Fuel Characteristics and Requirements for the Advanced High-Temperature Reactor

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Next Generation Nuclear Reactors
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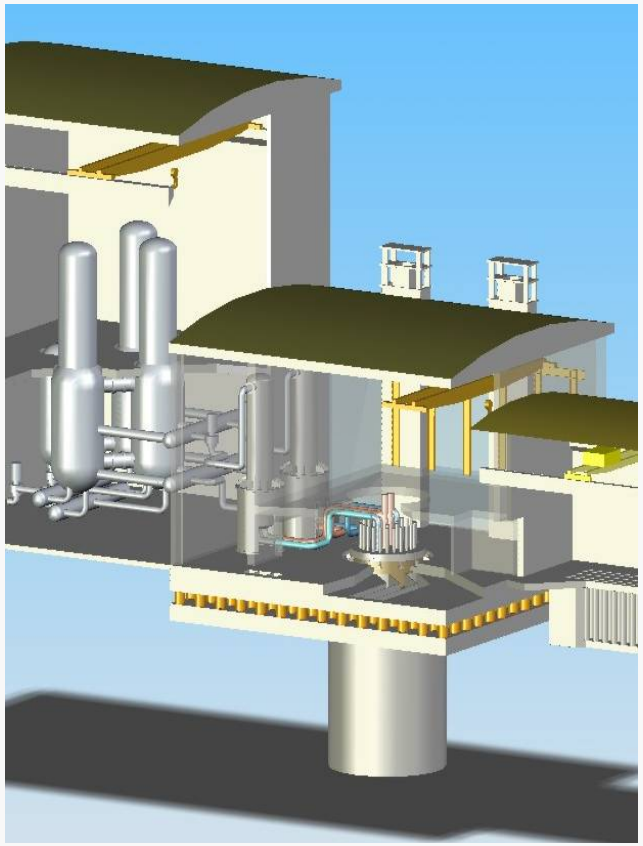

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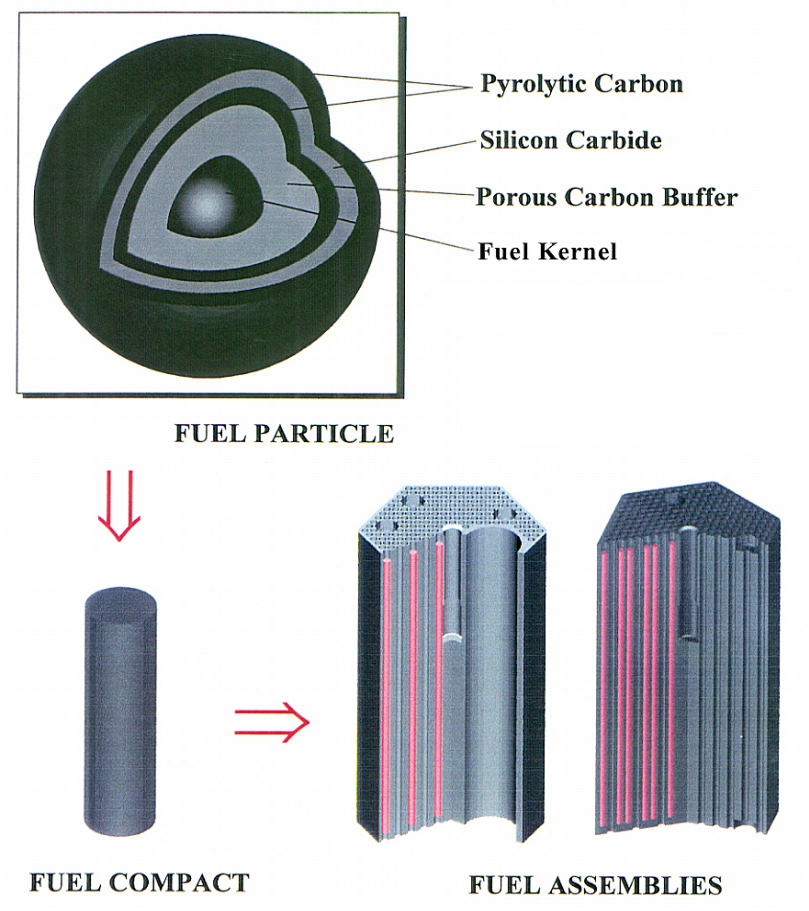
High-Temperature Reactors (HTRs): Fuel Description and Reactor Types

