Liquid-Salt-Cooled Very-High-Temperature Reactor

(Advanced High Temperature Reactor)

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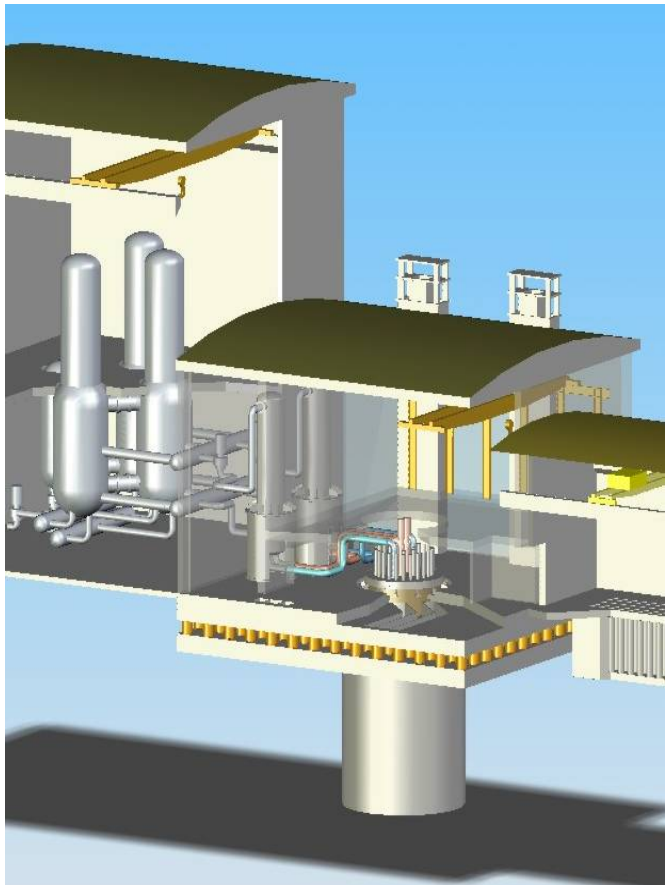

Briefing for Dixon Butler
House Energy and Water Development Subcommittee
U.S. Congress

Washington, D.C.
July 19, 2005

OAK RIDGE NATIONAL LABORATORY

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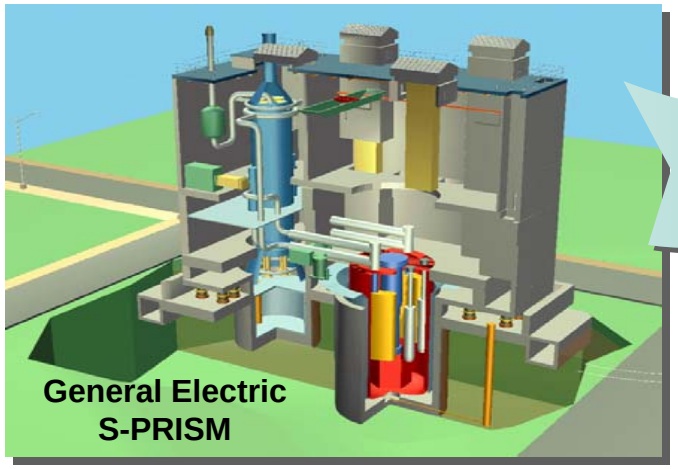
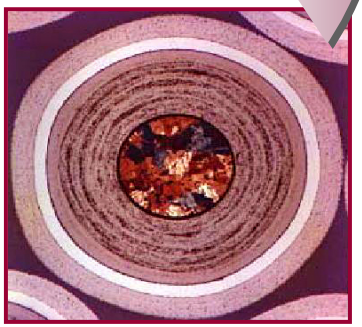
The Advanced High-Temperature Reactor

Combining Existing Technologies in a New Way



Passively Safe Pool-Type Reactor Designs

Brayton Power Cycles (All High-Temperature Reactors)

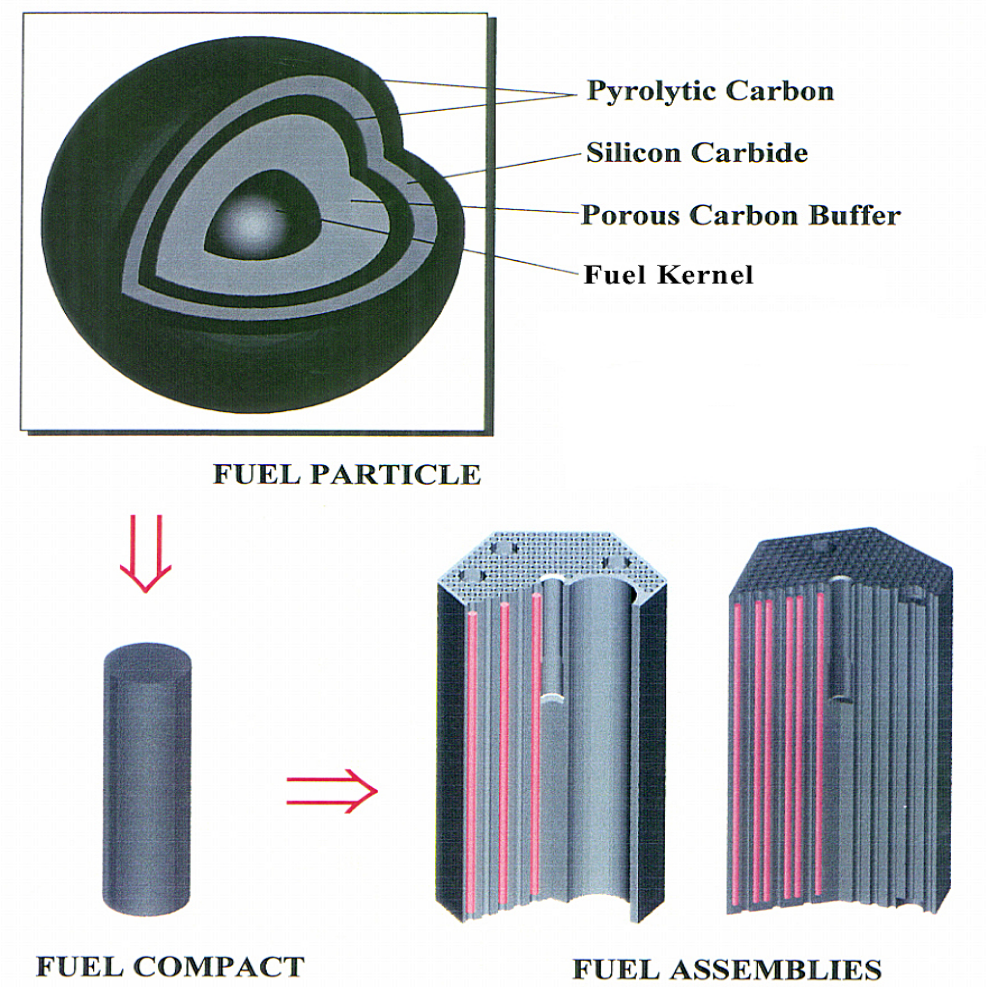


High-Temperature Coated-Particle Fuel

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

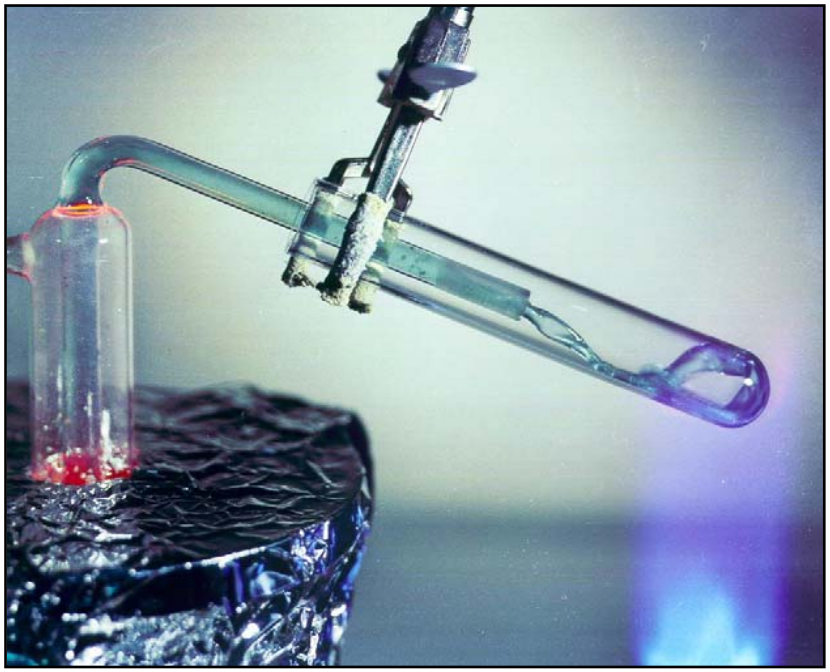
There is Only One Class of Demonstrated High-Temperature Reactor Fuels

