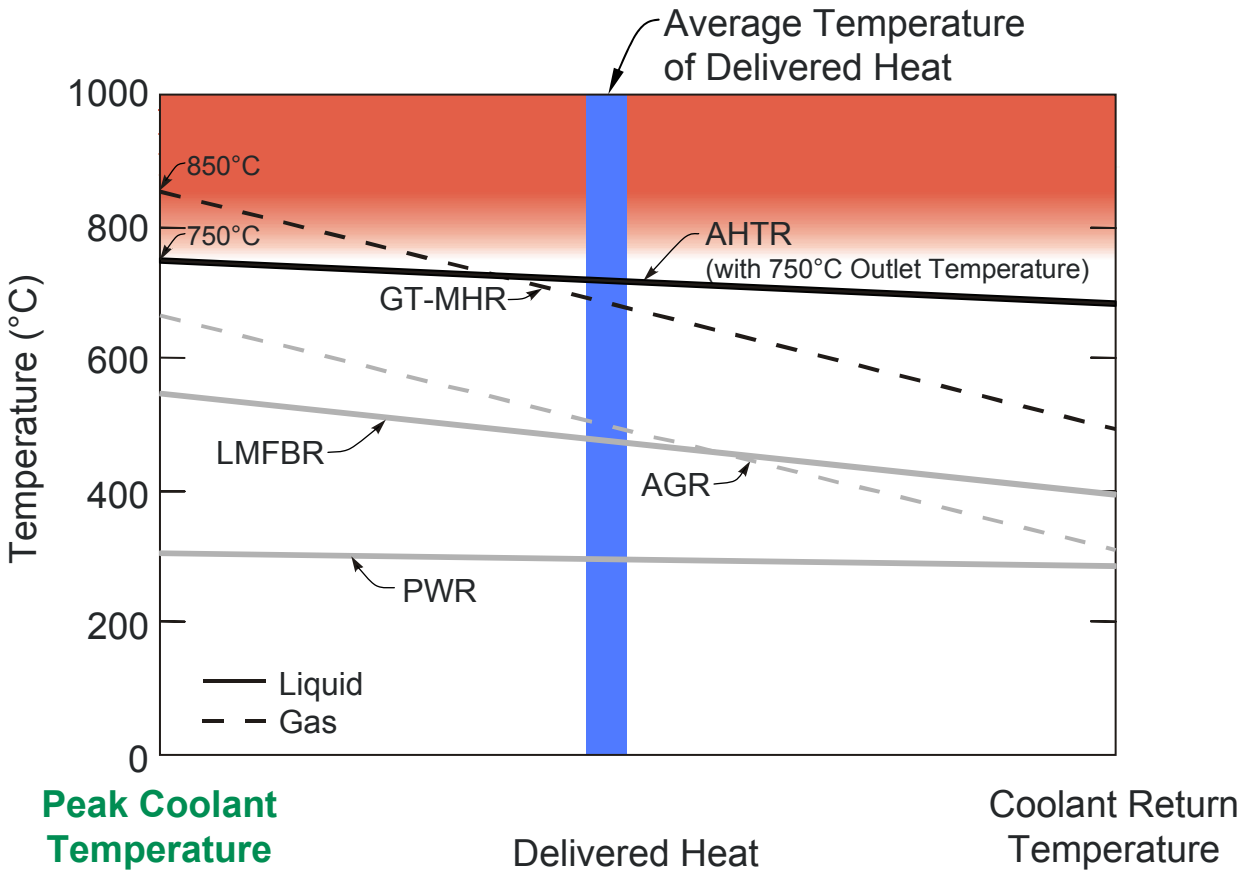


Conceptual 2400 MW(t) AHTR Design



- **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**

AHTR Lowers Peak Coolant Temperatures For A Given Temperature Of Delivered Heat



Passive Safety

Decay Heat to the Reactor Vessel Wall With Silo Cooling

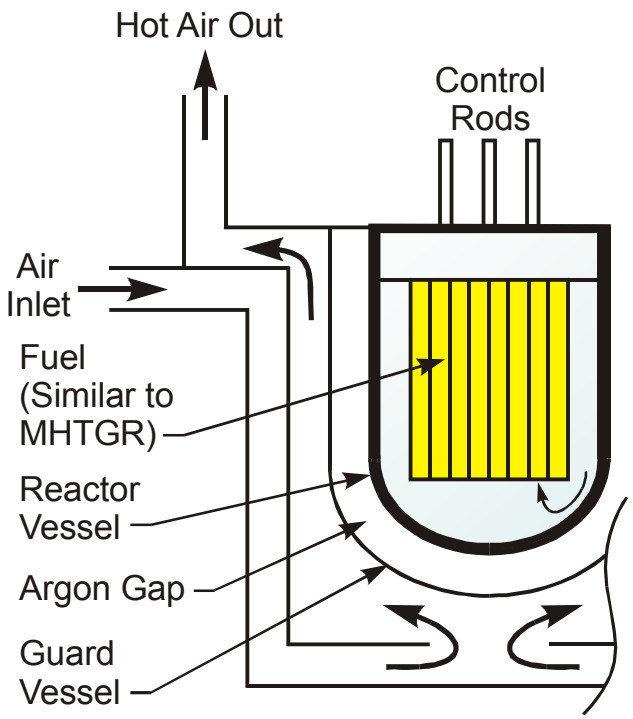
Same approach as Modular High-Temperature Gas-Cooled Reactors and the General Electric Sodium-Cooled Modular S-PRISM