HTRs Use Graphite-Matrix Coated-Particle Fuel

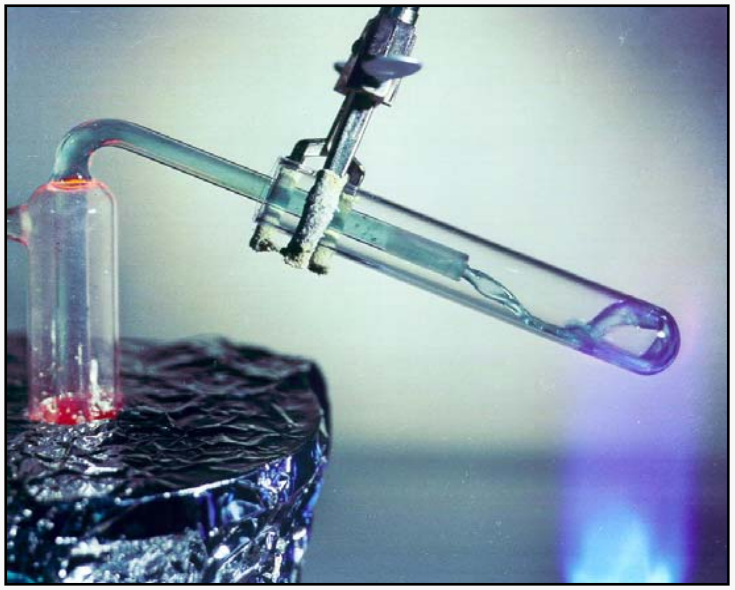
- Fuel is encapsulated in multilayer microspheres
  - Carbon layers
  - Silicon carbide layers
- Microspheres are embedded in a graphite matrix
- Fuel has high-temperature capabilities
  - Operating temperatures to 1200ºC
  - Allowable accident temperatures to ~1650ºC
- Multiple fuel geometries are possible



Two Reactor Coolants are Chemically Compatible with Graphite-Matrix Fuel

Modular High-Temperature Gas-Cooled Reactor

Advanced High-Temperature Reactor



Helium

(High Pressure/Transparent)

Liquid Fluoride Salts

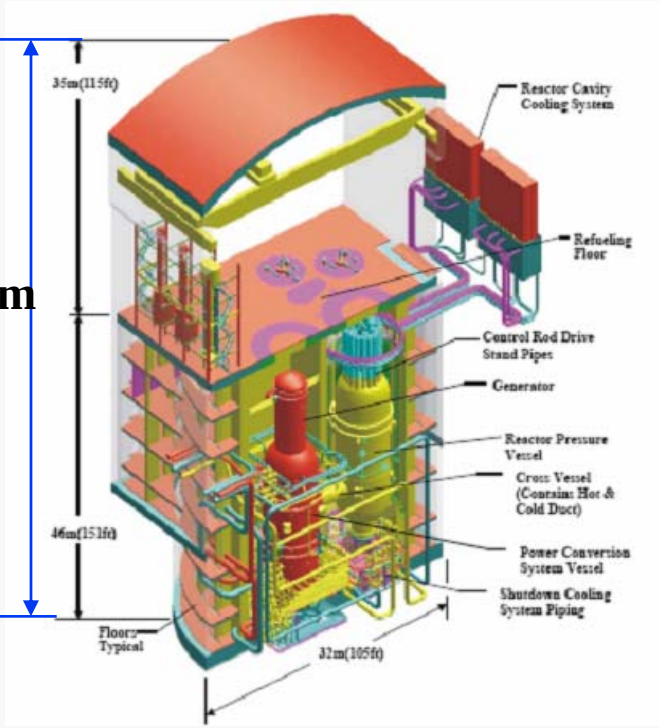
(Low Pressure/Transparent)

Two Reactor Options Based on Choice of Coolant

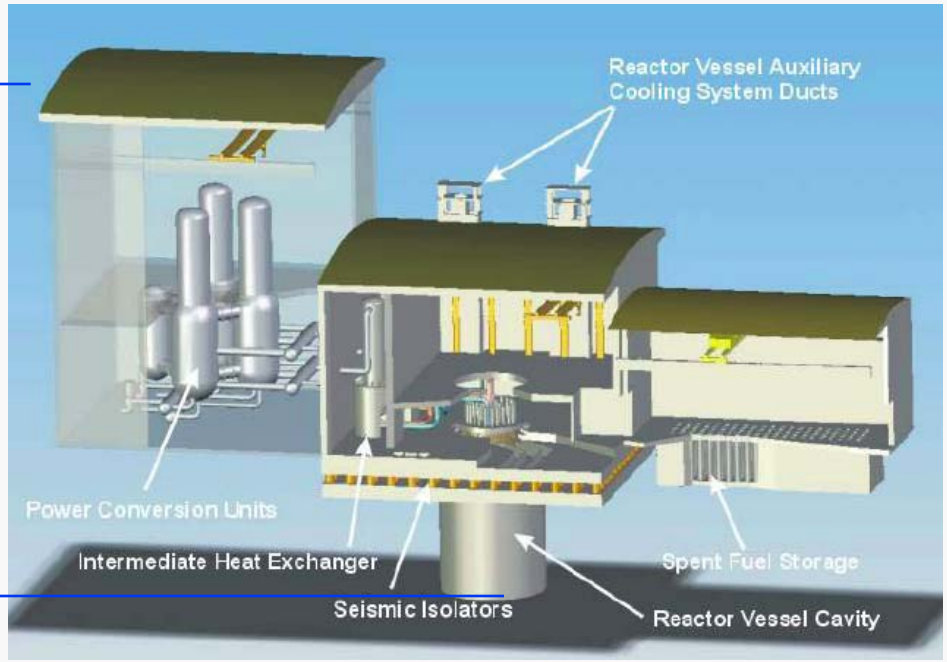
Two Types of High-Temperature Reactors are Being Developed

