Very High Temperature Gas Reactor (VHTR) Technology

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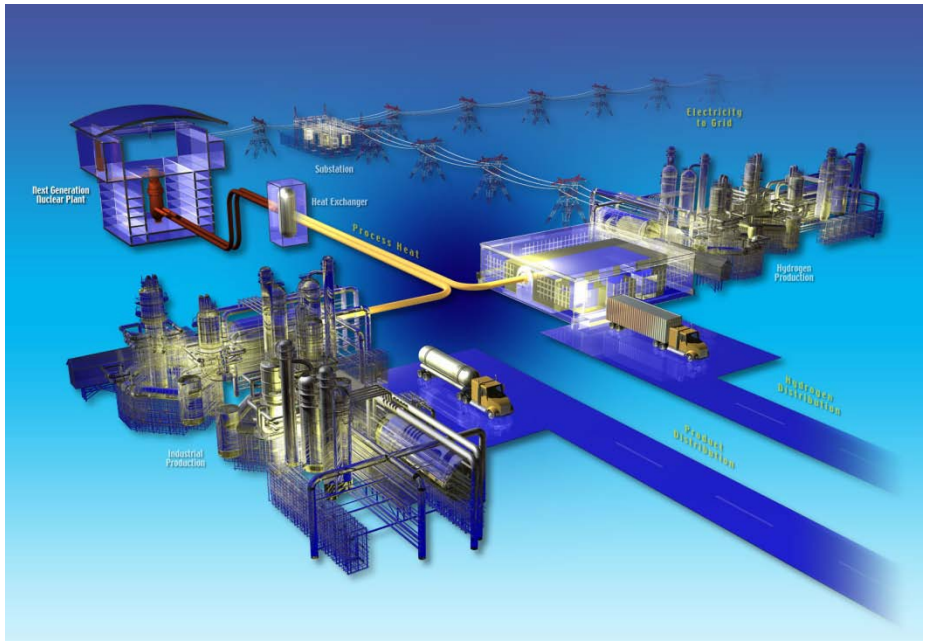
Director
Very High Temperature Reactor Technology Development Office