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**

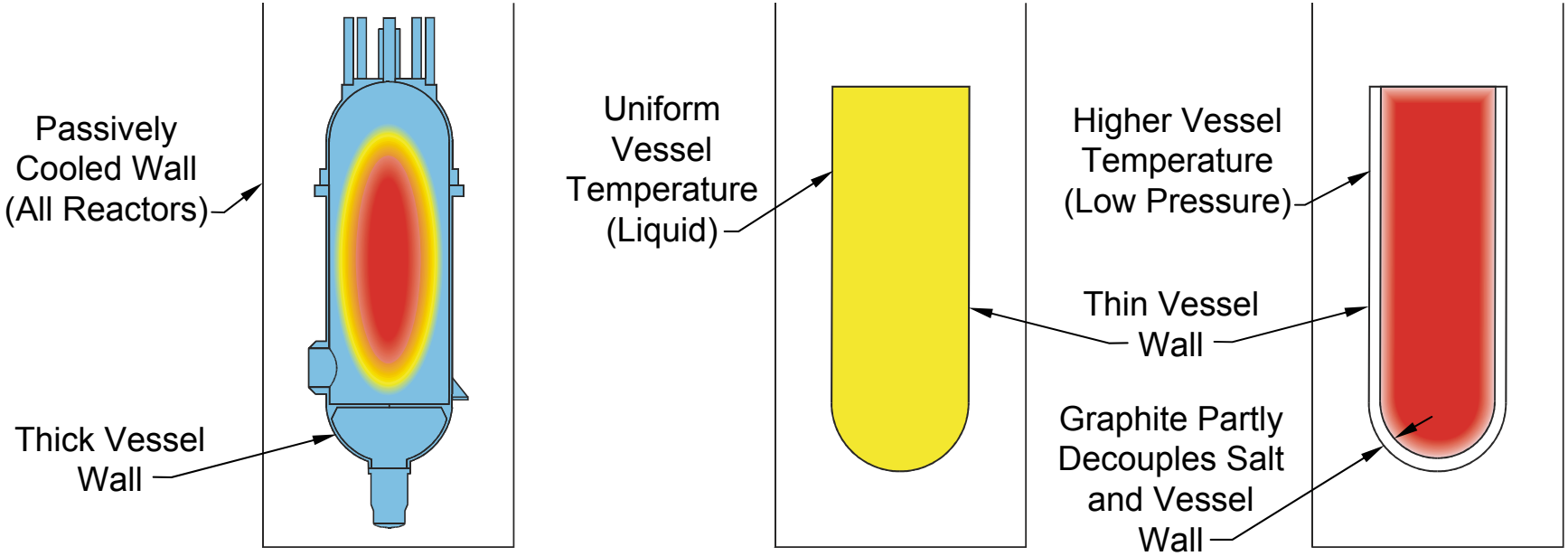


Decay-Heat Cooling System Characteristics

- 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



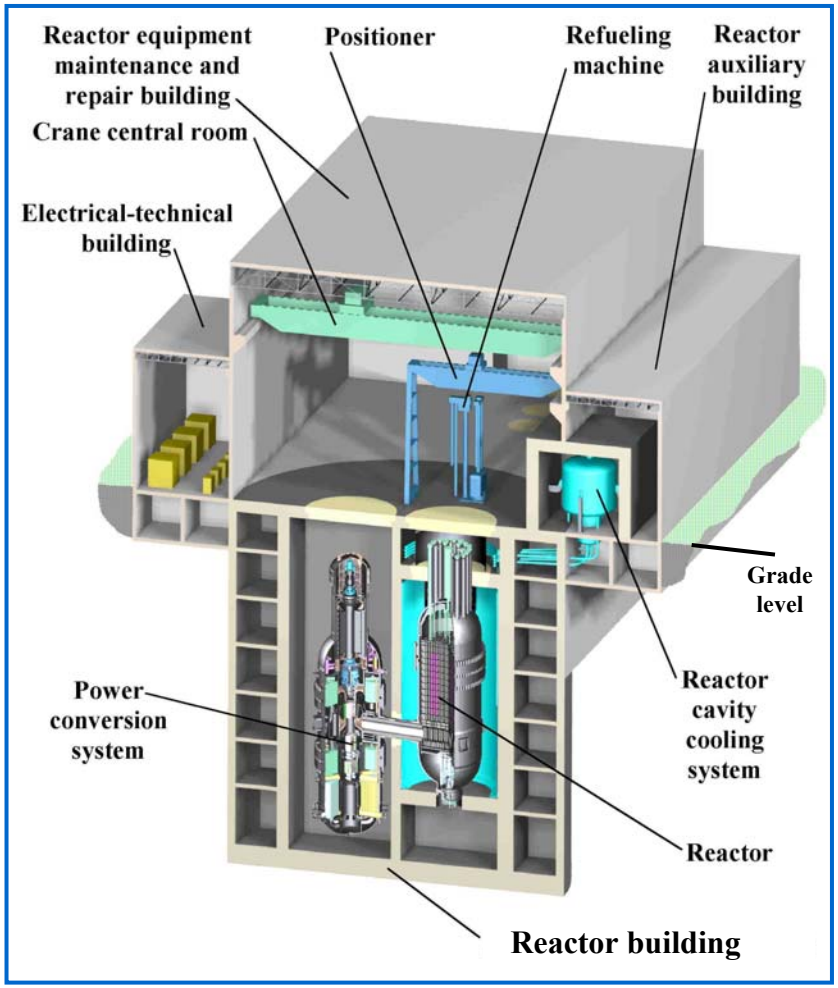
Beyond-Design-Basis Accident (BDBA)

Goal: No major fuel failures after failure of the decay-heat system and structural systems

Same strategy as 600 MW(t) Modular High-Temperature Gas-Cooled Reactor (MHTGR)