Coated-Particle Graphite-Matrix Fuel



Liquid-Salt- and Helium-Cooled High-Temperature Reactors Use The Same Fuel Type

Two Coolants are Compatible with Graphite Materials and High-Temperature Operations



Helium

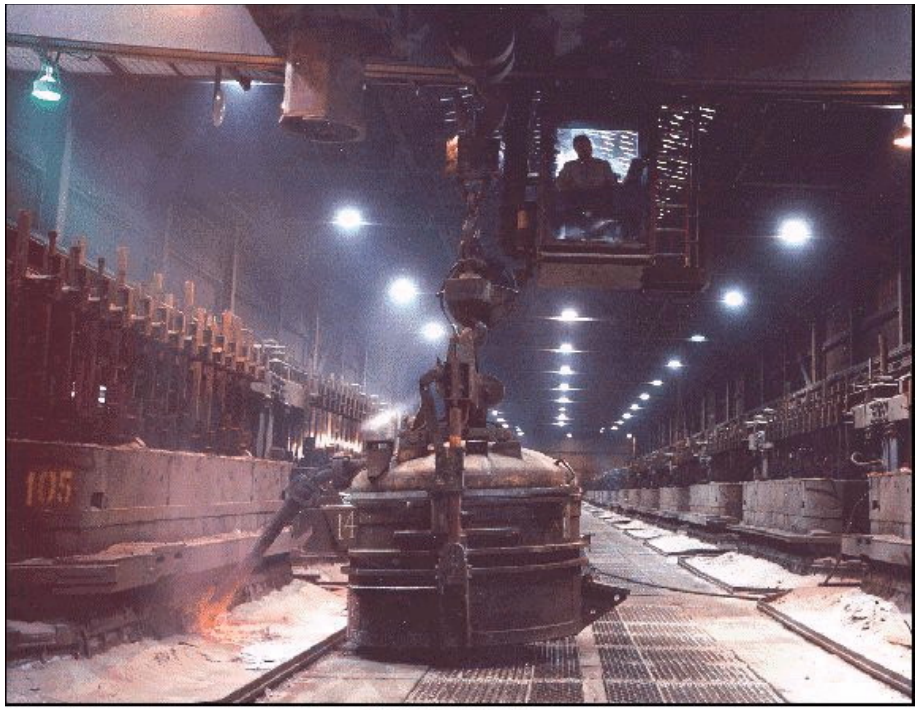
(High Pressure/Transparent)

Liquid Fluoride Salts

(Low Pressure/Transparent)

Liquid Fluoride Salts have been Used for a Century to Make Aluminum

- **Aluminum is made by the Hall electrolytic process**
- **Graphite bath is used to contain the salt**
- **Bauxite (aluminum oxide) is dissolved in cryolite (sodium-aluminum fluoride)**
- **Operating temperature ~1000ºC**



Tapping aluminum

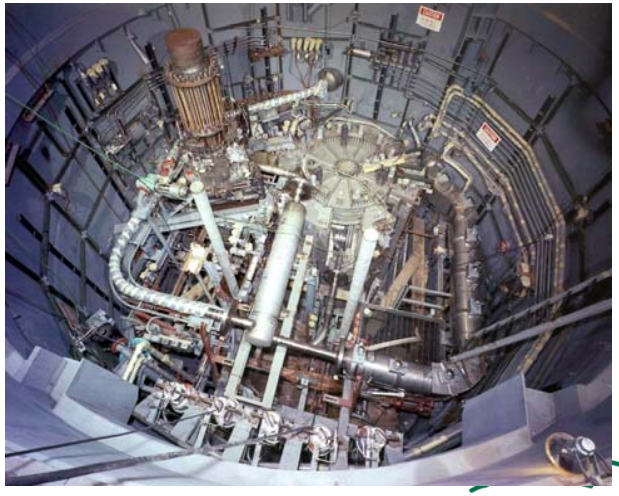
Aluminum is tapped from a Kitimat Works electrolytic-reduction cell into a steel vessel called a crucible. The crucible holds approximately 4,000 kg of aluminum and is used to transfer the molten aluminum to the furnaces in the casting department.

Liquid Salt Coolants Were Developed to Support Several Programs (1950–1970)

Molten Salt Reactors: Fuel Dissolved in Coolant; Intermediate Loops Used Clean Salts (AHTR Uses Clean Salt and Solid Fuel)

Aircraft Nuclear Propulsion Program

← ORNL Aircraft Reactor Experiment
2.5 MW; 882ºC
Fuel Salt: Na/Zr/F



Molten Salt Breeder Reactor Program

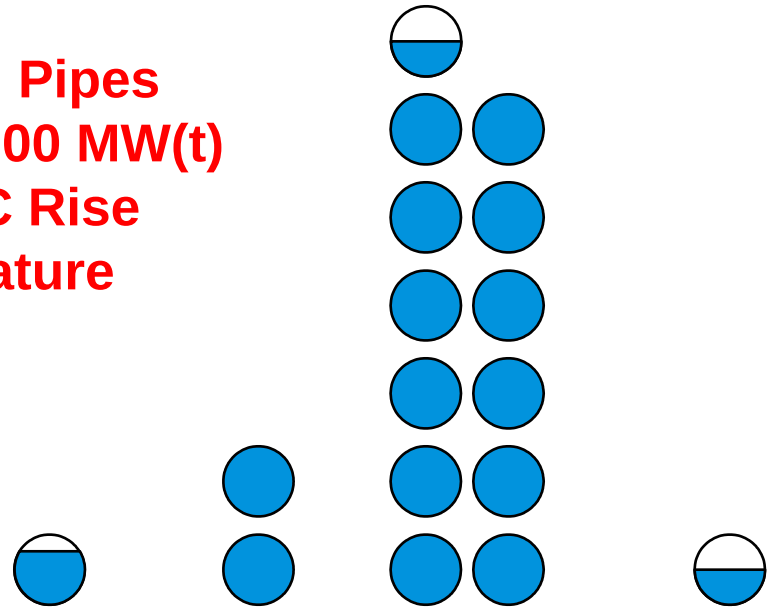
ORNL Molten Salt Reactor Experiment
Power level: 8 MW(t)
Fuel Salt: ^{7}Li/Be/F; *Clean Salt: Na/Be/F*

Air-Cooled Heat Exchangers →

Coolant Properties Determine Pipe, Valve, and Heat-Exchanger Sizes

(Small Equipment with Liquid Coolants)

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

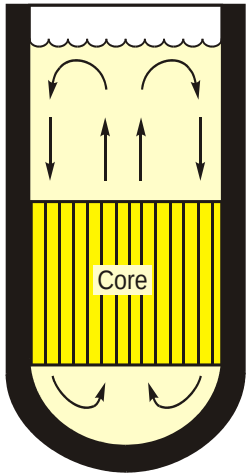


	Water (PWR)	Sodium (LMR)	Helium	Liquid Salt
Pressure (MPa)	15.5	0.69	7.07	0.69
Outlet Temp (ºC)	320	540	1000	1000
Coolant Velocity (m/s)	6	6	75	6

