Gen IV Research and Development Programs in the United States

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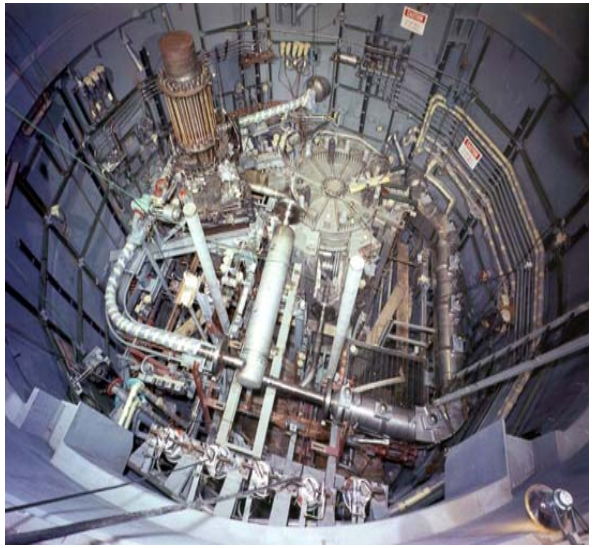
Generation IV International Forum
Molten Salt Reactor Systems
Steering Committee Meeting
Best Western Hotel Meteor Plaza
Prague, Czech Republic
September 9, 2005



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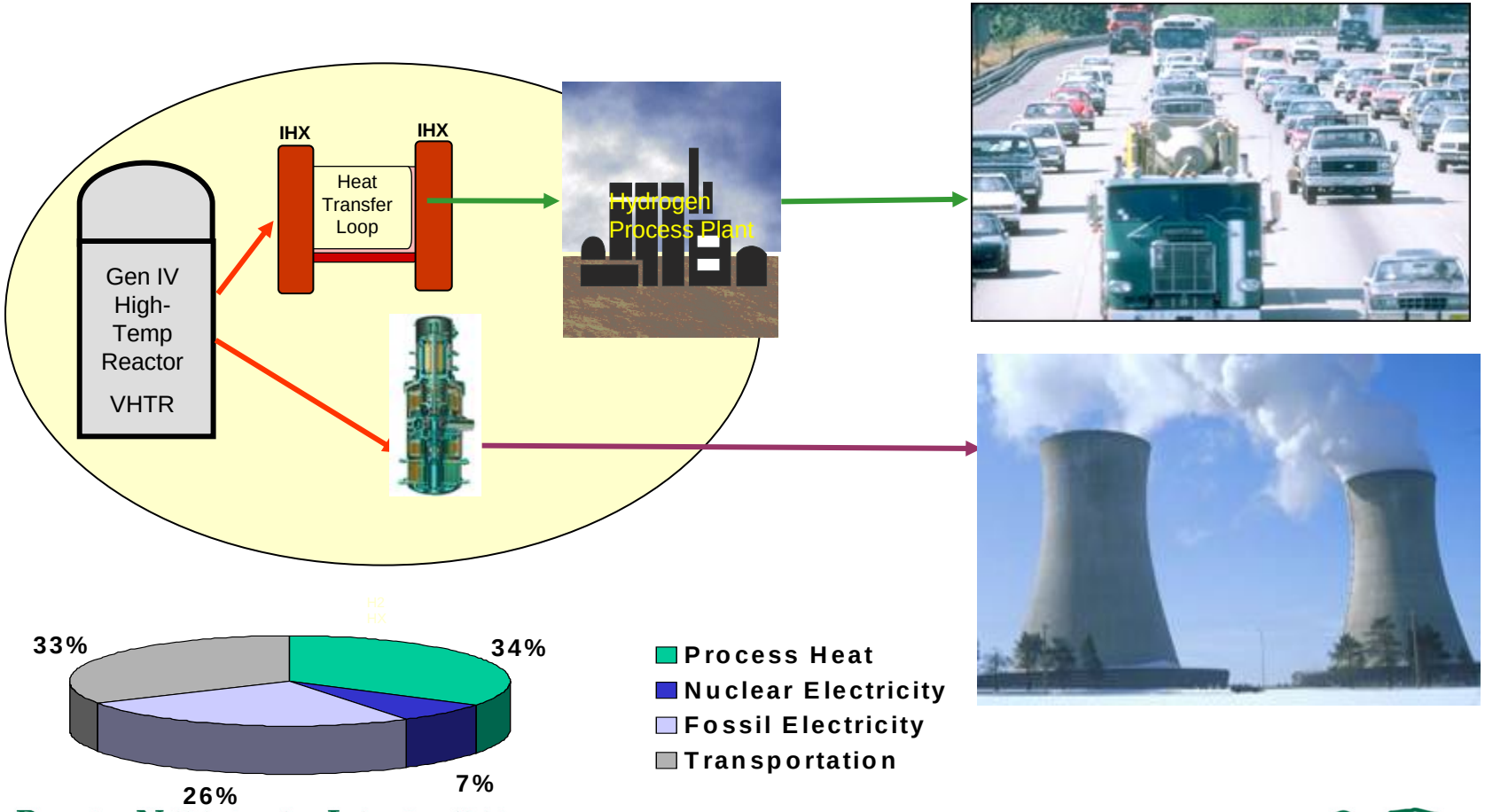
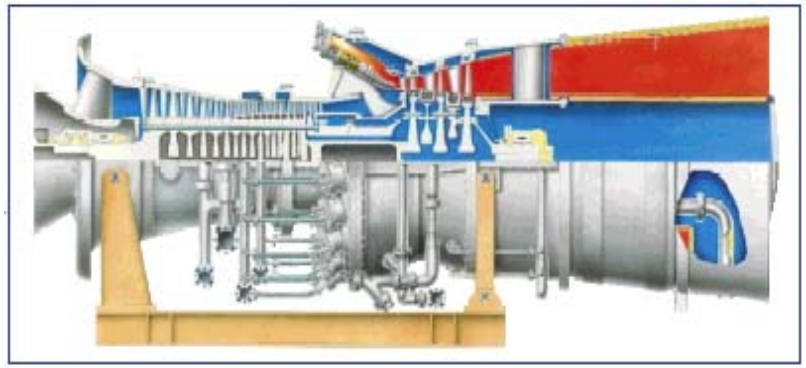
The U.S. Nuclear Energy GenIV Program Priorities: Hydrogen and Electricity Production