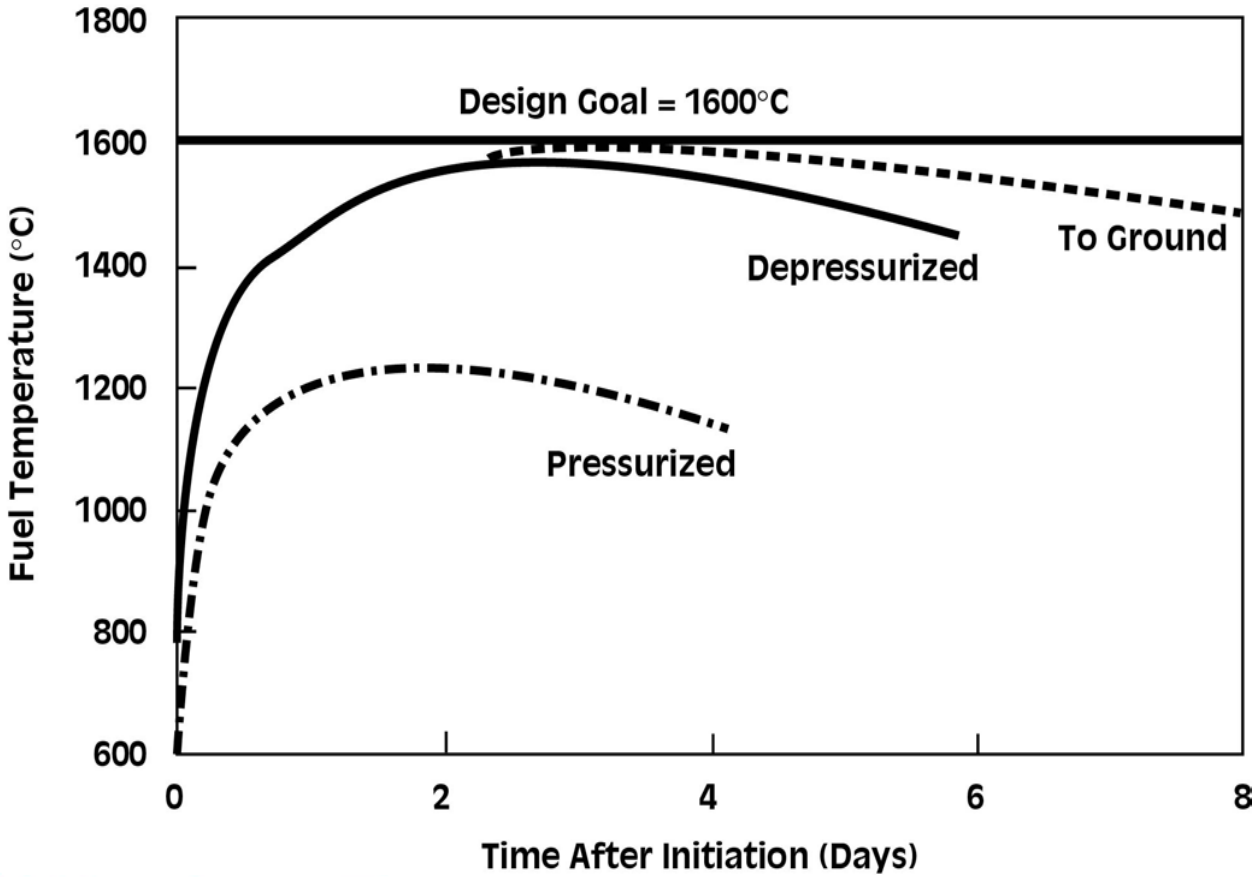
If The Goal Is To Withstand All Accidents, Reactor Size Is limited (MHTGR Example)

- To prevent radionuclide releases, must not have catastrophic fuel failures
- If catastrophic fuel failure is to be prevented in an accident, the fuel must not overheat
- Decay heat raises fuel temperature
- Capability to remove decay heat under all circumstances determines the largest reactor that can be built with beyond-design-basis safety
- MHTGR (helium cooled) decay heat is conducted to ground in a beyond design basis accident (BDBA)



The Maximum Size MHTGR (Gas Cooling) With BDBA Safety Is 600 MW(t)