(MHTGR: Near Term; AHTR: Medium Term)

81m



70m



Modular High-Temperature Gas-Cooled Reactor

Gas Cooled: 600 MW(t); Near-Term Option

Advanced High-Temperature Reactor

Liquid Salt Cooled: 2400 MW(t)

Medium-Term Option

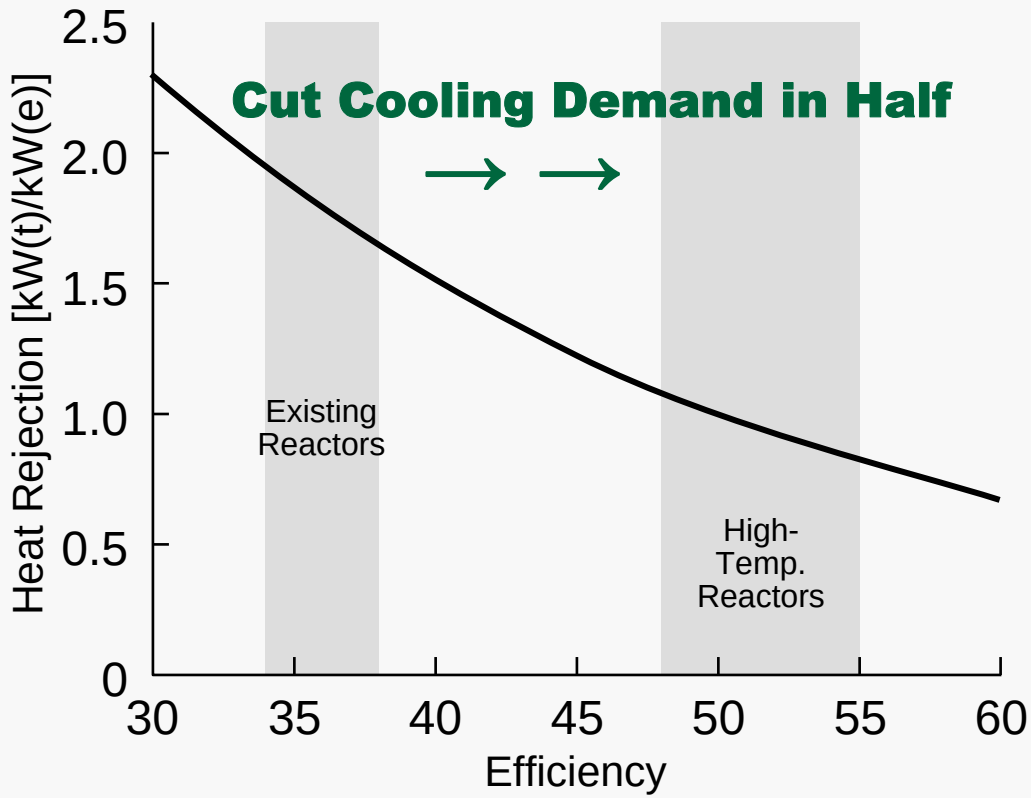
Per Peterson (Berkeley): American Nuclear Society 2004 Winter Meeting

Comparison of HTRs and LWRs

HTRs are More Efficient in Converting Heat to Electricity

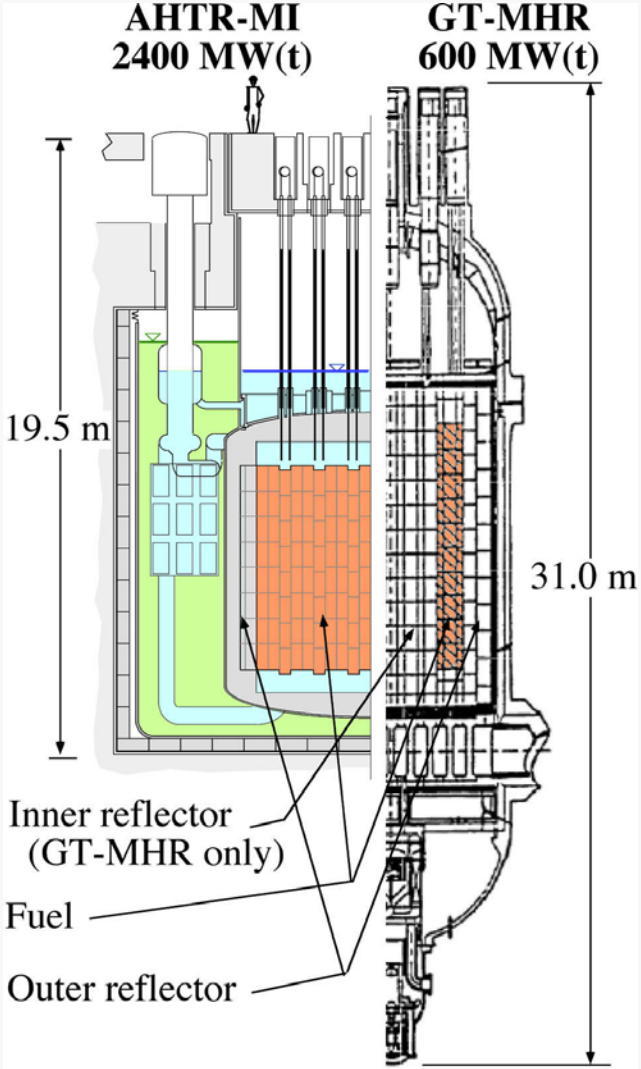
- **Thermal efficiency**
  - **50% for an HTR**
  - **33% for an LWR**
- **Potential fuel advantages relative to those for LWRs**
  - **Lower fissile fuel consumption**
  - **Lower waste generation**
    - **Fission products**
    - **Actinides**
    - **Decay heat**