(High Temperatures Required for Hydrogen Production)

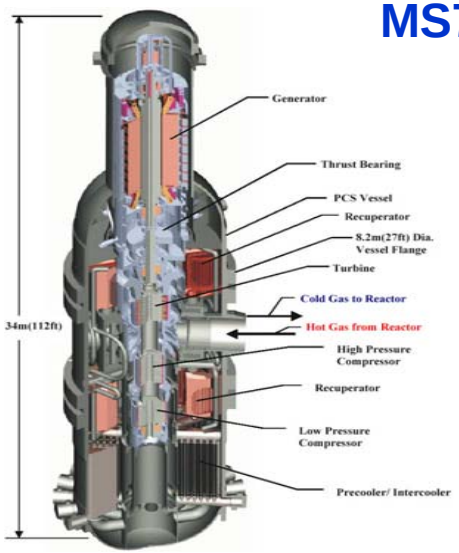


Brayton Technology is Also Creating an Interest in High-Temperature Reactors

- **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>efficient, 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**
  - **Higher efficiency**
  - **Economic dry cooling options**



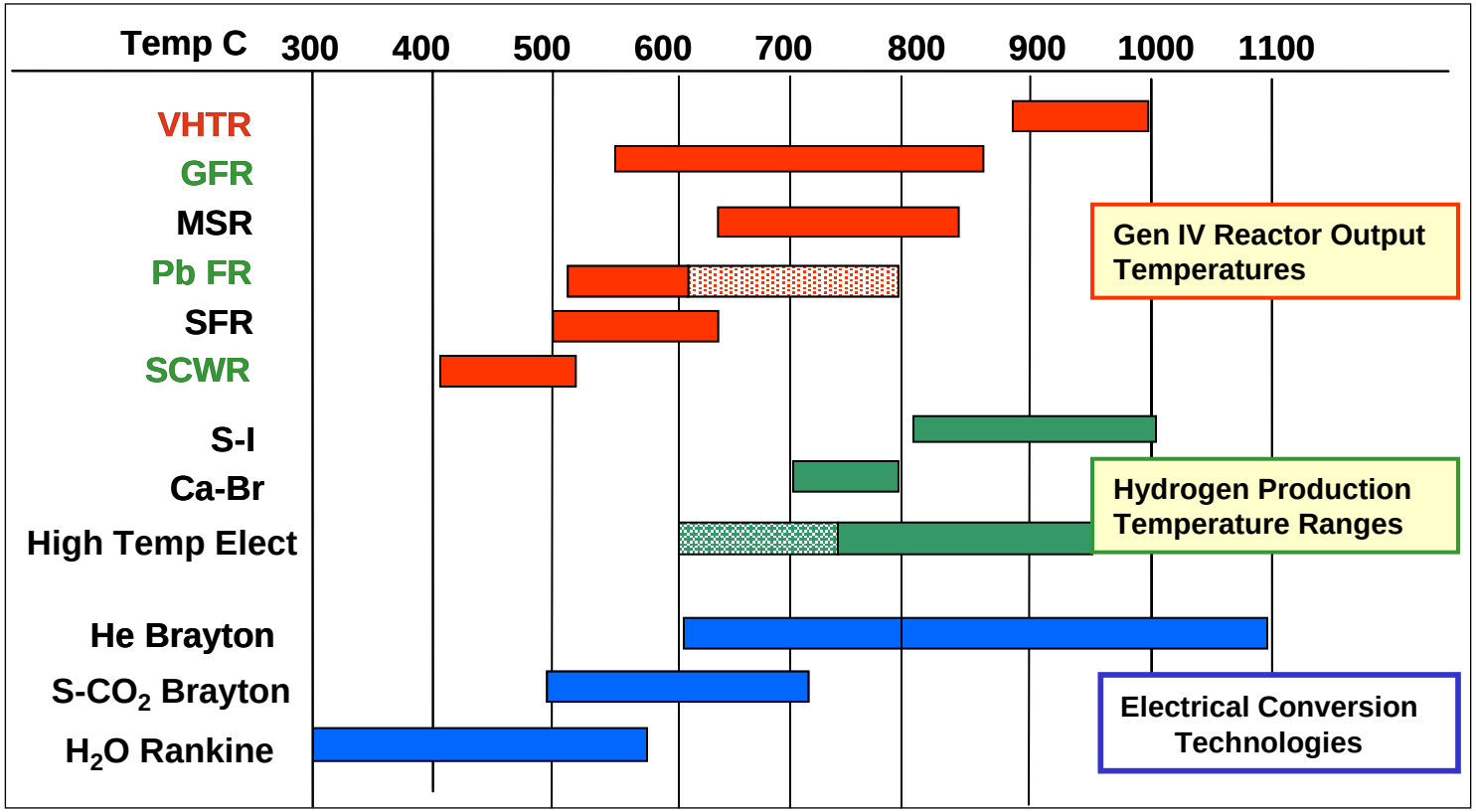
GE Power Systems MS7001FB



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

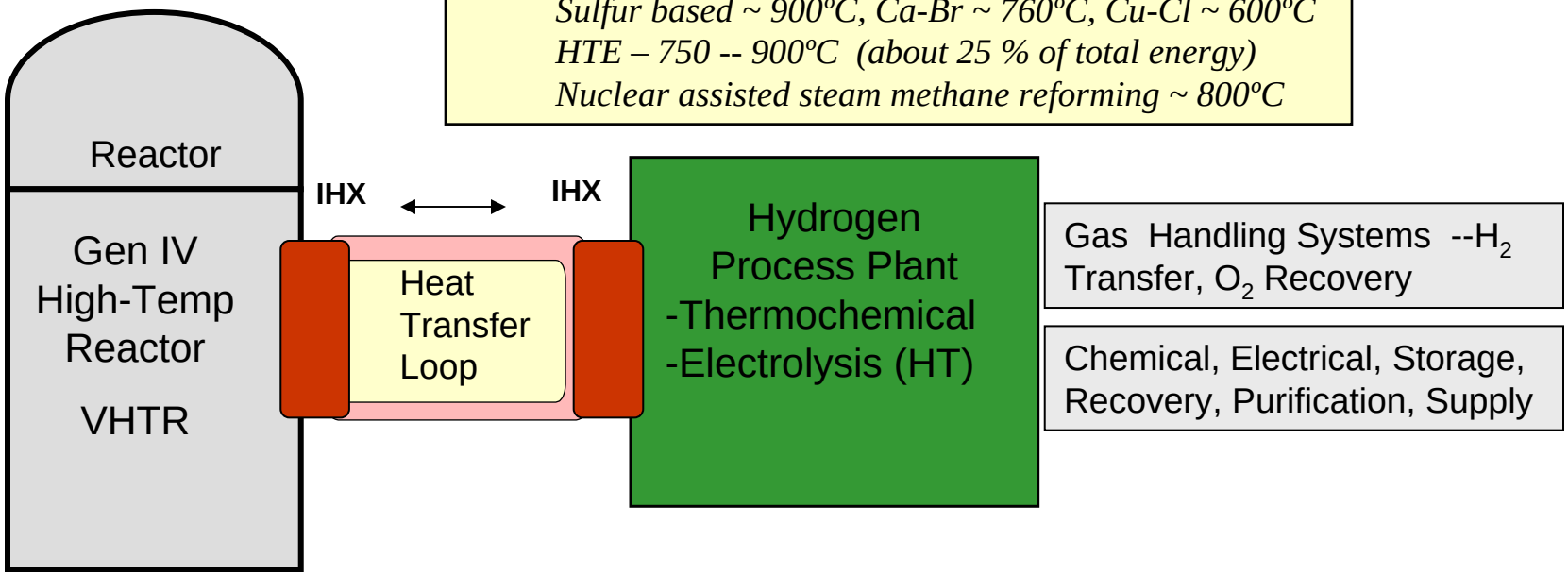
Primary U.S. Gen IV Interest is the VHTR

(Priorities: High, Exploratory, Low)



H_2 Production Requires High-Temperature Heat Transfer from Reactor to H_2 Plant

H_2 Process temperature requirements
Sulfur based ~ 900ºC, Ca-Br ~ 760ºC, Cu-Cl ~ 600ºC
HTE – 750 -- 900ºC (about 25 % of total energy)
Nuclear assisted steam methane reforming ~ 800ºC