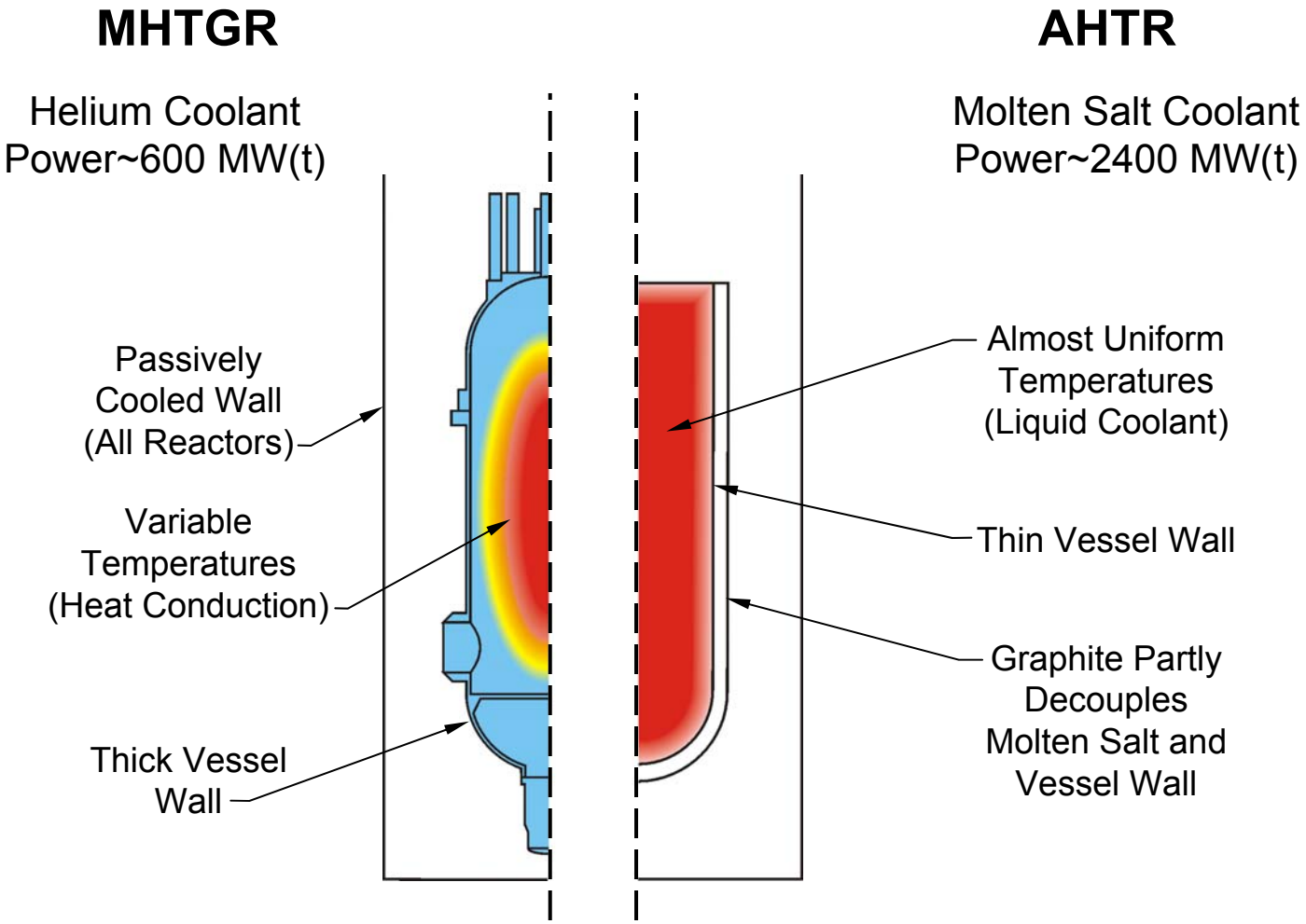
(Fuel Temperature Limit is 1600ºC)