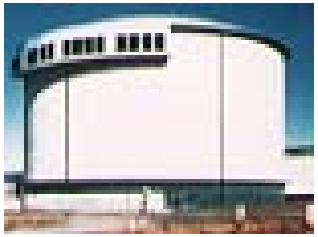
July 2010



www.inl.gov

HTGR Technology Well Established

PROTOTYPE PLANTS



DRAGON – 20 MWt
(U.K.)
1964 1975

AVR – 46 MWt
(FRG)
1967 1988

PEACH BOTTOM 1 – 115 MWt
(U.S.A.)
1967 1974

HTTR – 30 MWt
(JAPAN)
1999 - present

HTR-10 – 10 MWt
(CHINA)
2000 - present

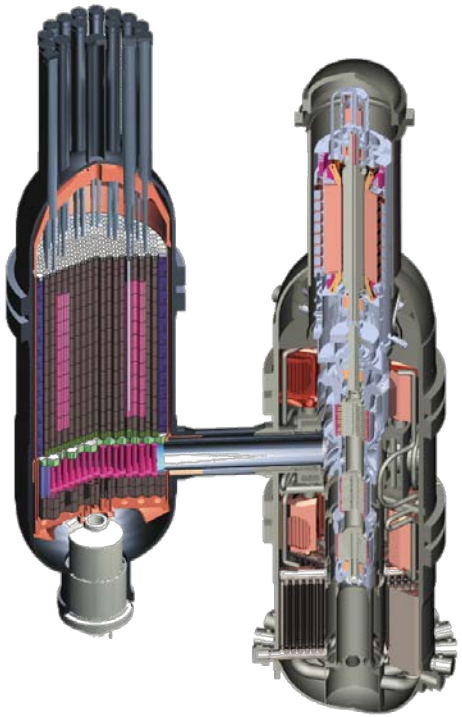
DEMONSTRATION PLANTS

FORT ST. VRAIN – 842 MWt
(U.S.A.)
1976 1989

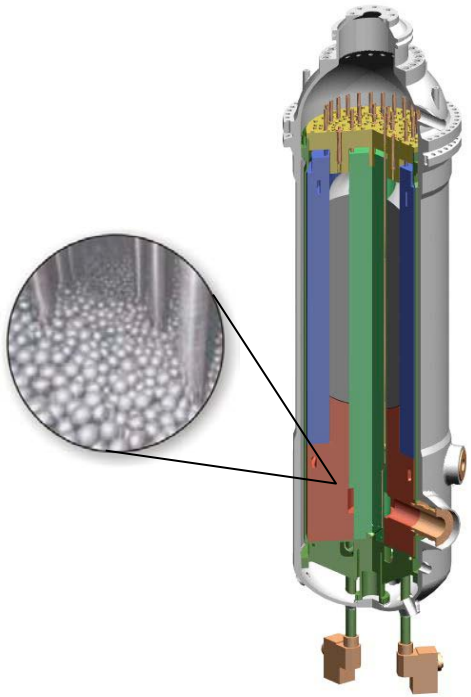
THTR – 750 MWt
(FRG)
1986 1989

Photos courtesy of GA

HTGR Design Dependent On Fuel Form



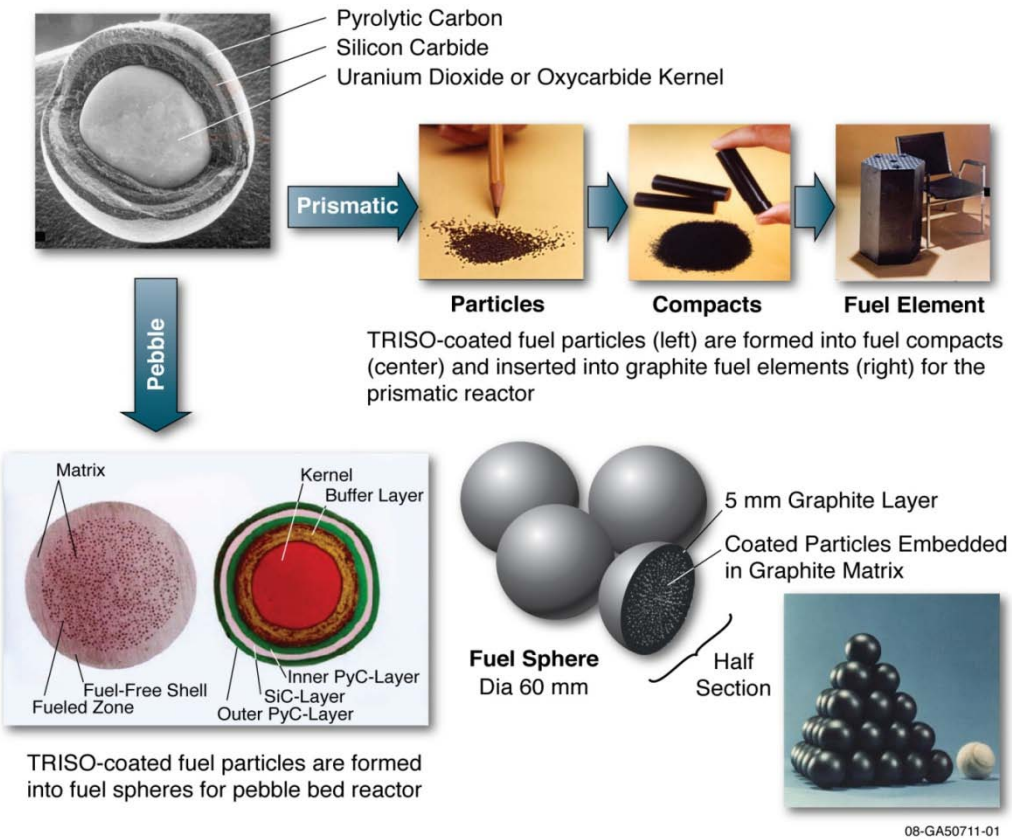
Prismatic
(Dragon, Peach Bottom, FSV, etc.)