More Electricity and Less Heat to Cooling Towers



Differences Between the MHTGR and the AHTR

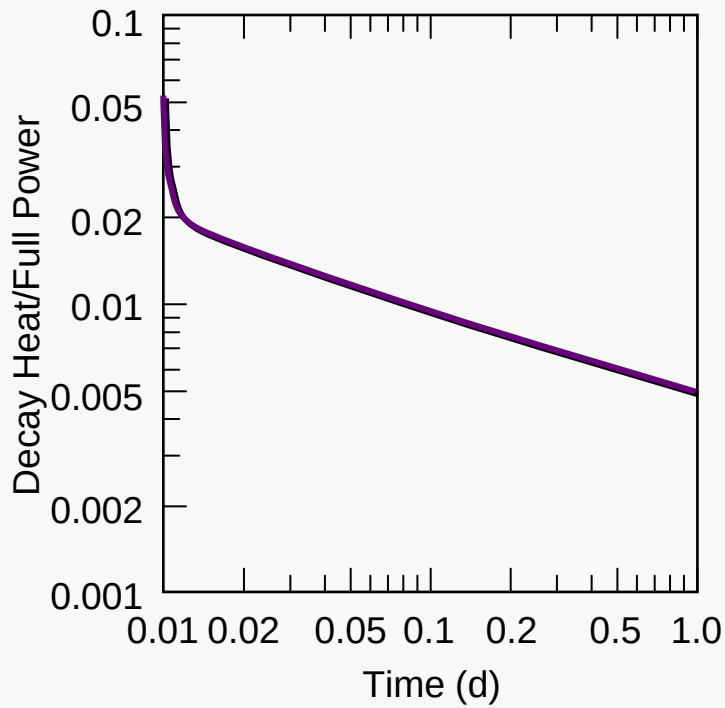
The AHTR Goal is Superior Economics



- **HTR requirements include passive safety systems for decay heat removal**
  - **Output of gas-cooled HTR is limited to ~600 MW(t)**
  - **Output of liquid-cooled AHTR can exceed 2400 MW(t)**
- **AHTR benefits from economics of scale**
- **AHTR is a large reactor with multiple fuel impacts**

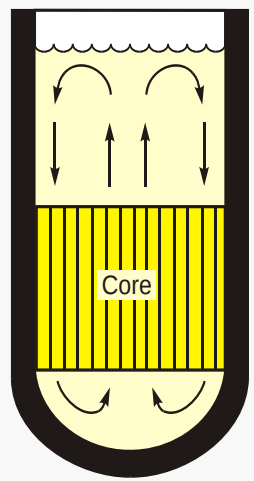
Liquid Cooling Allows Large Reactors with Passive Decay Heat Removal

Decay Heat vs Time



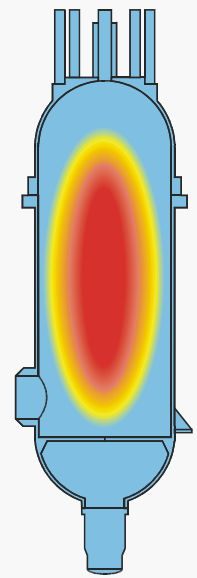
Alternative Decay-Heat-Removal Options to Vessel Surface (Max Reactor Size)

Liquid
[1000s of MW(t)]