Liquid Cooling Allows Large Reactors With Passive Decay Heat Removed

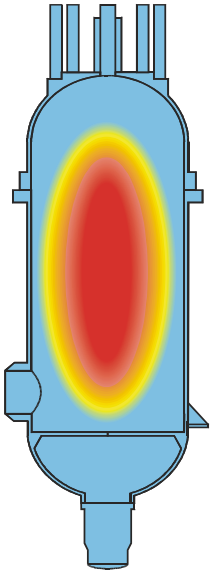
(Alternative Decay Heat Removal Options to Move Heat to Vessel Surface or Heat Exchanger)

Liquid
(1000s of MW(t))



Convective Cooling
(~50º C Difference in Liquid Temperature)

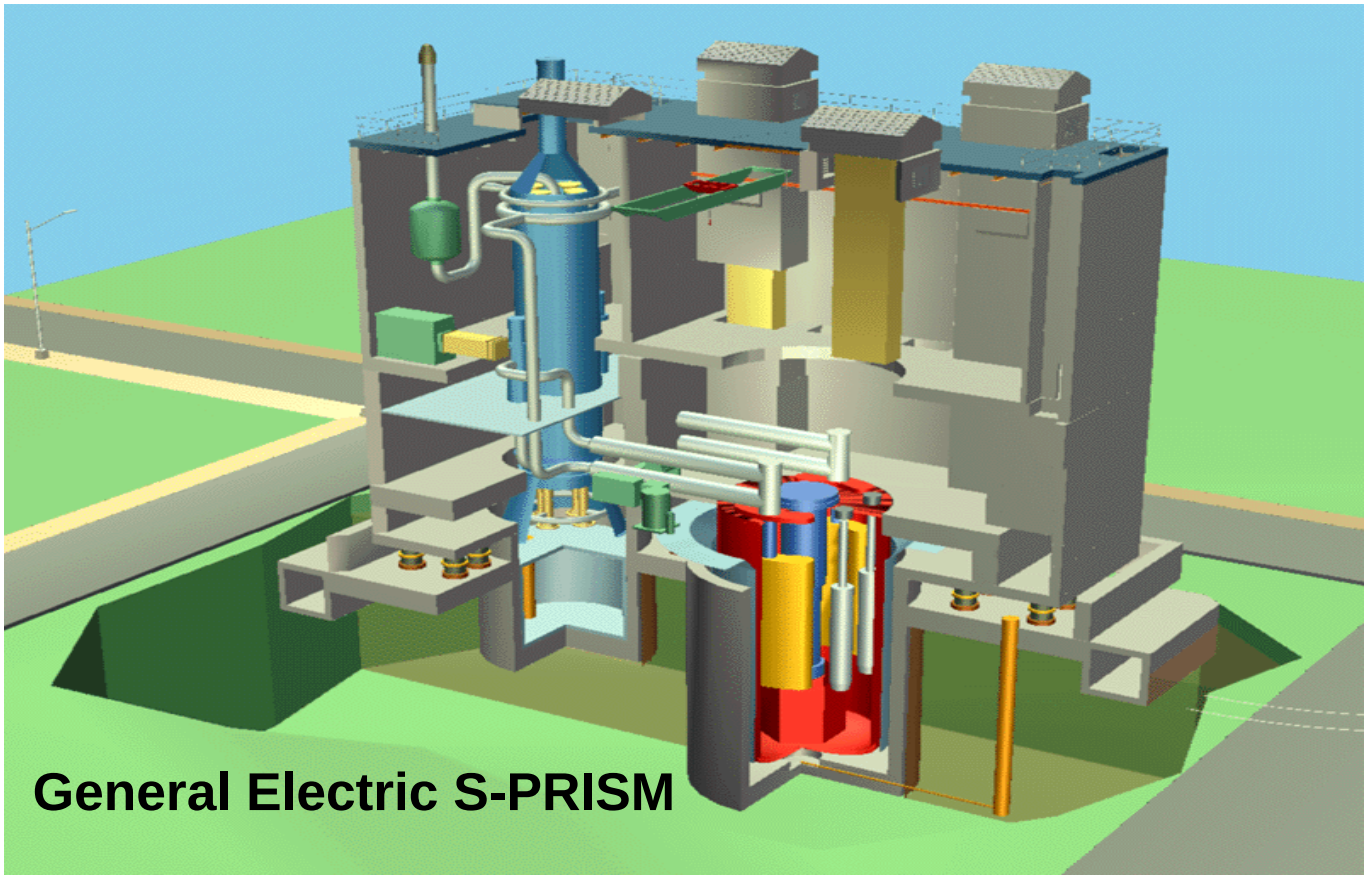
Gas
(~600 MW(t))



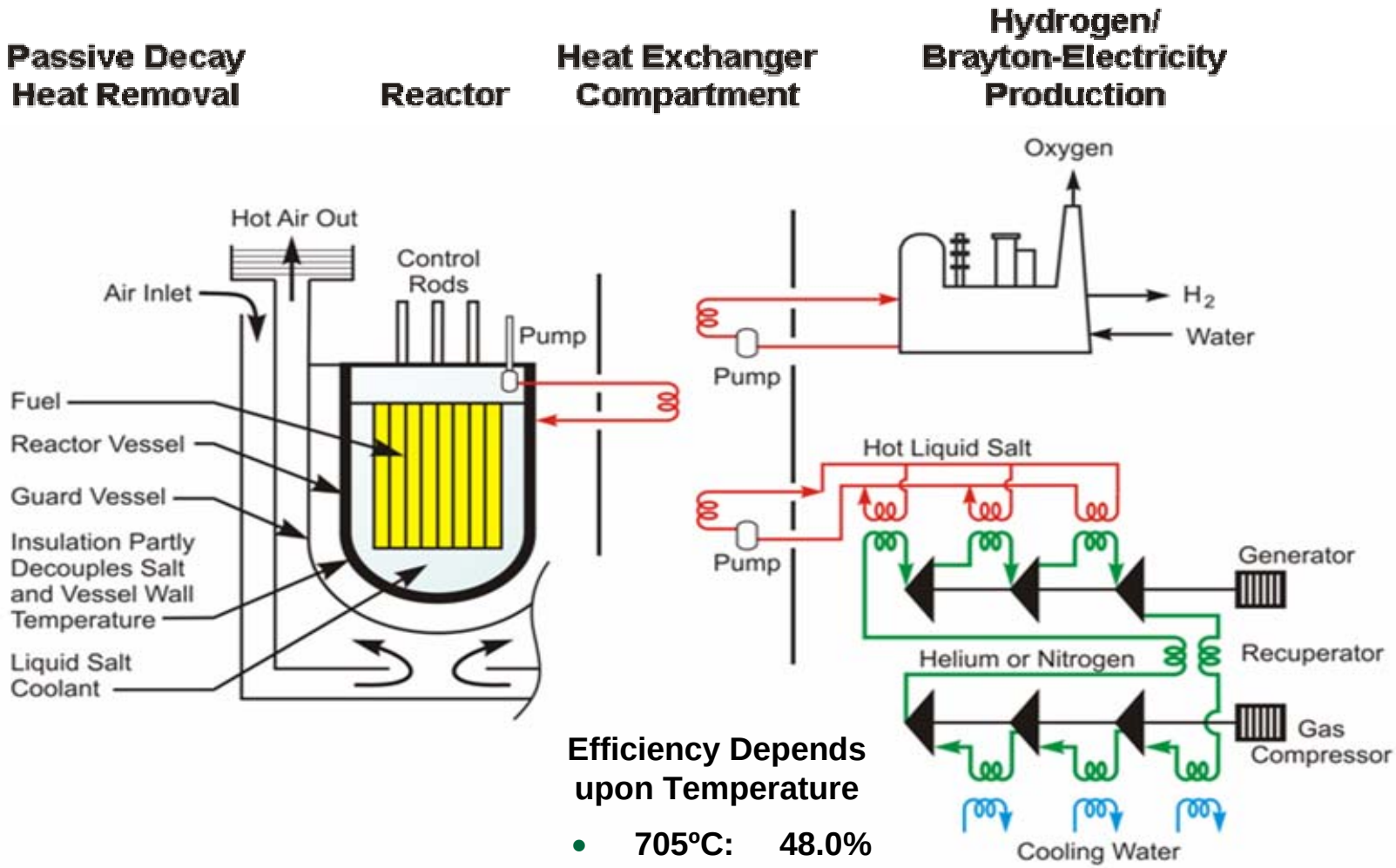
Conduction Cooling
(~1000º C Difference in Fuel Temperature)