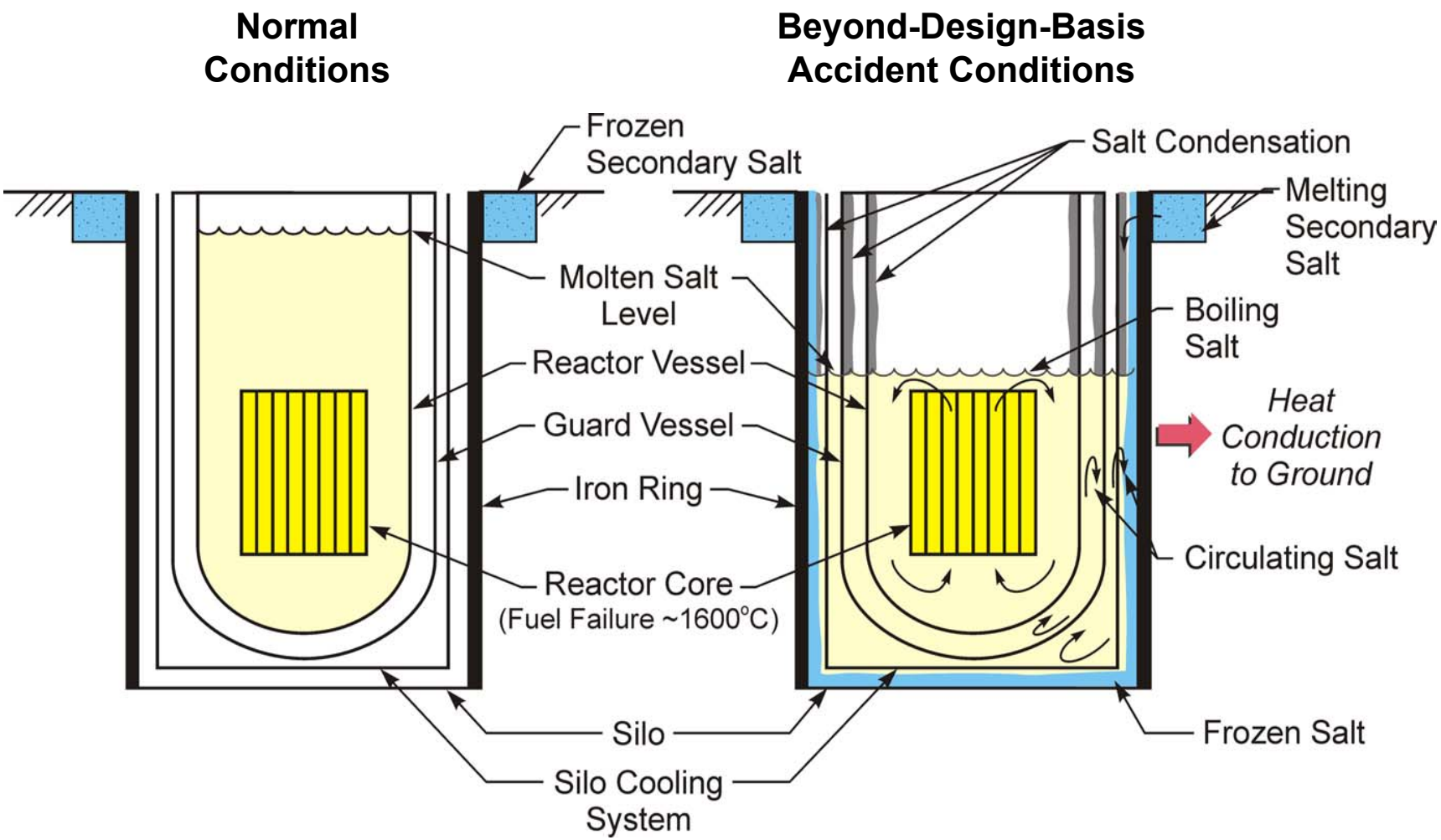
A 2400 MW(t) AHTR May Withstand BDBAs Without Fuel Failure

- Reactor vessel heat up
- Vessel Failure
- Silo wall heat conduction
- Secondary salt melting
- Heat Conduction to earth

The MHTGR (600 MW(t)) And AHTR (2400MW(t)) Have Similar Decay-Heat Vessel Heat-Up Rates



Beyond-Design-Basis Accident Avoids Catastrophic Fuel Failure By Decay-Heat Conduction To The Environment