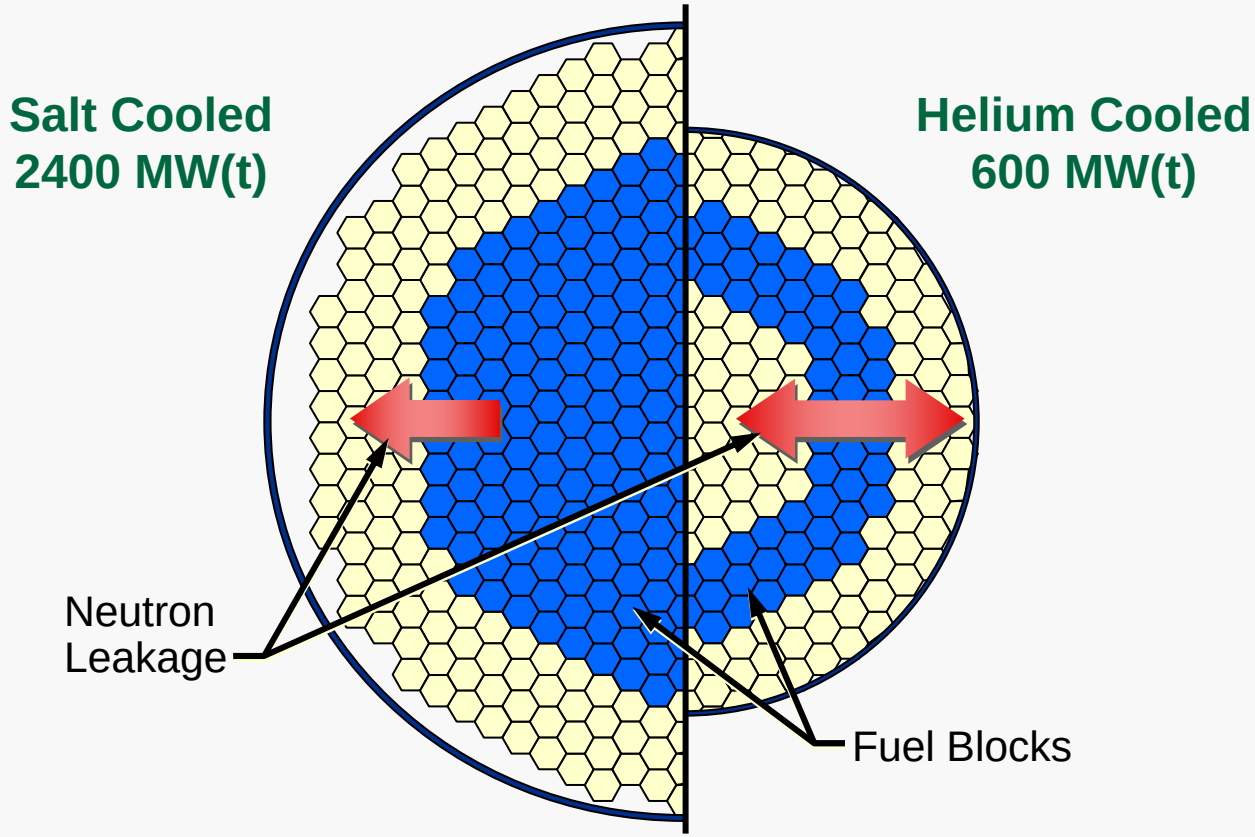
Convective Cooling (~50ºC Difference in Liquid Temperature)

Gas
[~600 MW(t)]



Conduction Cooling (~1000ºC Difference in Fuel Temperatures)

A Large Reactor Core Implies Smaller Neutron Leakage and Higher-Burnup SNF for the Same Fuel Enrichment



The AHTR has Higher Fuel Burnup

Property	PWR	MHTGR	AHTR
Fuel burnup [GWd(t)/ton uranium]	50	100*	150*
Electrical efficiency (%)	33	50	50
Electricity per unit volume of fuel [GWd(e)/m^3]	20	3.3	5

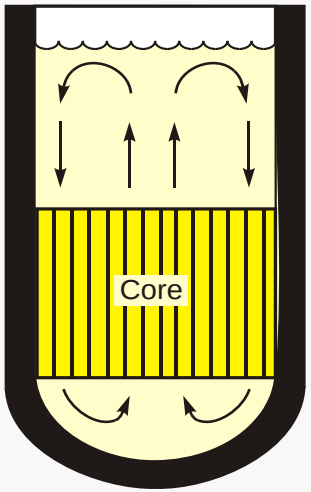
***Similar uranium enrichment in fresh fuel; assumes prismatic fuel block**

Implications of Higher-Burnup Fuel with Similar Fuel Enrichments

- AHTR fuel fabrication cost per unit of electricity is one-third less than that of an MHTGR
- AHTR has lower consumption of natural uranium per unit of electricity for once-through fuel cycle
  - AHTR uranium consumption is less than that of an LWR
  - MHTGR uranium consumption is greater than that of an LWR
- AHTR has one-third less SNF volume per unit of electricity than the MHTGR

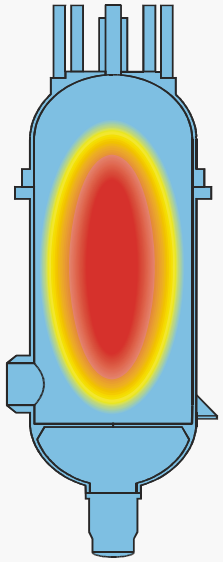
Liquid Cooling Allows Alternative Fuel Designs