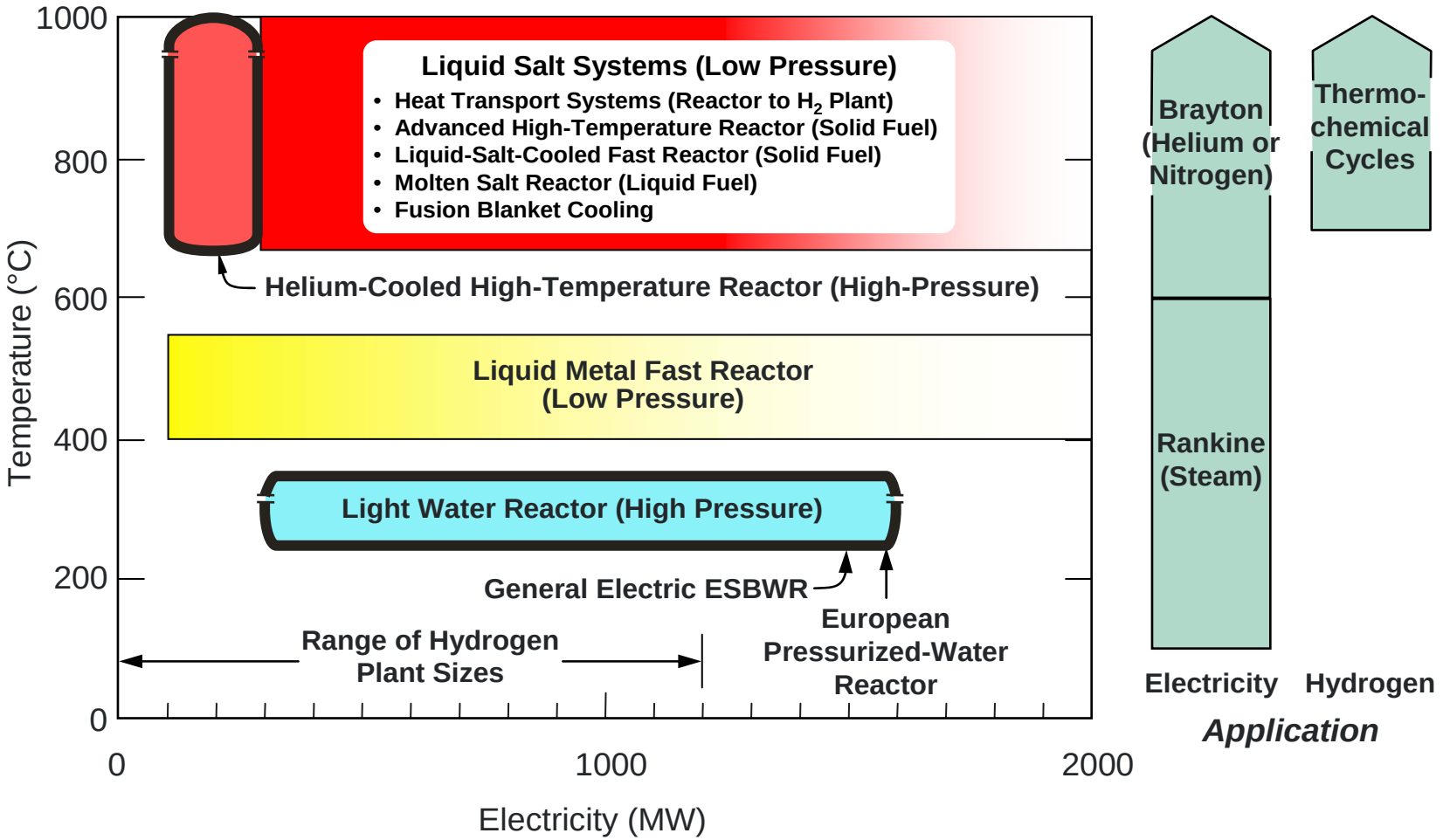


Liquid salts are leading candidates for heat transfer

Liquid-Salt Nuclear Applications

Salt Coolants can be Used for High-Temperature Nuclear Applications

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



High-Temperature Heat Transport Systems

Candidates: Liquid Salts and Helium

H_2 Process temperature requirements
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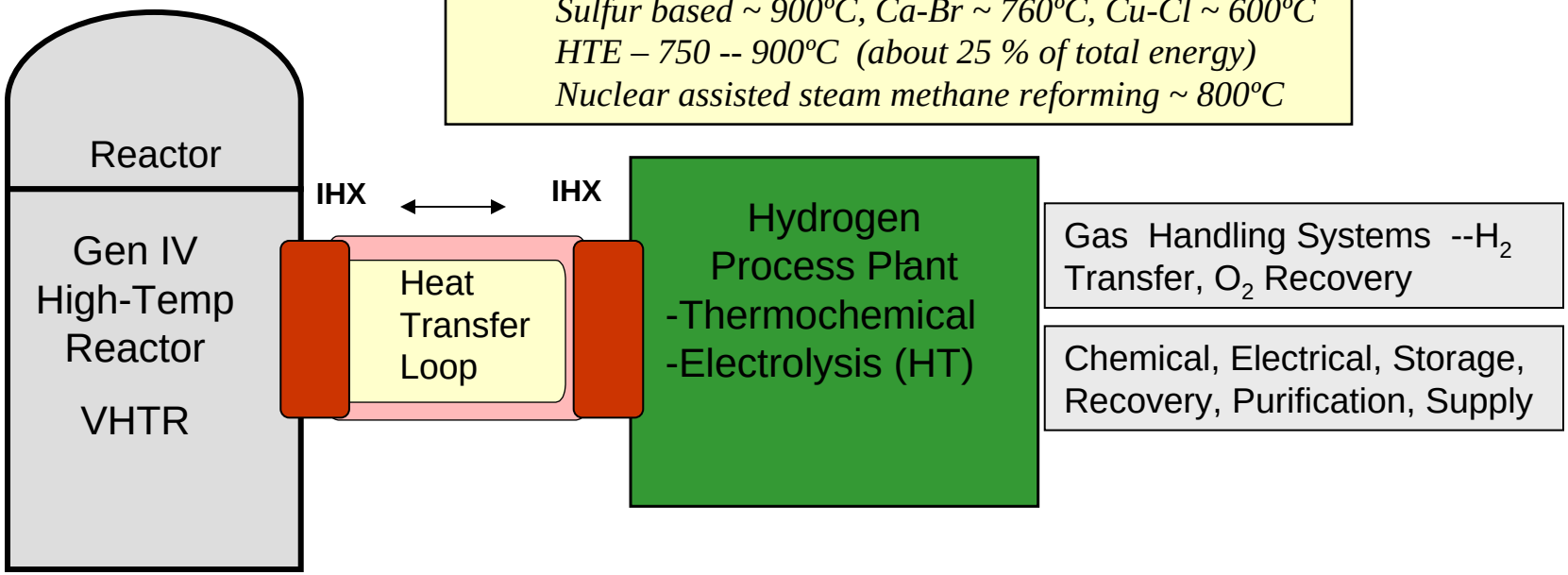
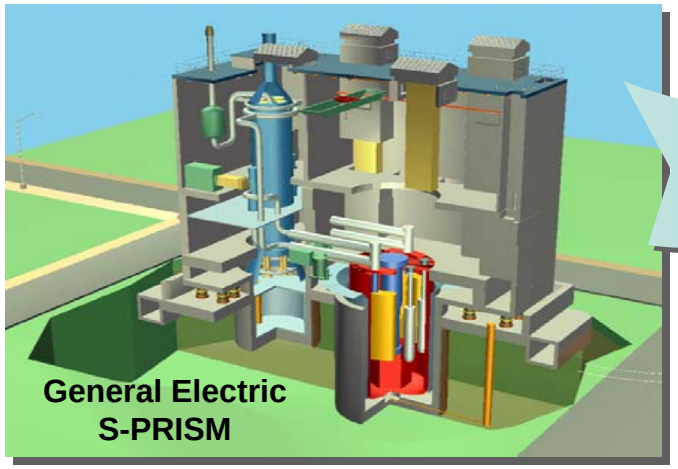


High-priority: Required for H_2 production with any VHTR