Pebble-bed
(AVR, THTR, SA PBMR, China, etc.)

Photos and figures courtesy of GA and PBMR-Pty

TRISO-Coated Particle Fuel is at the Heart of the High Temperature Gas Reactor Concept



HTGRs Feature Passive Safety

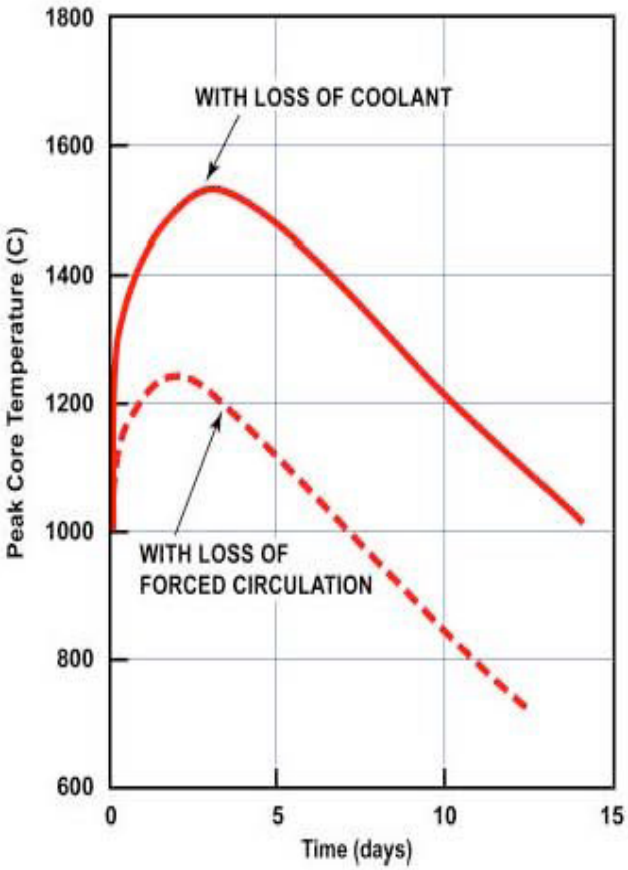


Figure courtesy of GA

- Inert single-phase helium coolant
- Massive graphite core moderator
  - High temperature
  - Large heat capacity
  - Low power density
- Coated particle fuel
  - High temperature
  - Fission particle retention
- Large negative temperature coefficient