AHTR Facility Layouts are Based on Sodium-Cooled Fast Reactors

Low Pressure, High Temperature, Liquid Cooled



Liquid-Salt-Cooled Very-High-Temperature Reactor for Hydrogen/Electricity Production



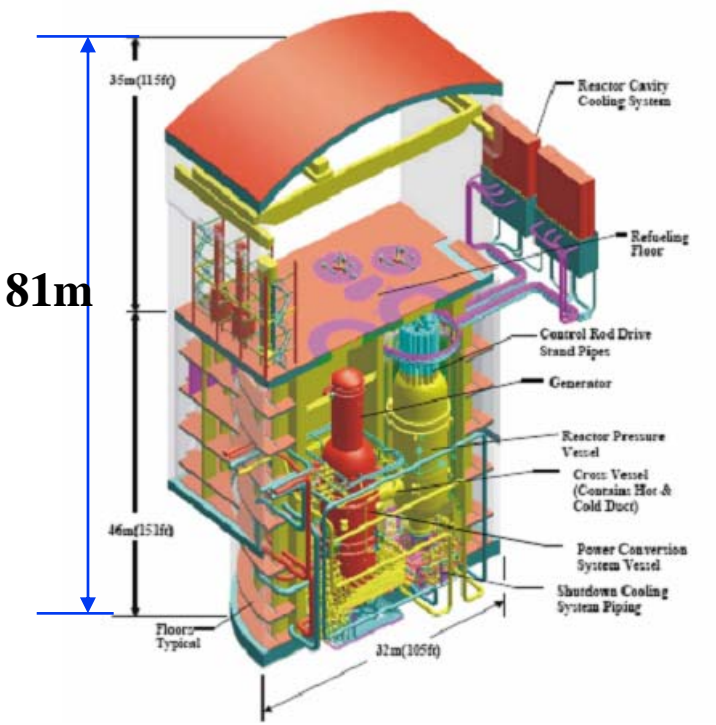
Efficiency Depends upon Temperature

- **705ºC: 48.0%**
- **800ºC: 51.5%**
- **1000ºC: 56.6%**

Economics

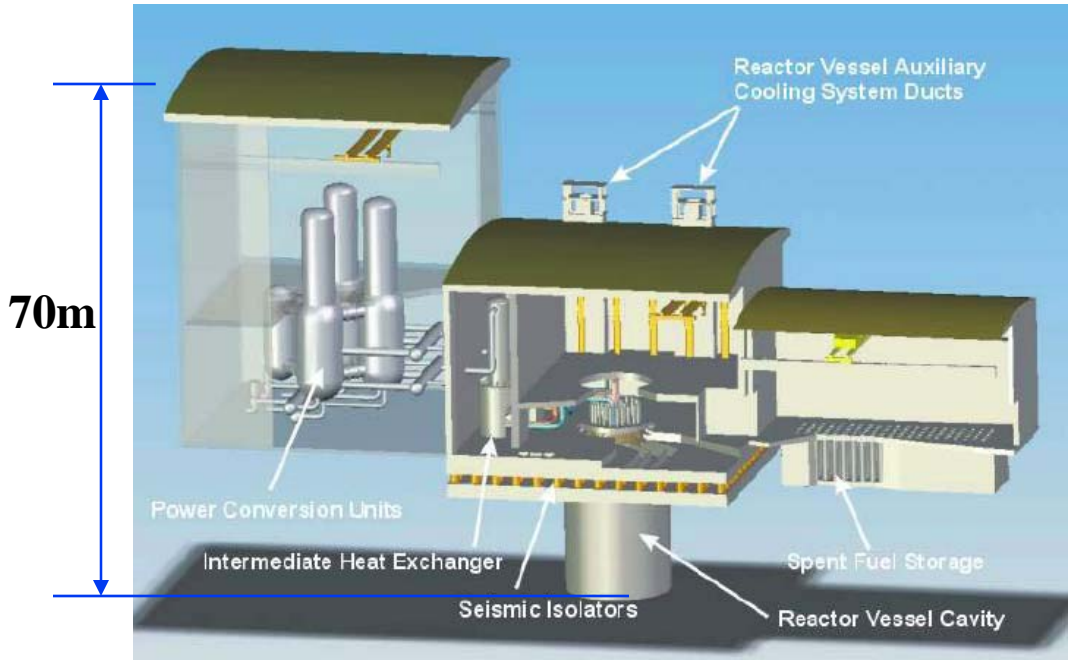
Liquid-Salt Cooling Aids Economics

(Figures to Scale: Liquid Salts Enable Construction of Large Passively-Safe Reactors)



Gas Cooling

Modular (600 MW(t))

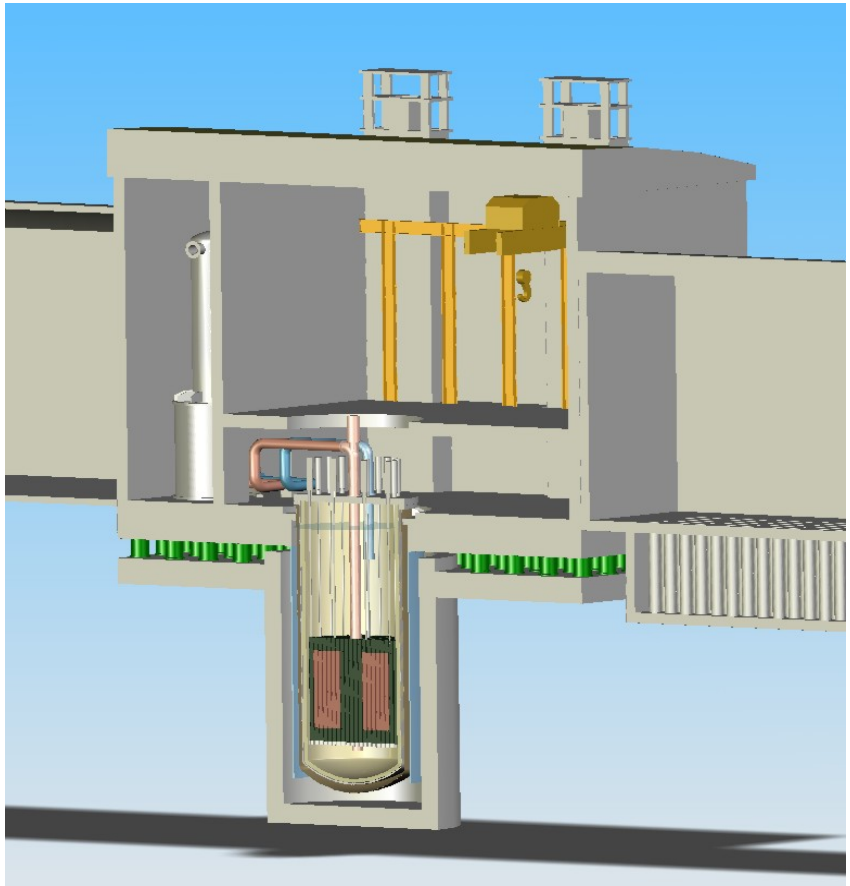


Liquid Cooling

Large Reactor (2400 MW(t))