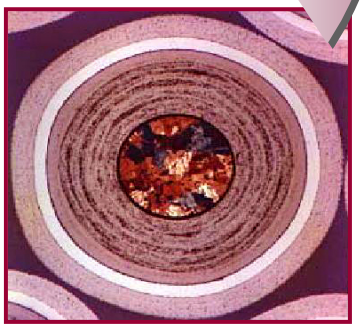
The Advanced High-Temperature Reactor

Liquid-Salt-Cooled VHTR



Passively Safe Pool-Type Reactor Designs

Brayton Power Cycles



High-Temperature Coated-Particle Fuel

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

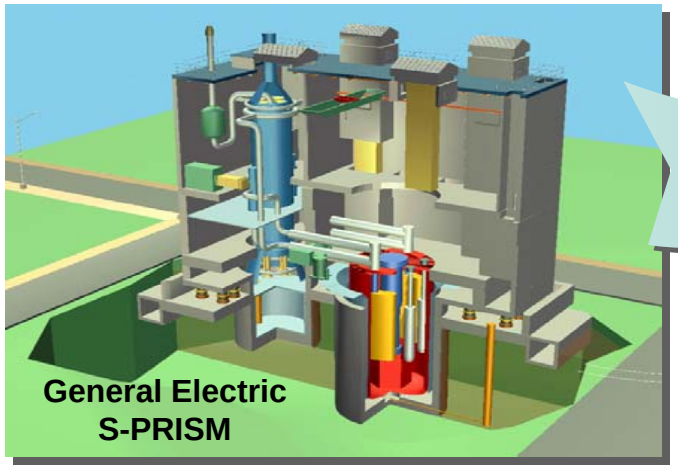
There Are Four VHTR Concepts

[Gas-Cooled: ~600 MW(t); Liquid-Cooled: >2000 MW(t)]

Concept	Fuel	Coolant	Power Cycle
General Atomics	Prismatic	Helium	Direct
Framatome	Prismatic	Helium	Indirect
Westinghouse	Pebble Bed	Helium	Direct
AHTR	Prismatic	Liquid Salt	Indirect