Liquid
[1000s of MW(t)]



Fuel Design Controlled by Convective Cooling Requirements

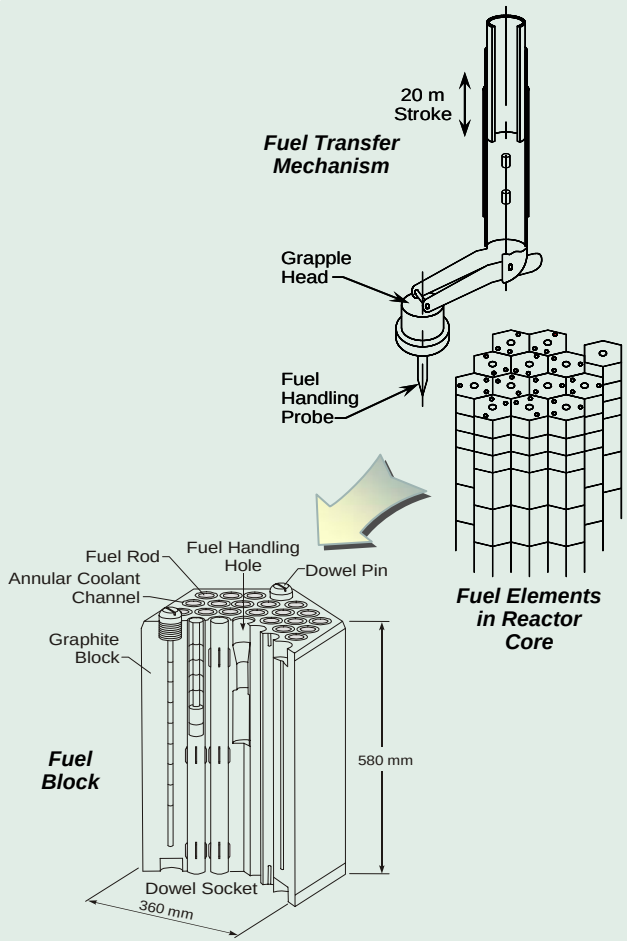
Gas
[~600 MW(t)]



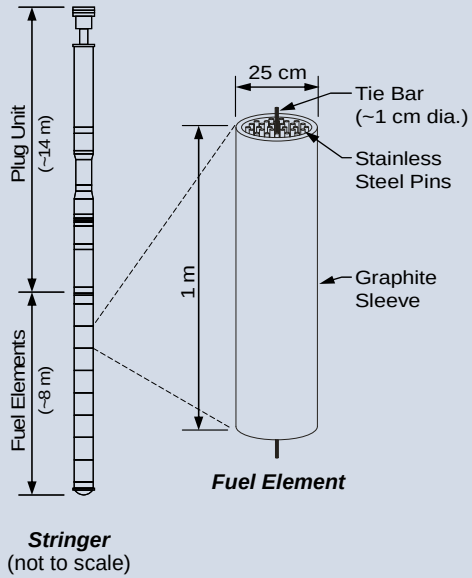
Fuel Design Controlled by Conduction Cooling Requirements

Alternative Fuel Configurations

(Same Microspheres; Different Graphite Forms)