HTGRs Offer Economic Advantages

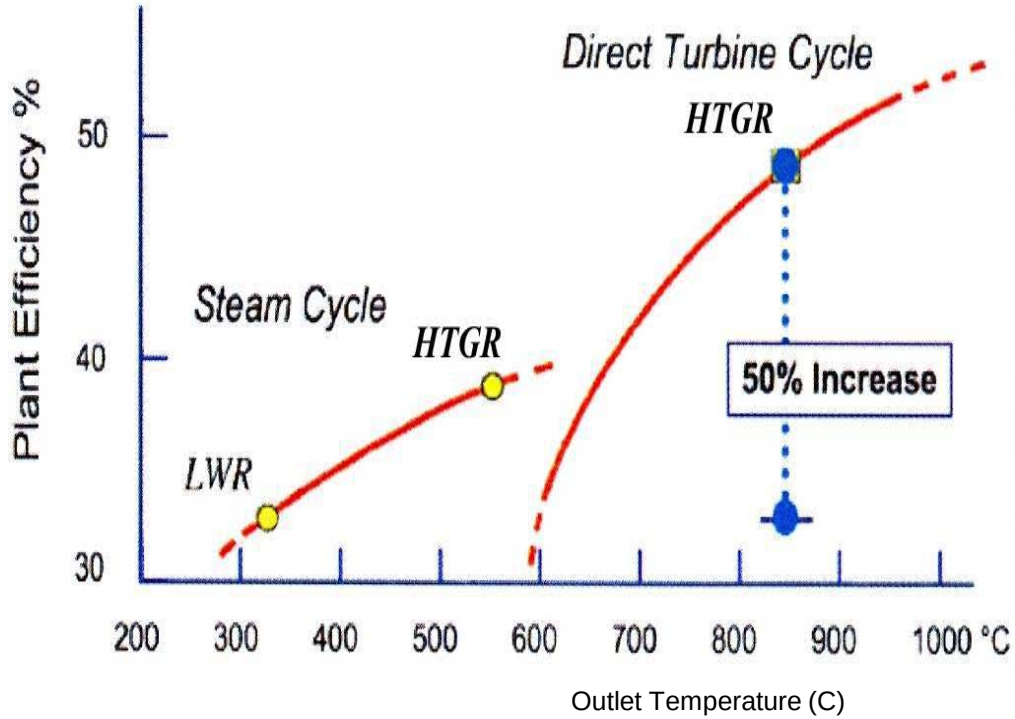
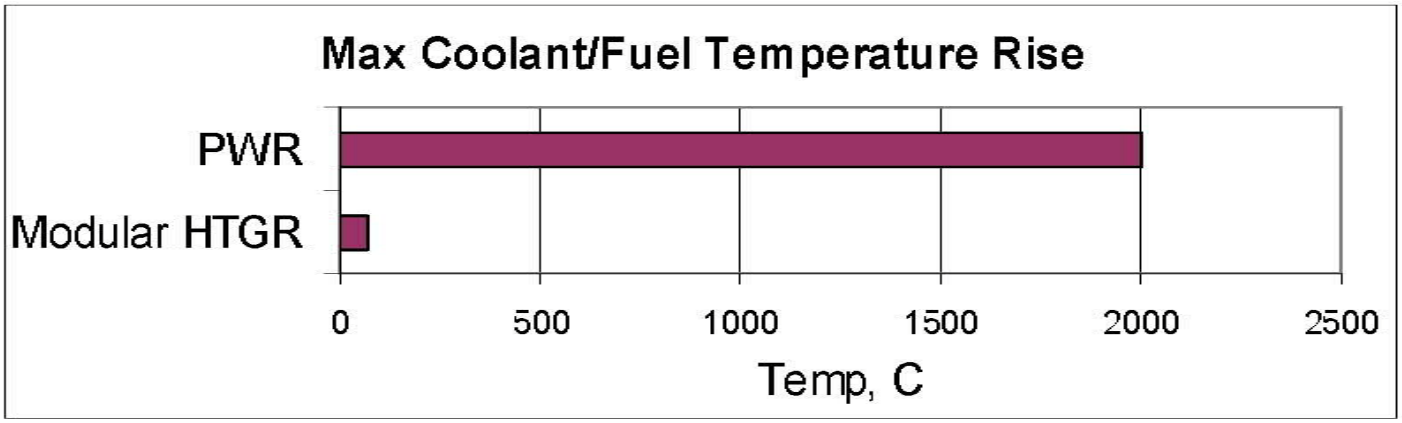