The Liquid-Salt-Cooled Fast Reactor

Higher-Temperature Liquid-Salt Coolant Replacing Sodium



Fast Reactor Facility Design

High Temperature Brayton Power Cycles

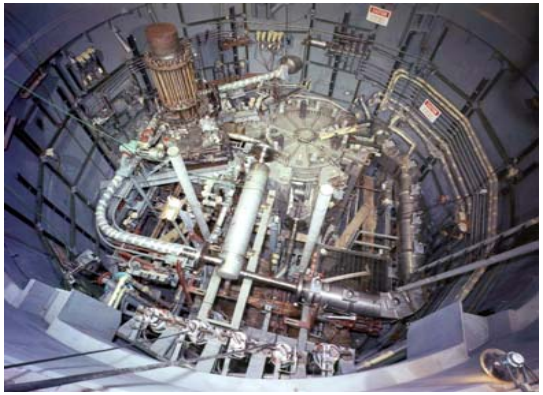
Fast Reactor Core

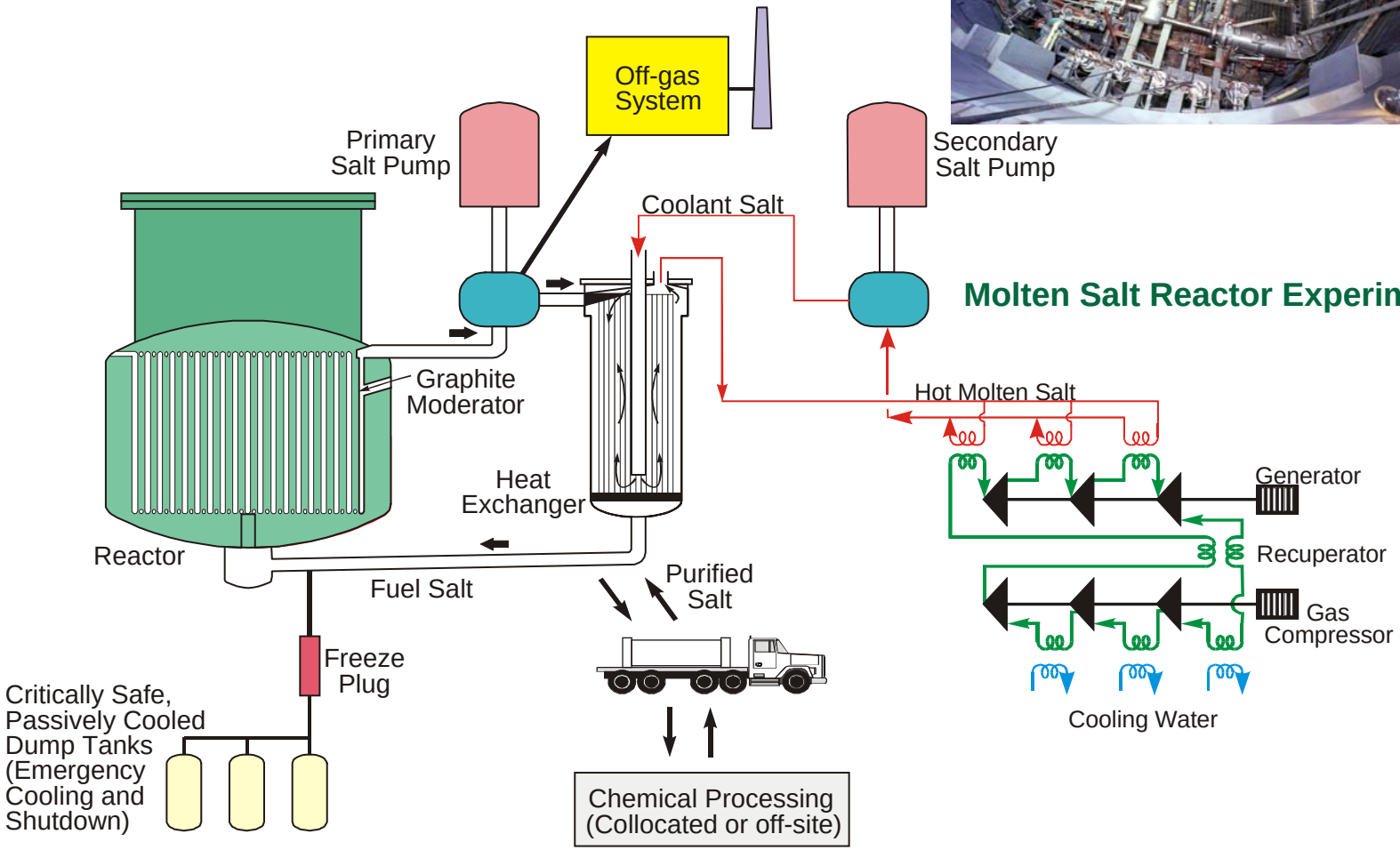
(Picture of PFR Core)

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

Molten Salt Reactor

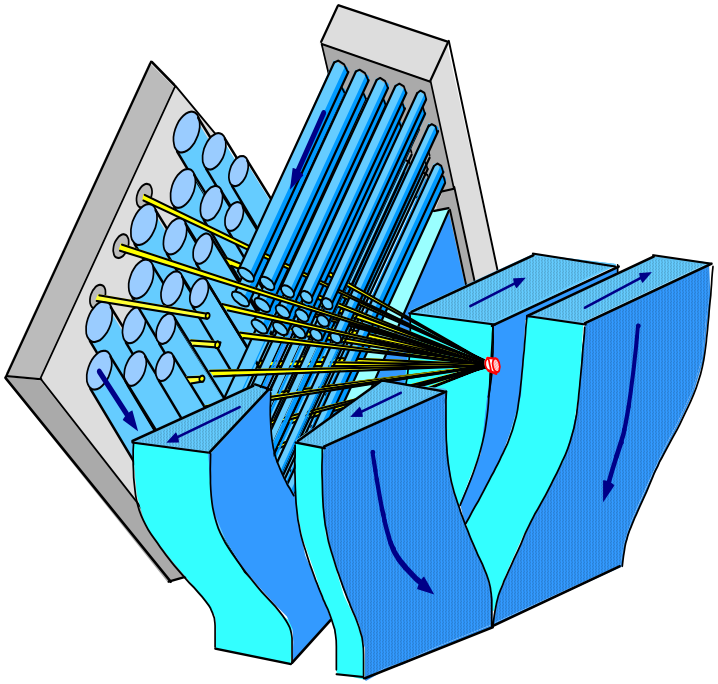
(Modern Version with Brayton Power Cycle)