Prismatic Fuel Block

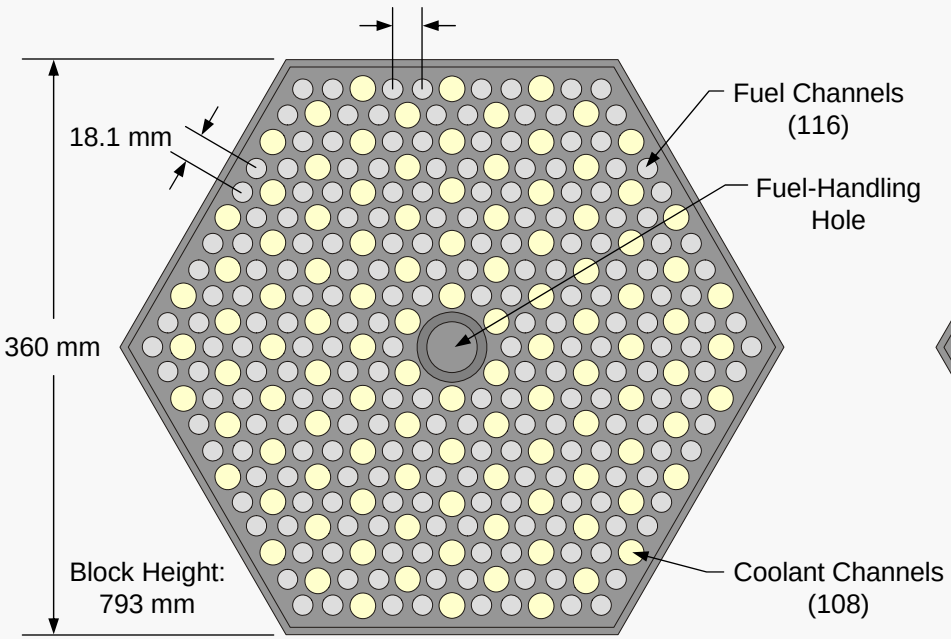


Stringer

Pebble Bed

Example of an Alternative AHTR Fuel Design

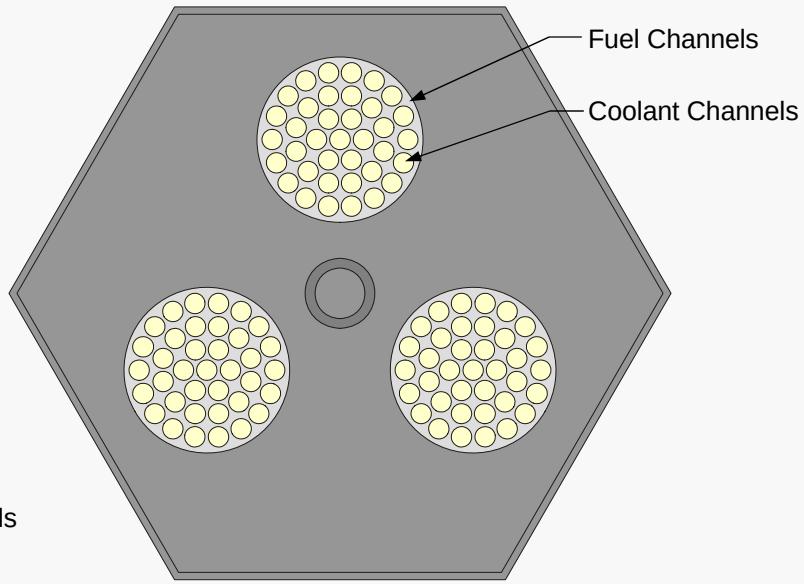
Homogeneous Fuel



Usable for all HTRs

(Decay heat removal by conduction or liquid convection)

Heterogeneous Fuel

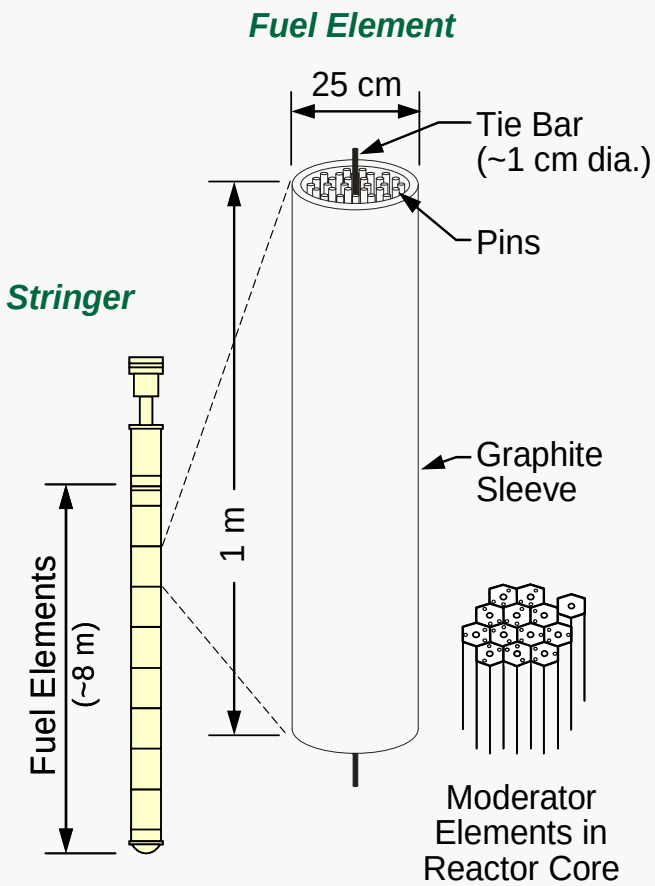


AHTR option

(Decay heat removal by liquid convection)