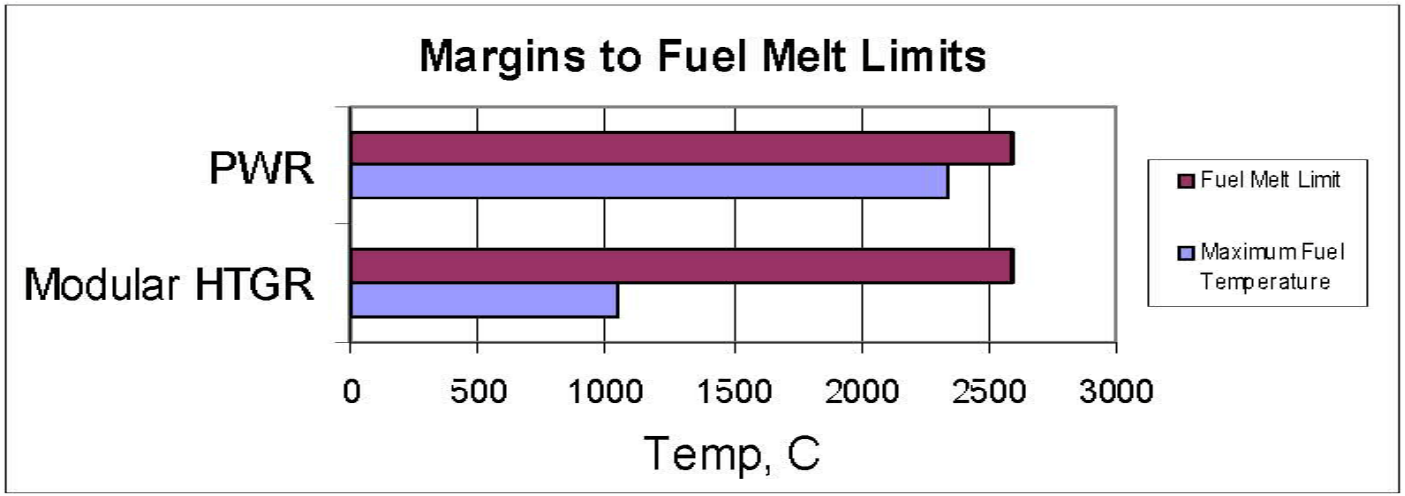
Figure courtesy of GA

- High thermal efficiency
- Reduced emergency planning costs
- Simplified safety systems
- Lower component contamination levels