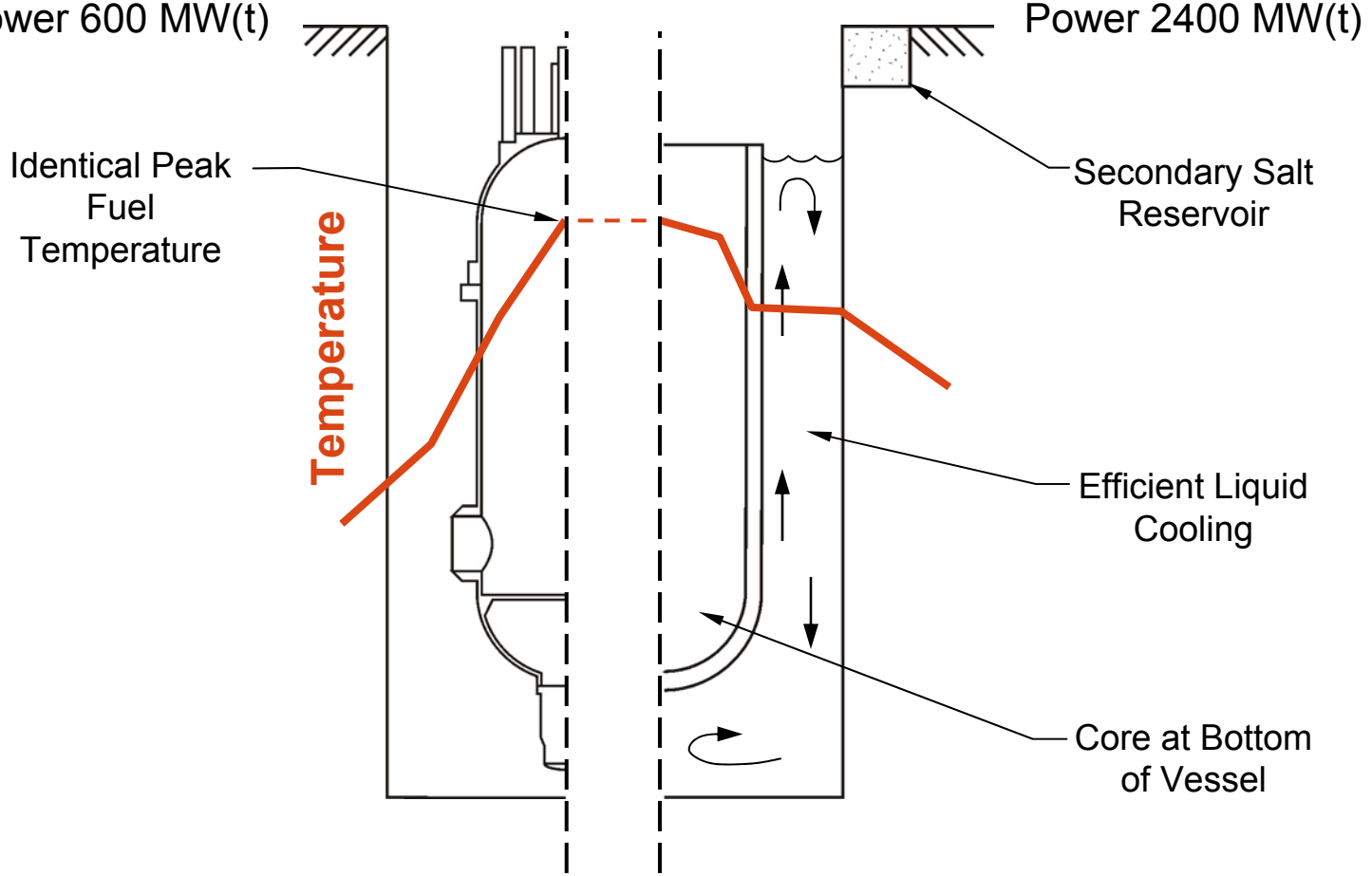
Liquid Cooling Results In More Efficient Heat Transfer