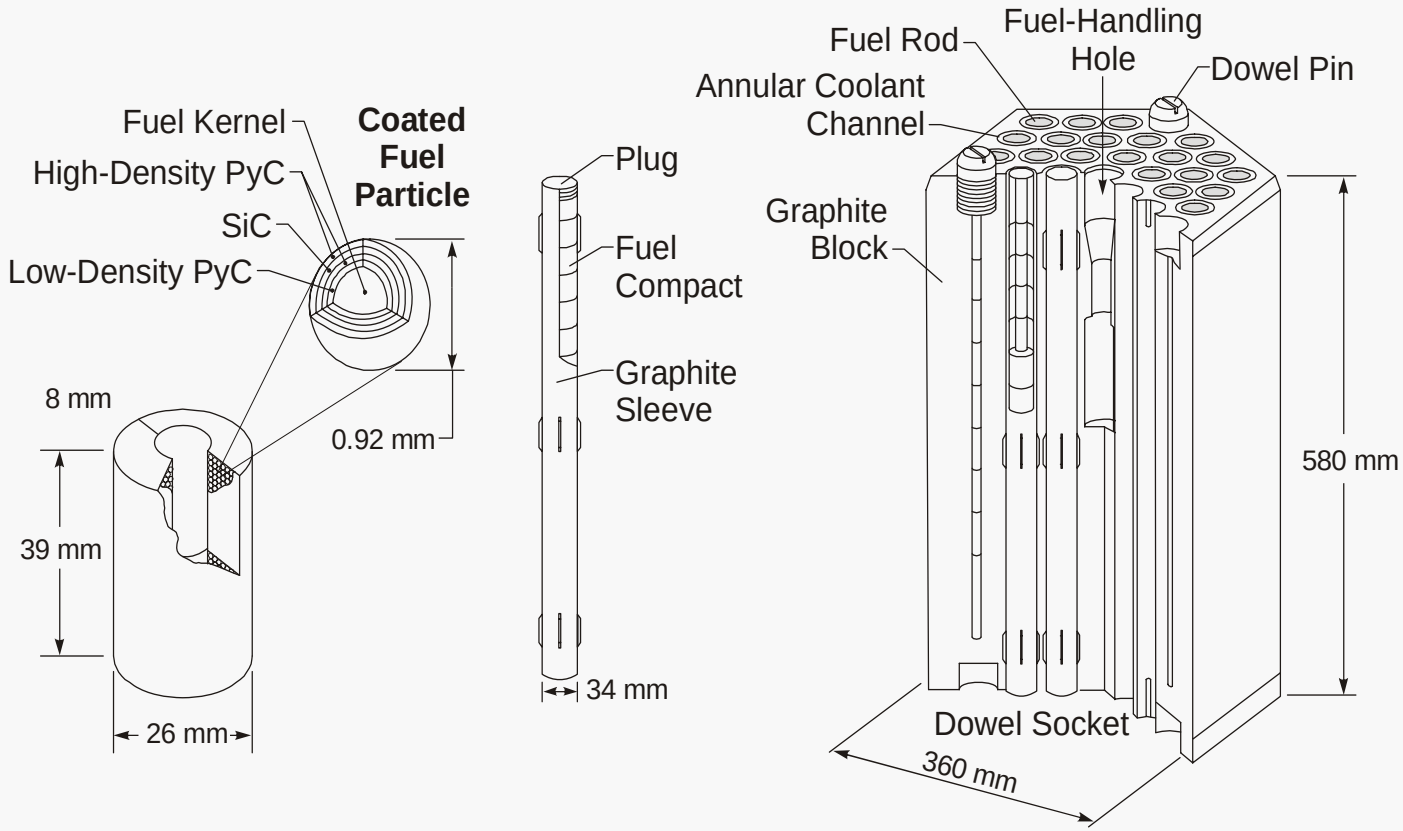
AHTR Bundle Assembly (Similar to British Advanced Gas-Cooled Reactor Fuel) is Potentially Viable

- **AGR**
  - 620ºC
  - Carbon dioxide coolant
  - Steel-clad pin-type assembly
  - Graphite sleeve
- **AHTR equivalent**
  - Carbon-based pin
  - Carbon-carbon composites for other metallic component composites
  - No "showstoppers" discovered in initial assessment
- **Moderator composed of columns of graphite blocks with center holes**



HTTR Fuel (Japan) has a Pin Design

(Limited-Height Pin is a Candidate for an AHTR Pin Assembly)



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

Potential Implications of Alternative Fuel Geometries

- Wider choices of fuel
- Lower fuel fabrication costs
- Lower volumes of SNF by separation of bulk graphite from fuel

Conclusions

- Two classes of passively safe high-temperature reactors
  - MHTGR (gas cooling, small)
  - AHTR (liquid cooling, large)
- Per unit of electricity, large HTRs have major fuel advantages
  - Less fuel fabrication
  - Lower uranium consumption
  - Less SNF
- A liquid-cooled high-temperature reactor allows alternative fuel designs
  - Wider choices of fuels
  - Potentially lower fabrication costs

Biography: Charles Forsberg

Dr. Charles Forsberg received his bachelor's degree in chemical engineering from the University of Minnesota and his doctorate in Nuclear Engineering from MIT. After working for Bechtel Corporation, he joined the staff of Oak Ridge National Laboratory, where he is presently a senior scientist. Dr. Forsberg is a fellow of the American Nuclear Society and received the 2002 ANS Special Award for Innovative Nuclear Reactors. He also received the 2005 American Institute of Chemical Engineers Nuclear Energy Division Robert E. Wilson Award for outstanding chemical engineering contributions to nuclear energy and the Oak Ridge National Laboratory Engineer of the Year Award in 2005 for his work on advanced high-temperature reactors. Dr. Forsberg has been awarded 10 patents and has published over 200 papers, many on advanced reactor and repository designs.