Increased public acceptance

Advantages of VHTRs: Safety Advantage of VHTRs





Courtesy Global Virtual LLC

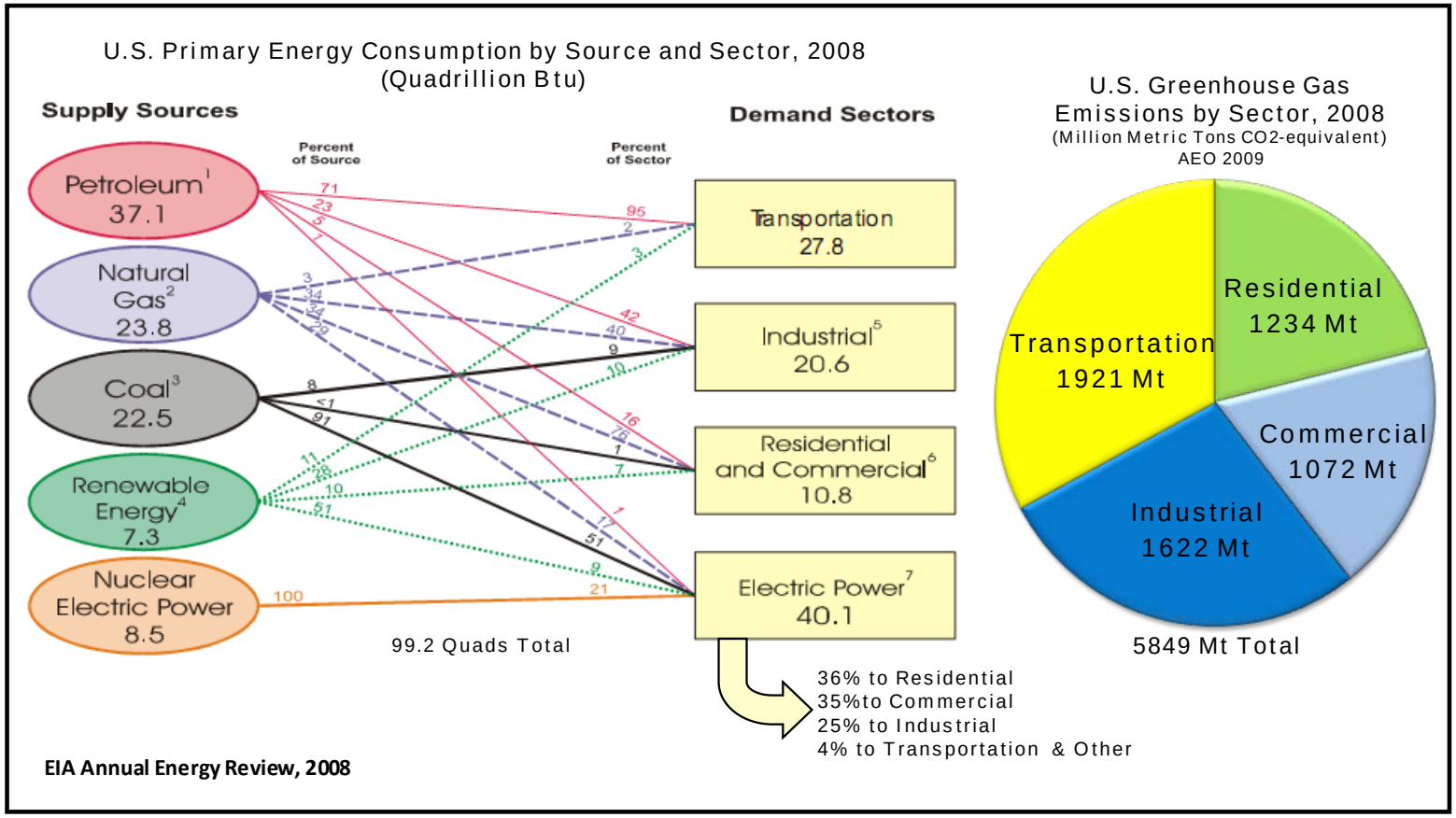
Advantages of VHTRs: Robust High Performance Fuel

Parameter	LWR	PBMR	GT-MHR
Discharge burn up (MWt-day/kg)	55	92	160
Fuel enrichment (%)	5.0	9.4	15
Thermal efficiency (%)	33	42	45
Natural uranium consumption (kg/MWe-day)	0.630	0.573	0.497
Separative work consumption (SWU/MWe-day)	0.397	0.415	0.385
Depleted uranium generation (kg/MWe-day)	0.575	0.547	0.483
Relative natural uranium consumption	1.00	0.91	0.79
Relative SWU consumption	1.00	1.05	0.97
Relative spent fuel volume per unit of electricity generated	1.00	0.47	0.25

Several Factors Motivate Recent U.S. HTGR Interest

- High temperature applications
  - Process heat
  - Hydrogen production
- Inherent safety
  - Simplified licensing and emergency planning requirements
  - Reduced safety requirements
  - More flexible siting requirements
- Political
  - Reduce greenhouse gas emissions
  - Energy Policy Act of 2005 (EPAct)
  - Energy independence
  - Grow U.S. nuclear infrastructure
  - Increased public acceptance