To The Silo Wall

MHTGR

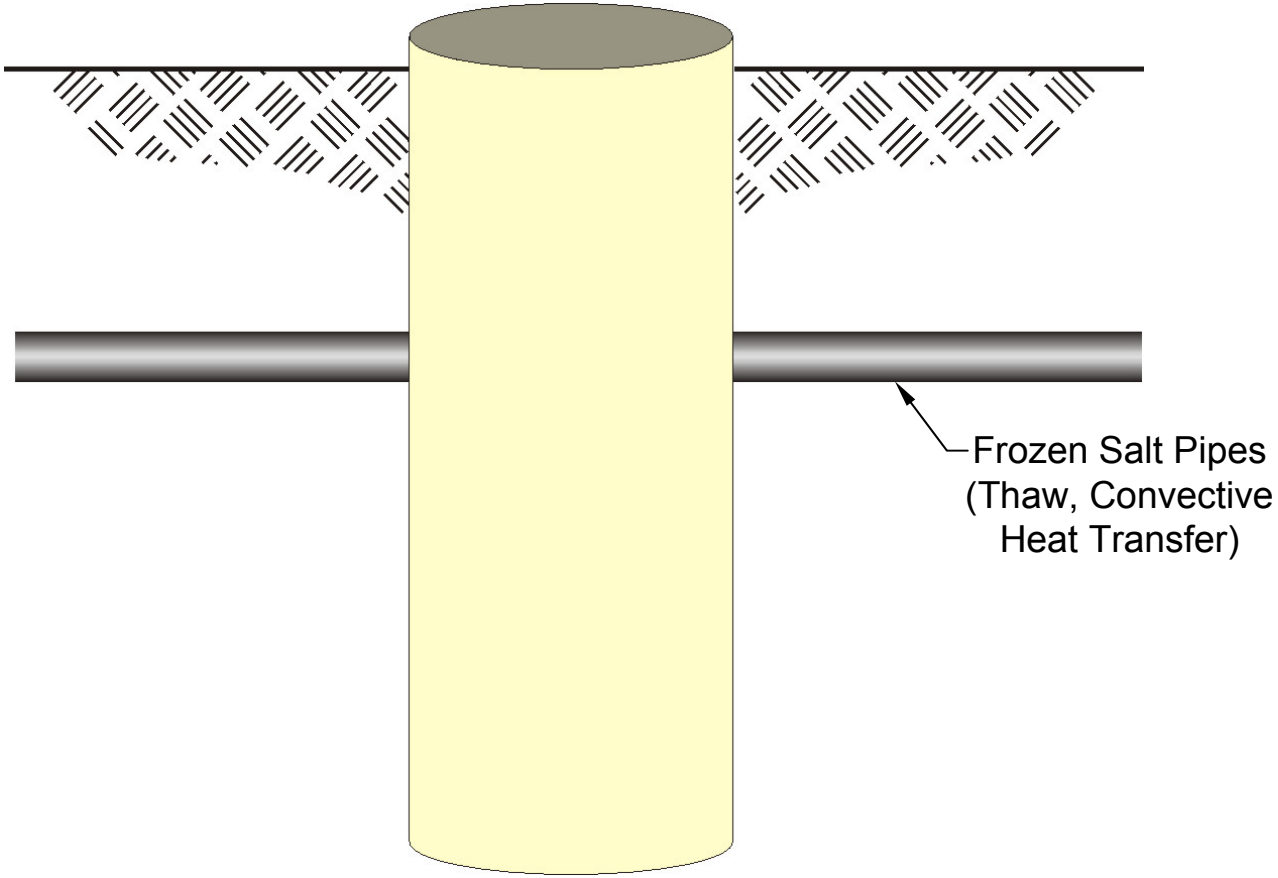
Helium Coolant
Power 600 MW(t)