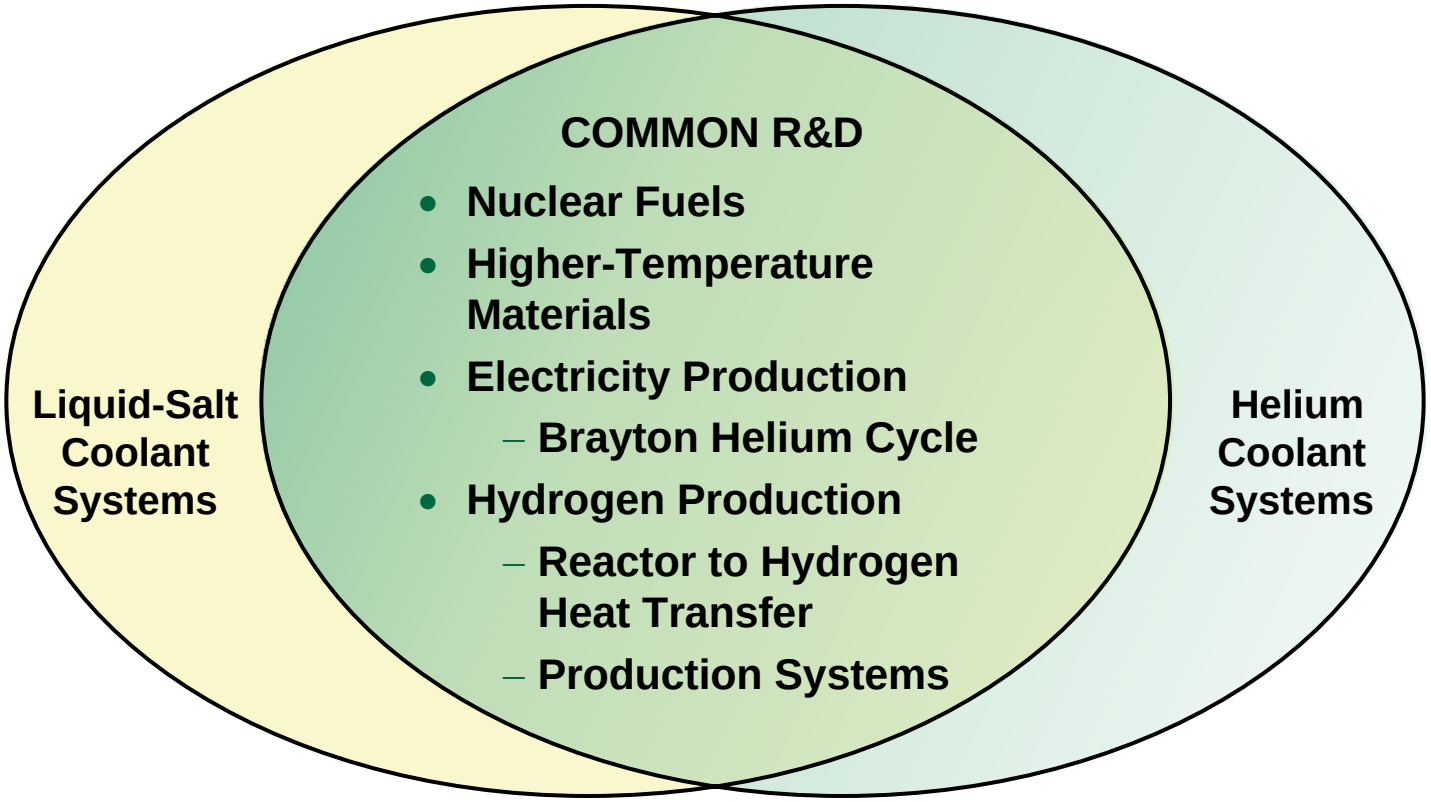
Per Peterson (Berkeley): American Nuclear Society 2004 Winter Meeting

Salt-Cooled Reactor Capital Costs per kW(e) are Estimated to be 50 to 60% of Gas-Cooled Modular Reactors



- **Economics of scale**
  - **Gas-cooled: 300 MW electric**
  - **Liquid-cooled: 1200 MW electric**
  - **Long-term options for larger liquid-cooled reactors**
- **Smaller equipment size with high volumetric heat-capacity fluid**
- **Higher efficiency multi-reheat Brayton cycle**
- **No high-pressure vessel**

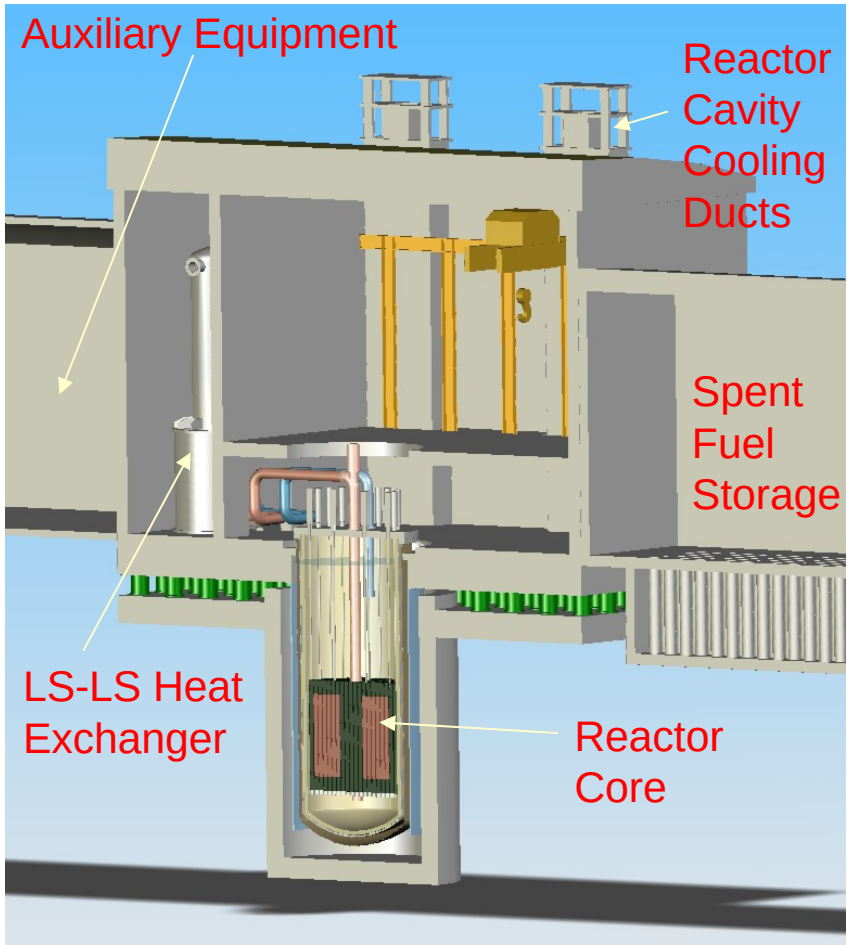
The Research and Development (R&D) Requirements for the Liquid-Salt- Cooled and Helium-Cooled Very-High-Temperature Reactors have Much in Common



Liquid-Salt-Cooled Reactor R&D Challenges

- ***New reactor concept using existing technologies in a new way***
  - ***No salt-cooled reactor has been built***
  - ***Many gas-cooled reactors have been built***
- **Materials: Needs are goal dependent**
  - **Qualified materials to 750ºC**
  - **Significant R&D required for >900ºC**
- **Reactor core design**
  - **Salt selection and processing (several options)**
  - **Neutronics**
- **Refueling temperatures 350 to 500ºC (avoid salt freezing)**
- **Need for small pilot-plant reactor to test concept**