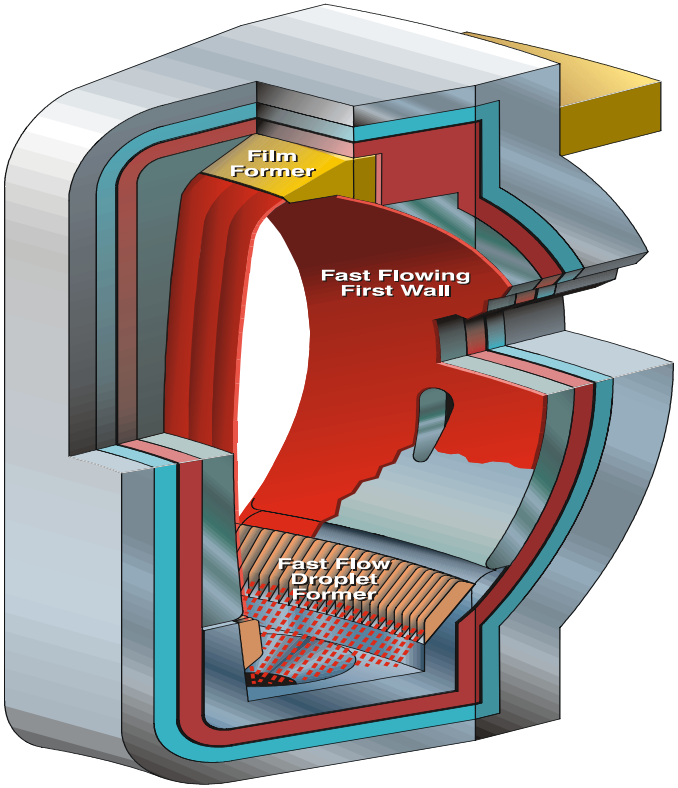


Liquid-Salt-Wall Fusion Machines

(Higher-Power Densities and Less Radiation Damage)



Heavy-Ion Inertial Fusion



Magnet Fusion Tokamak

U. S. Liquid Salt R&D Activities

Program	Participants
Heat Transport*	**Laboratories: INL, ORNL, Sandia** **Universities: UC-Berkeley, U of Nevada, U. of Wisconsin**
AHTR* **(Liquid-Salt-Cooled VHTR)**	**Laboratories: ORNL, INL, ANL, Sandia** **Universities: UC-Berkeley, U of Nevada, U. of Tennessee** **Vendors**
LSFR	**Laboratories: ORNL, ANL** **Universities: UC-Berkeley, MIT**
MSR	**Laboratories: ORNL, LLNL** **Universities: UC-Berkeley**

***Significant Programs**

Conclusions

- **Rapidly expanding programs on use of liquid salts in nuclear systems**
- **Heat transport systems and the AHTR are the priority activities**
- **Common technical challenges with MSR**
  - **Power cycles**
  - **Graphite**
  - **Corrosion-resistant materials**
  - **Salt properties**
  - **Salt cleanup**
  - **Salt system engineering (pumps, valves, etc.)**

Status of the AHTR and LSFR in the United States

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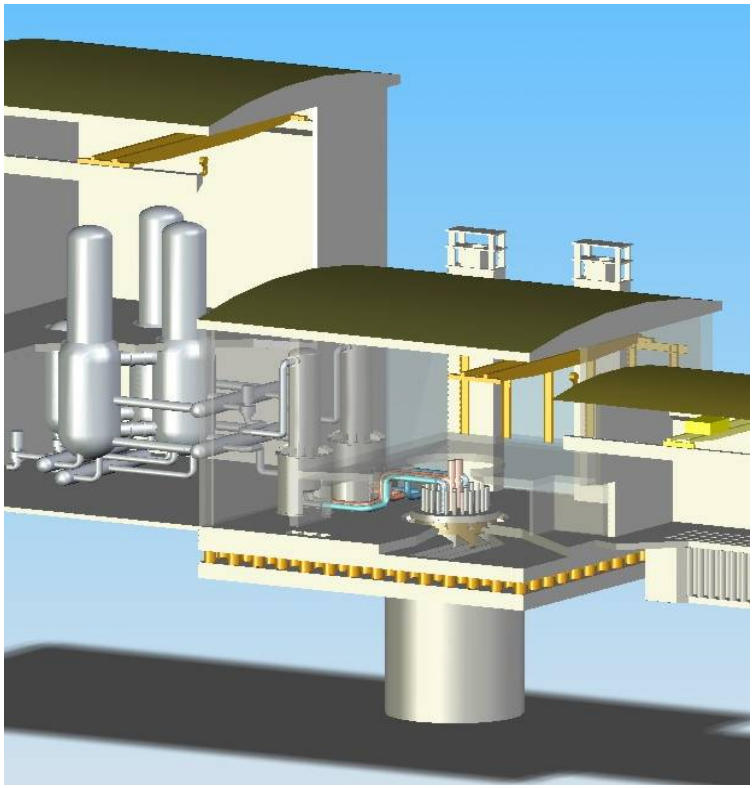