AHTR

Molten Salt Coolant
Power 2400 MW(t)



Many Options Exist To Boost Decay Heat Removal With A Silo Full Of Molten Salt



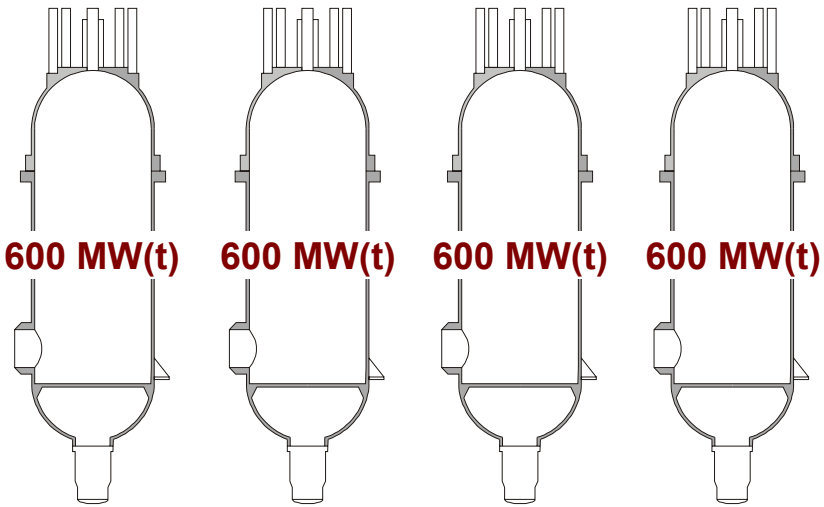
Economics

Larger Reactors Have the Potential for Lower Capital and Operating Costs

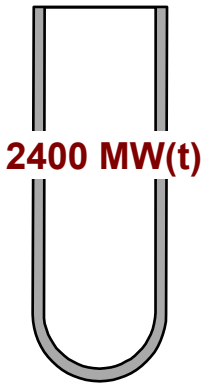
Molten Salt Preferred for Heat Transfer From Any Reactor to Hydrogen Plant

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

Conclusions

- AHTR goals
  - Improve economics with larger high-temperature reactor
  - Same passive safety basis as modular reactors
    - Passive decay-heat removal
    - BDBA decay heat removal (no catastrophic fuel failure)
- Technology based on
  - High-temperature fuel (Failure temperature >1600ºC)
  - Low-pressure high-temperature coolant
    - Molten fluoride salt
    - Boiling point ~1400ºC
- New reactor concept
  - Early in development
  - Major uncertainties