Conclusions



- **Goals**
  - **High temperature**
  - **Passive safety**
  - **Superior economics**
- **Technology**
  - **Combines four existing technologies**
  - **Shares key technologies with gas-cooled reactors**
- **Vendor interest**
  - **General Electric**
  - **Framatome ANP**
- **Significant development and demonstration remains**

Backup Slides

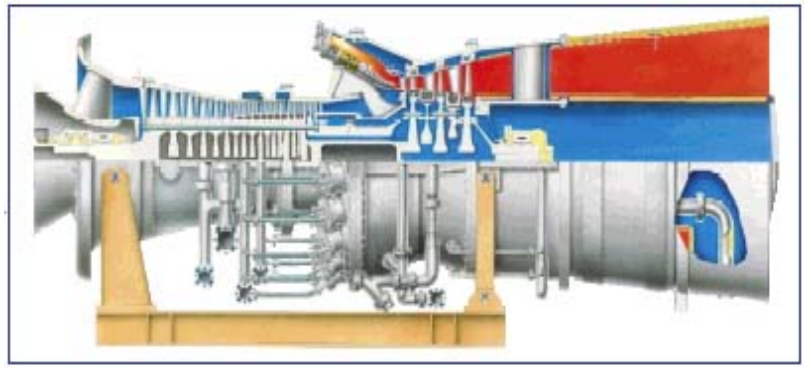
Backup Slides

Backup Slides

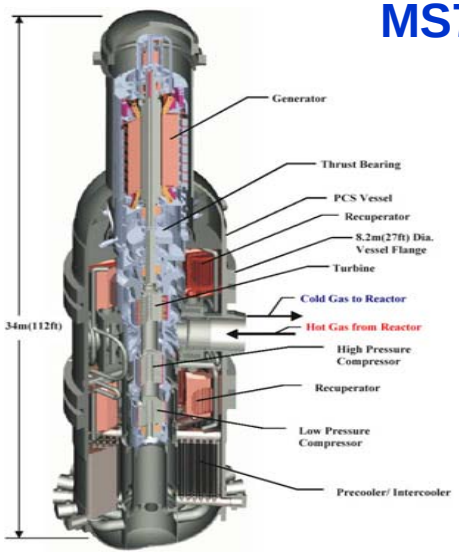
Why Were There No Earlier Programs To Develop Salt-Cooled Very-High-Temperature Reactors?

There is New Interest in High-Temperature Reactors Because of Brayton Technologies and Hydrogen Generation

- **High-temperature heat for a utility is only useful if it can be converted to electricity**
- **Steam turbines (with a 550ºC peak temperature) have been the only <u>industrial method</u> to convert heat to electricity**
- **Development of large efficient high-temperature Brayton cycles *<u>in the last decade</u>* makes high-temperature heat useful for electricity production**



GE Power Systems MS7001FB



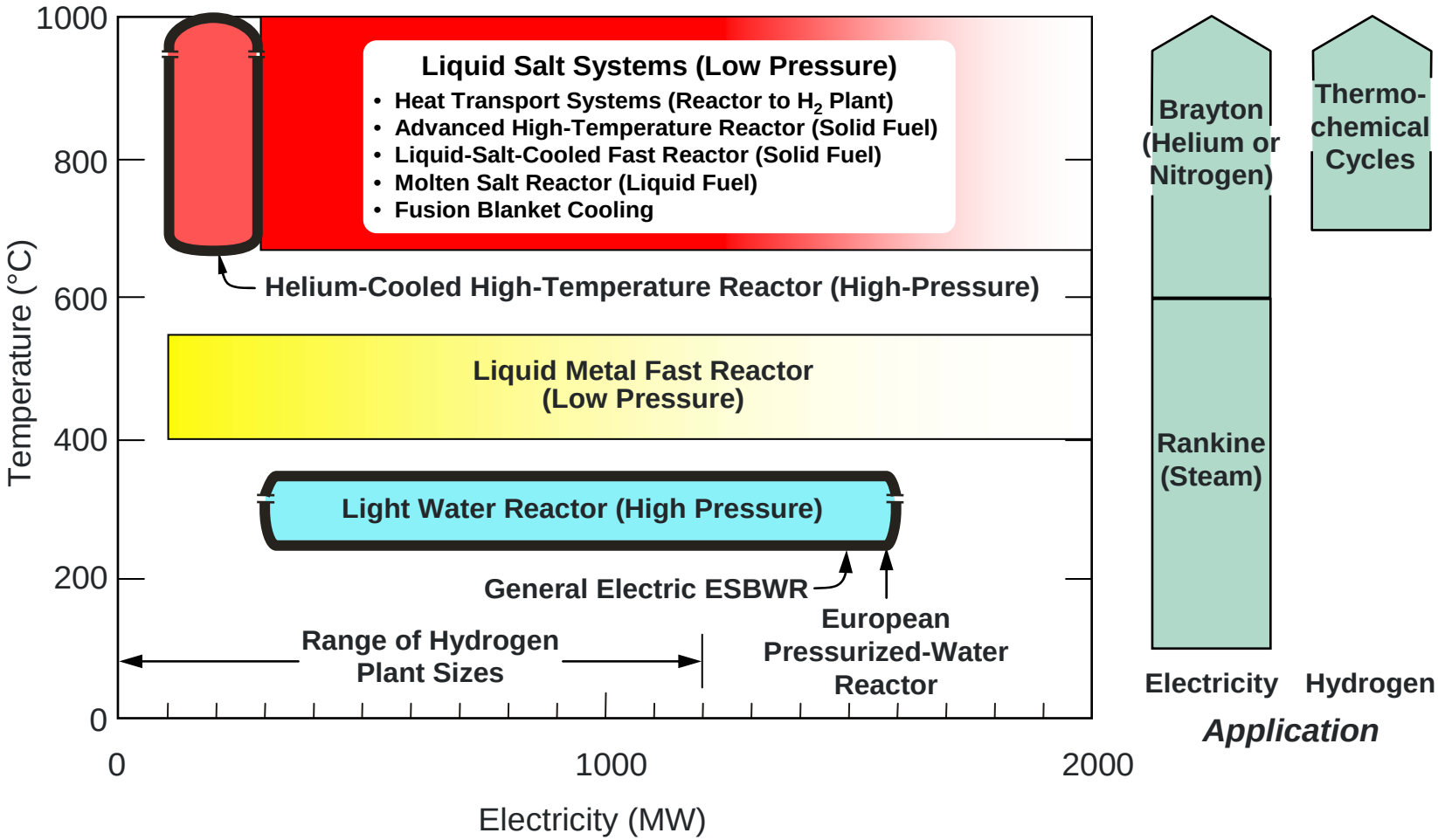
General Atomics GT-MHR Power Conversion Unit (Russian Design)

Salt-Cooled Reactors are Intrinsically High-Temperature Reactors

- **Freezing points are between 350 and 500ºC**
  - **Fluoride salts**
  - **Freezing point dependent on salt composition**
- **Not suitable for a lower-temperature reactor**
- **No incentive to consider salt cooling until the development of high-temperature Brayton power cycles or a need for hydrogen production**