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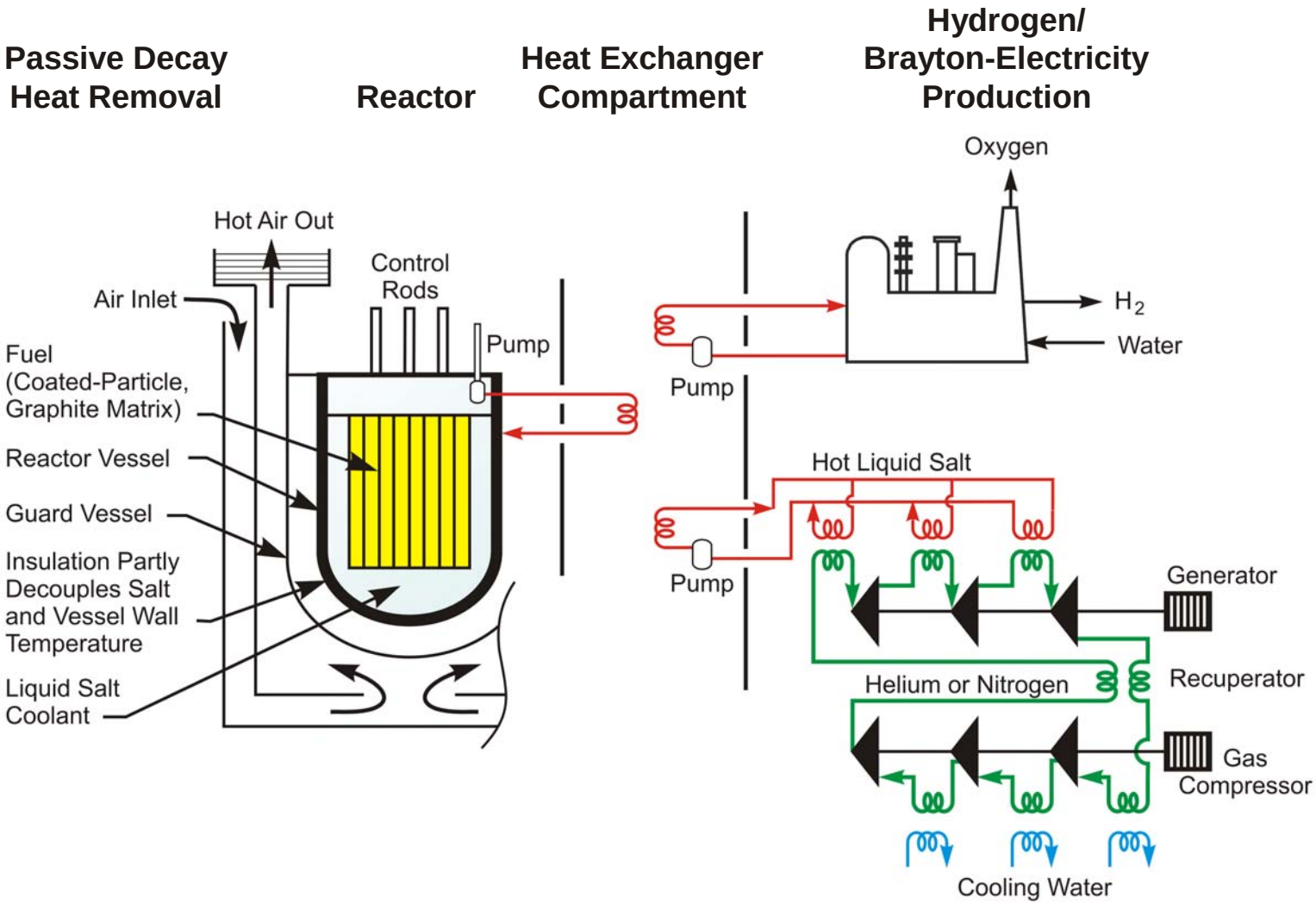
The Advanced High Temperature Reactor

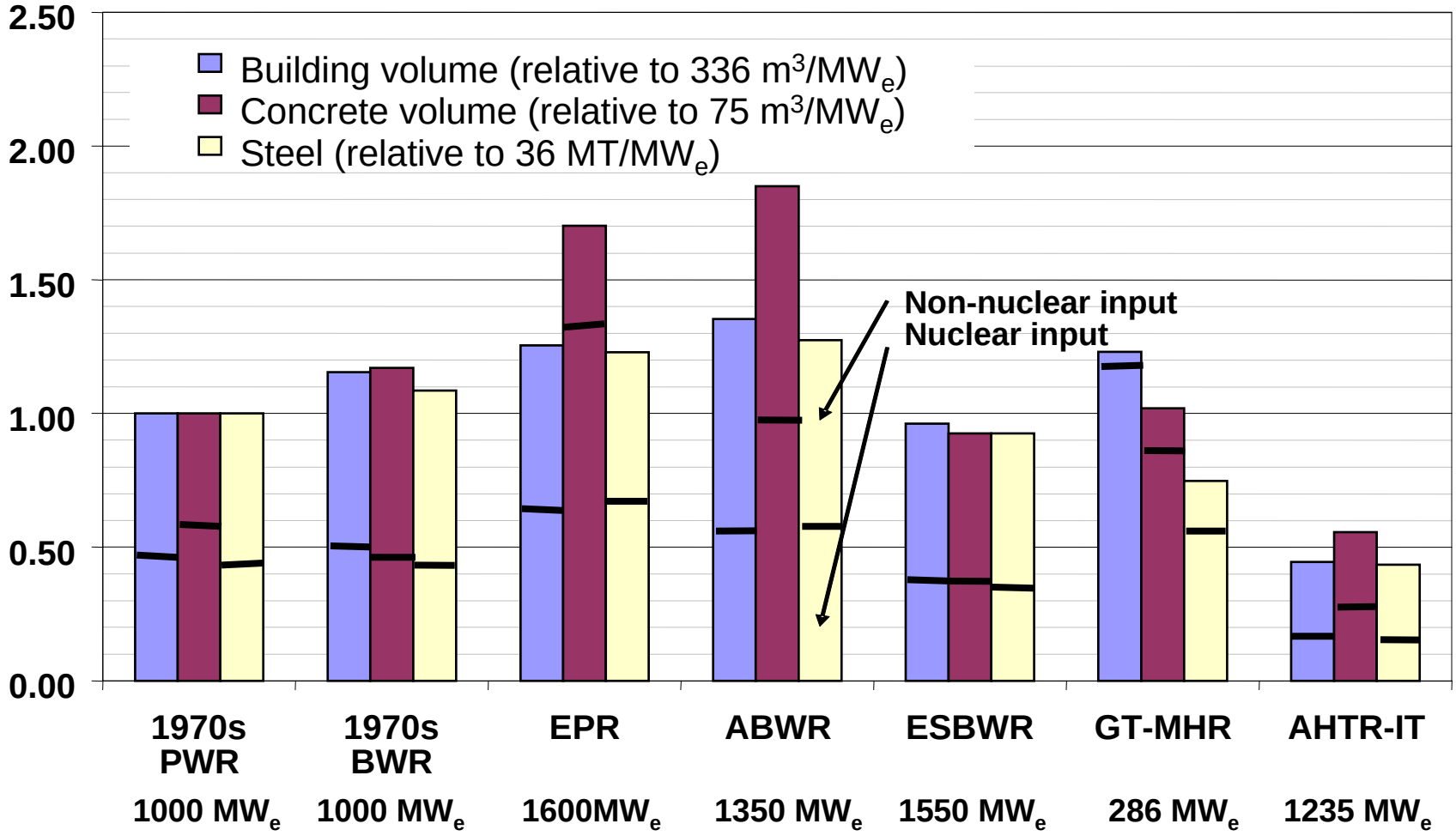


The AHTR (Liquid-Salt-Cooled VHTR) Program is Accelerating

- **Vendor interest**
  - **<u>Potentially superior economics relative to MHTGRs/LWRs</u>**
  - **Vendor interest in large reactors [1800 MW(e)]**
- **Funding is increasing**
  - **Liquid-Salt Heat-Transport Loop (any VHTR to H_2 plant)**
  - **AHTR**
- **Partners**
  - **Laboratories: ORNL, INL, SNL, ANL**
  - **Universities: UC-Berkeley, Wisconsin, and Tennessee**
  - **Vendors**