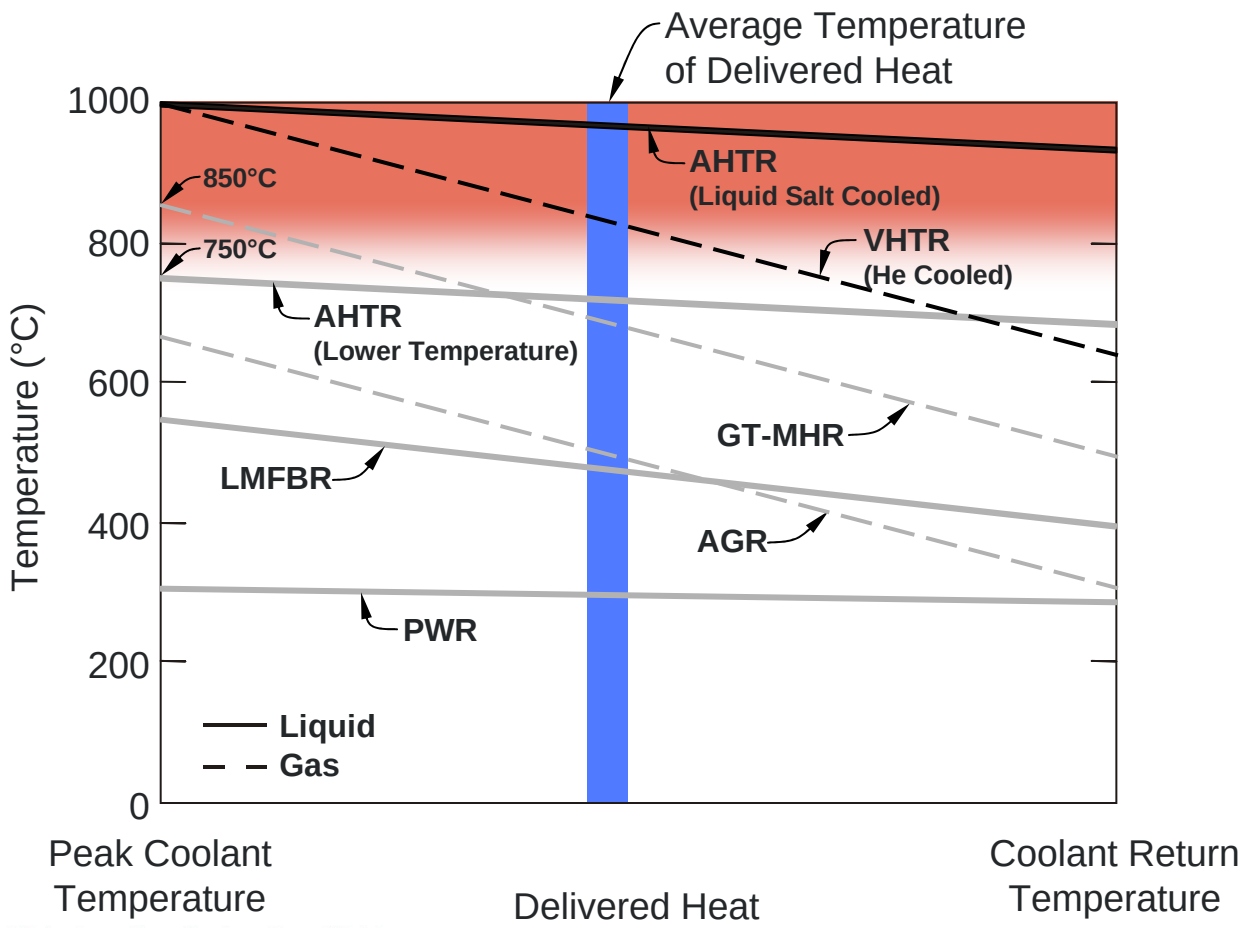
Liquid Salt Coolants can be Used for Many High-Temperature Reactors

(Liquid Salt Reactors: Clean Coolant with Solid Fuel or Fuel in Coolant)



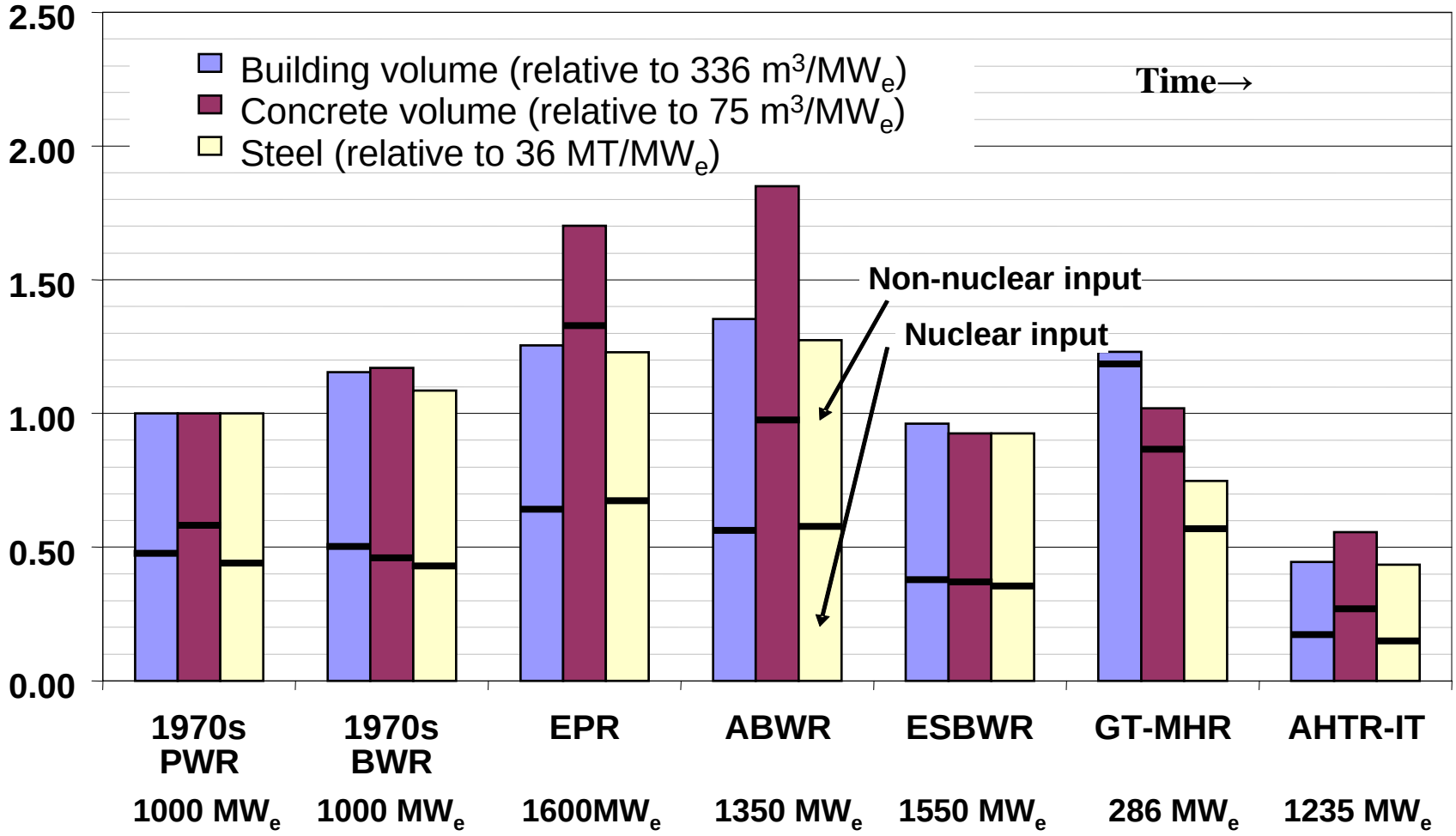
AHTR Efficiency Exceeds Gas-Cooled High-Temperature Reactors

(The Average Temperature of Delivered Heat is Higher with Liquid Coolants than with Gas Coolants)



Reactor Comparison of Building Volume, Concrete Volume, and Steel Consumption

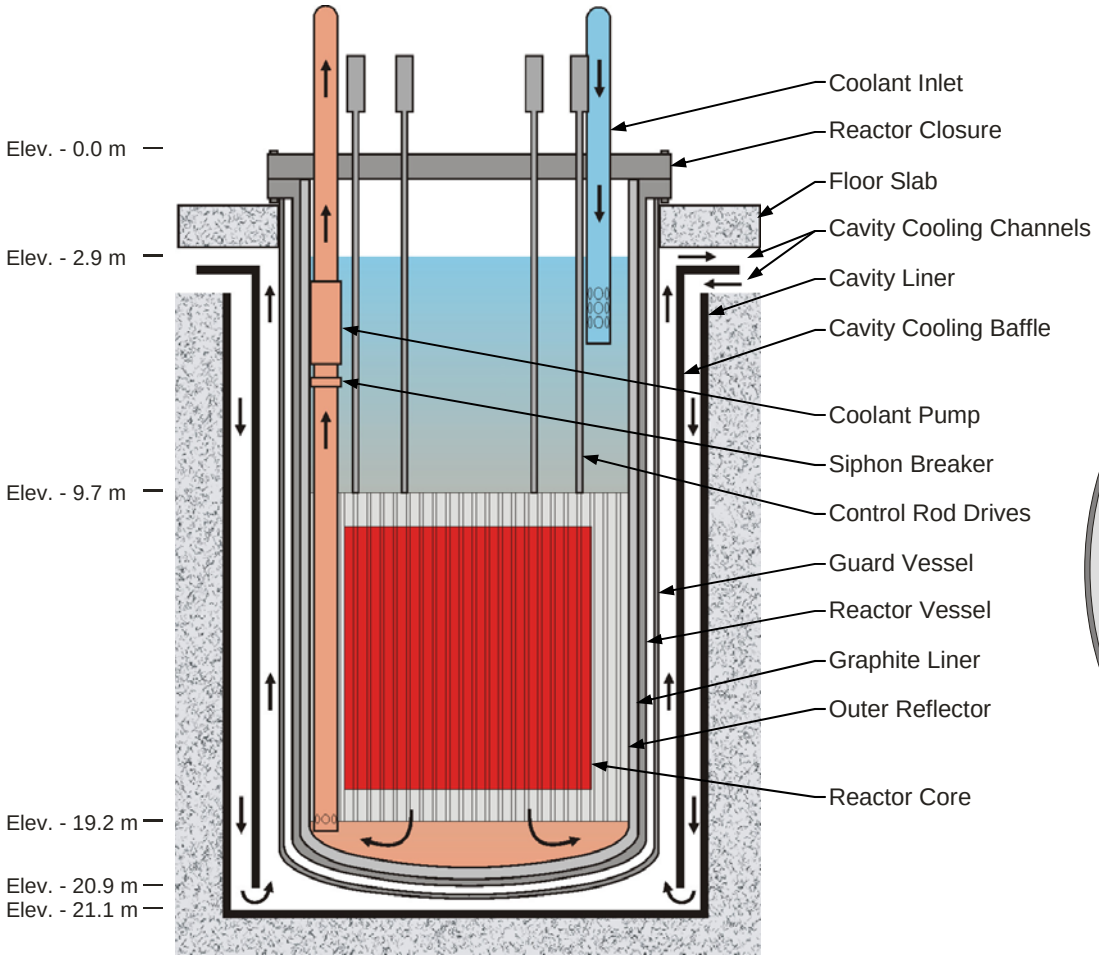
(Based on Arrangement Drawings)



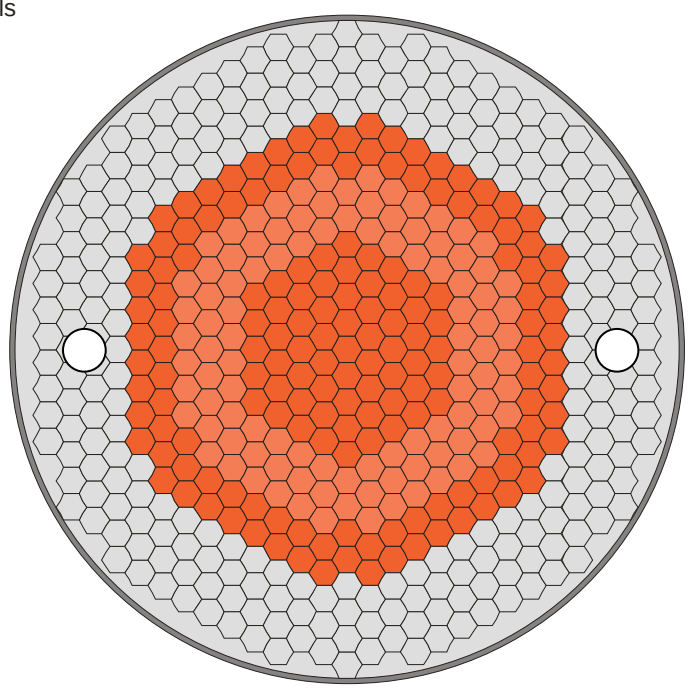
Per Peterson (Berkeley): American Nuclear Society 2004 Winter Meeting

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

(Same Vessel Size as the S-PRISM Reactor Vessel)



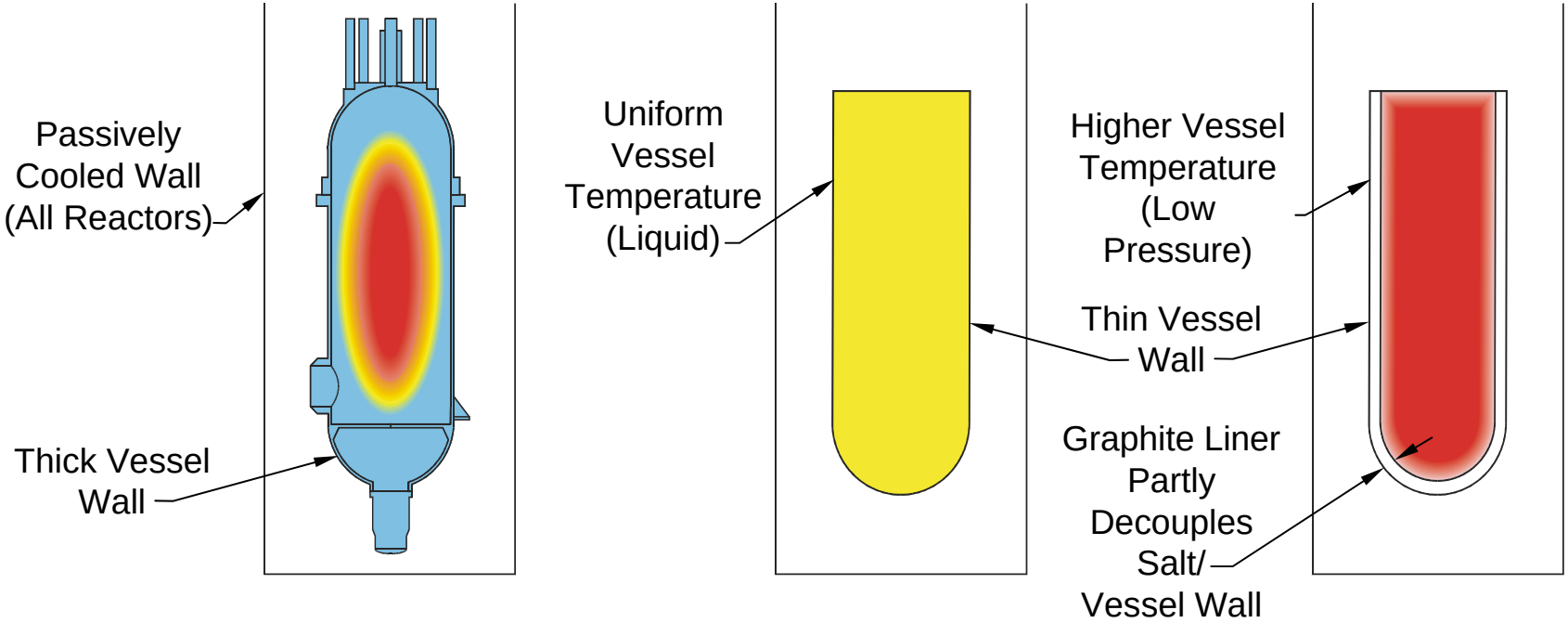
102 GT-MHR fuel columns
163 Additional fuel columns
265 Total fuel columns



Power density = 10.0 MW/m^3

High-Temperature Low-Pressure Liquid Coolants Enable Large Reactors with Passive Safety

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



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