Reactor Economics: Comparison of Building, Concrete, and Steel Consumption

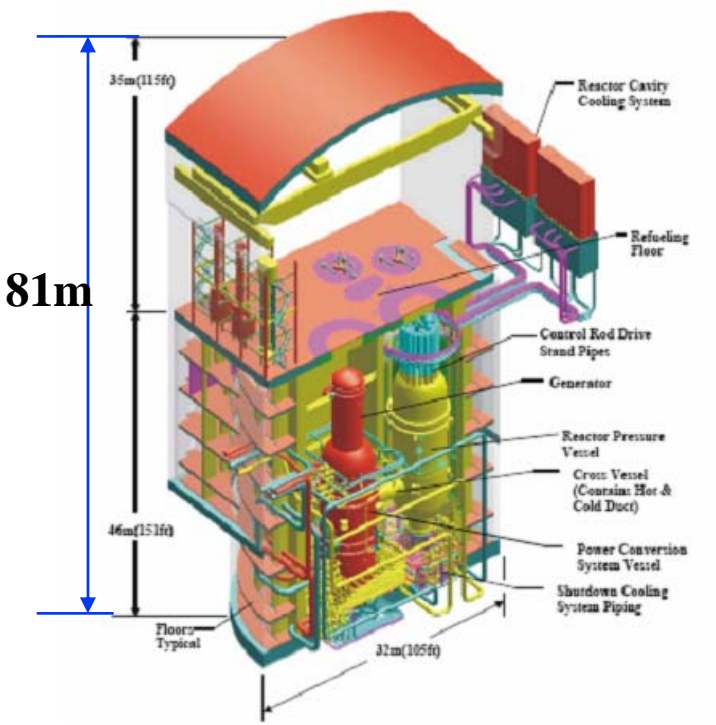
(Based on Arrangement Drawings)



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

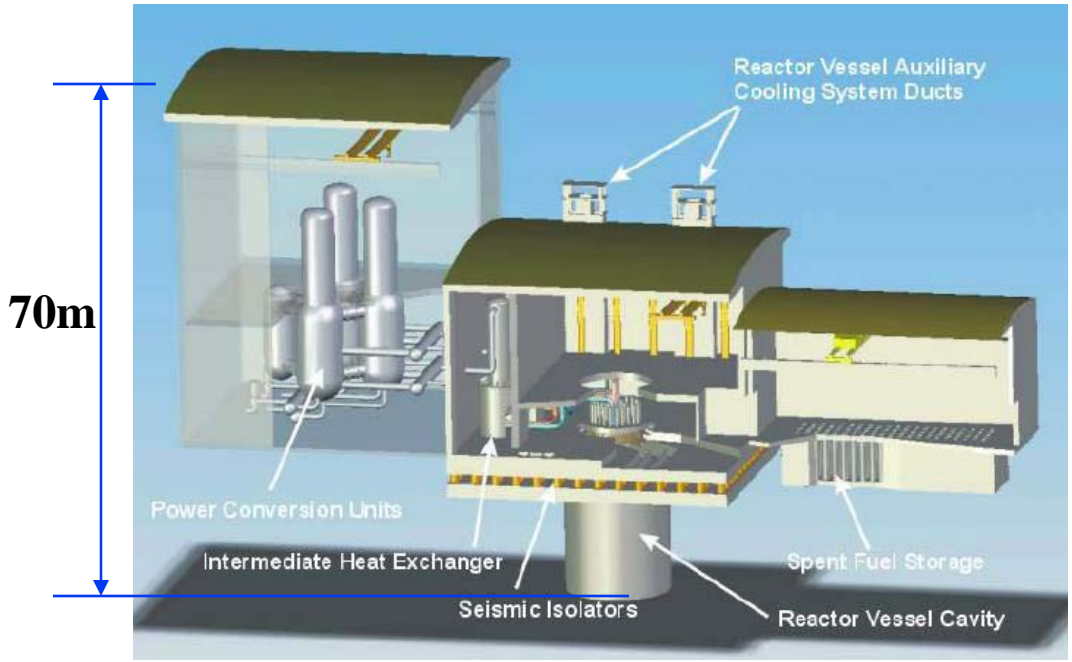
Salt Cooling Aids Economics

(Figures to Scale)



Gas Cooling

GT-MHR (600 MW(t))



Liquid Cooling

AHTR (2400 MW(t))

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The Liquid-Salt-Cooled Fast Reactor is a New Concept Early in Development

- **Basis of interest: potentially better economics**
  - **AHTR with a core change out**
  - **Higher temperature and thus higher efficiency**
  - **Avoid sodium-water issues**
- **Significant technical uncertainties but finding solutions to technical challenges**
- **No DOE funding yet (proposals)**
- **Studies and Evaluations**
  - **Oak Ridge National Laboratory**
  - **University of California at Berkeley**
  - **Argonne National Laboratory**
  - **Massachusetts Institute of Technology**

Massive Overlap Between Programs

Parameter	Heat Transport	Helium VHTR	AHTR	MSR
Power Cycle		X	X	X
Graphite		X	X	X
Materials	X	X	X	X
Salt Properties	X		X	X
Salt Cleanup	X		X	X
Systems (Pumps, etc.)	X		X	X
Fuel		X	X	

Status of Salt Facilities in the United States

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ORNL Salt Test Loop

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Status of Salt Test Facilities

- **Operational**
  - **ORNL test loop and properties laboratories**
  - **INL fusion tritium laboratory**
  - **UC Berkeley laboratory**
- **Construction/Committed**
  - **ORNL consolidated salt laboratory**
  - **Wisconsin salt test loop**
- **Planning**
  - **AHTR electrically-heated mockup**
  - **Liquid-salt heat-transfer test loop**