US Energy Consumption and Greenhouse Gas Emissions

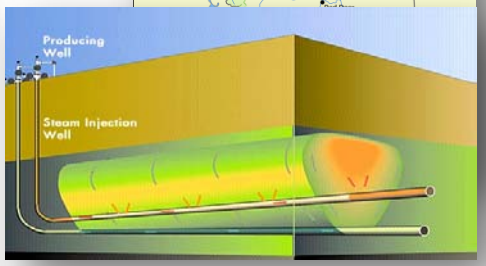


Using High Temperature Reactors to Produce Process Heat and Hydrogen

Petrochemical

Petroleum Refining

Coal-to-Liquids

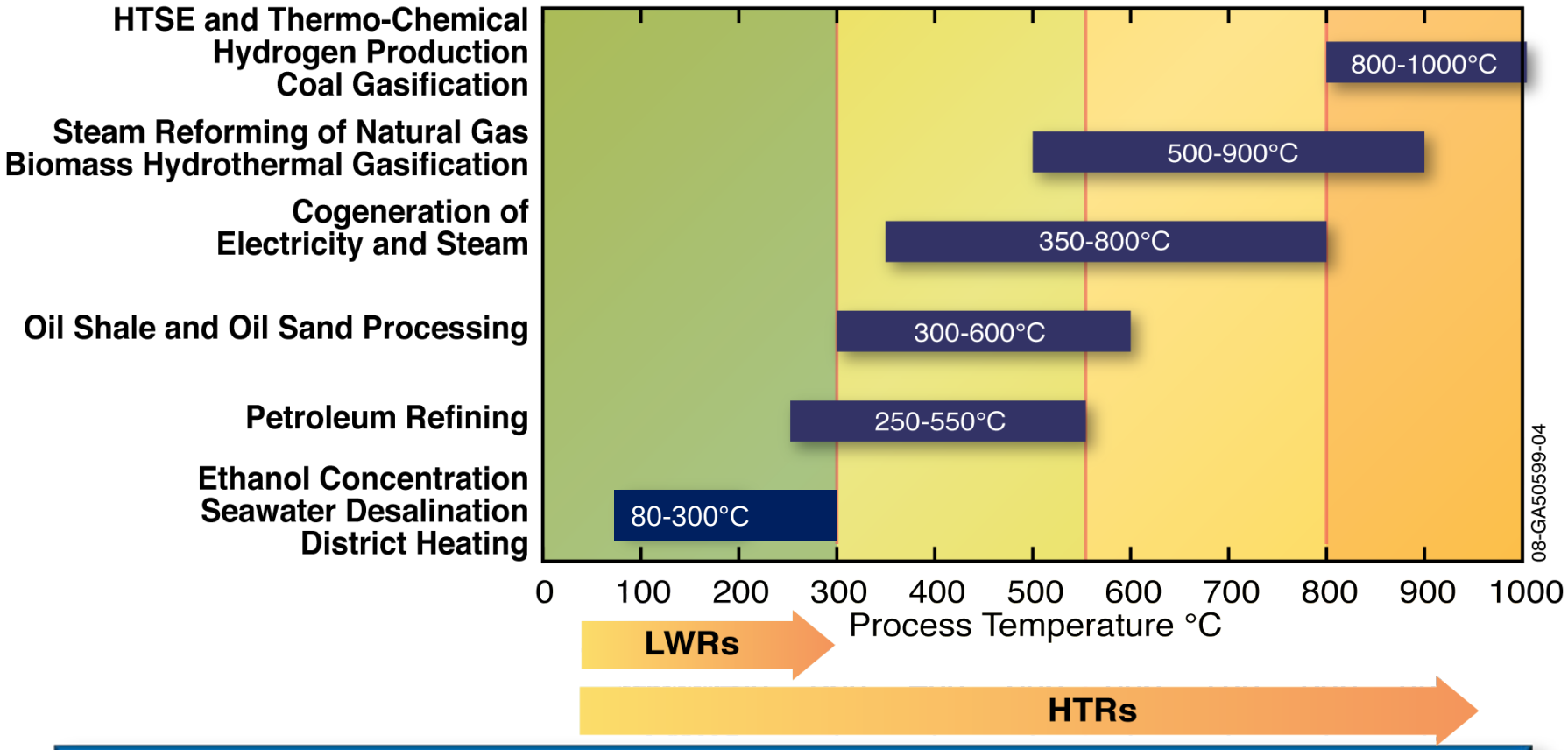


Oil Sands/Shale

Fertilizers/Ammonia

NGNP Next Generation Nuclear Plant

Beyond Electricity – Applications of HTRs

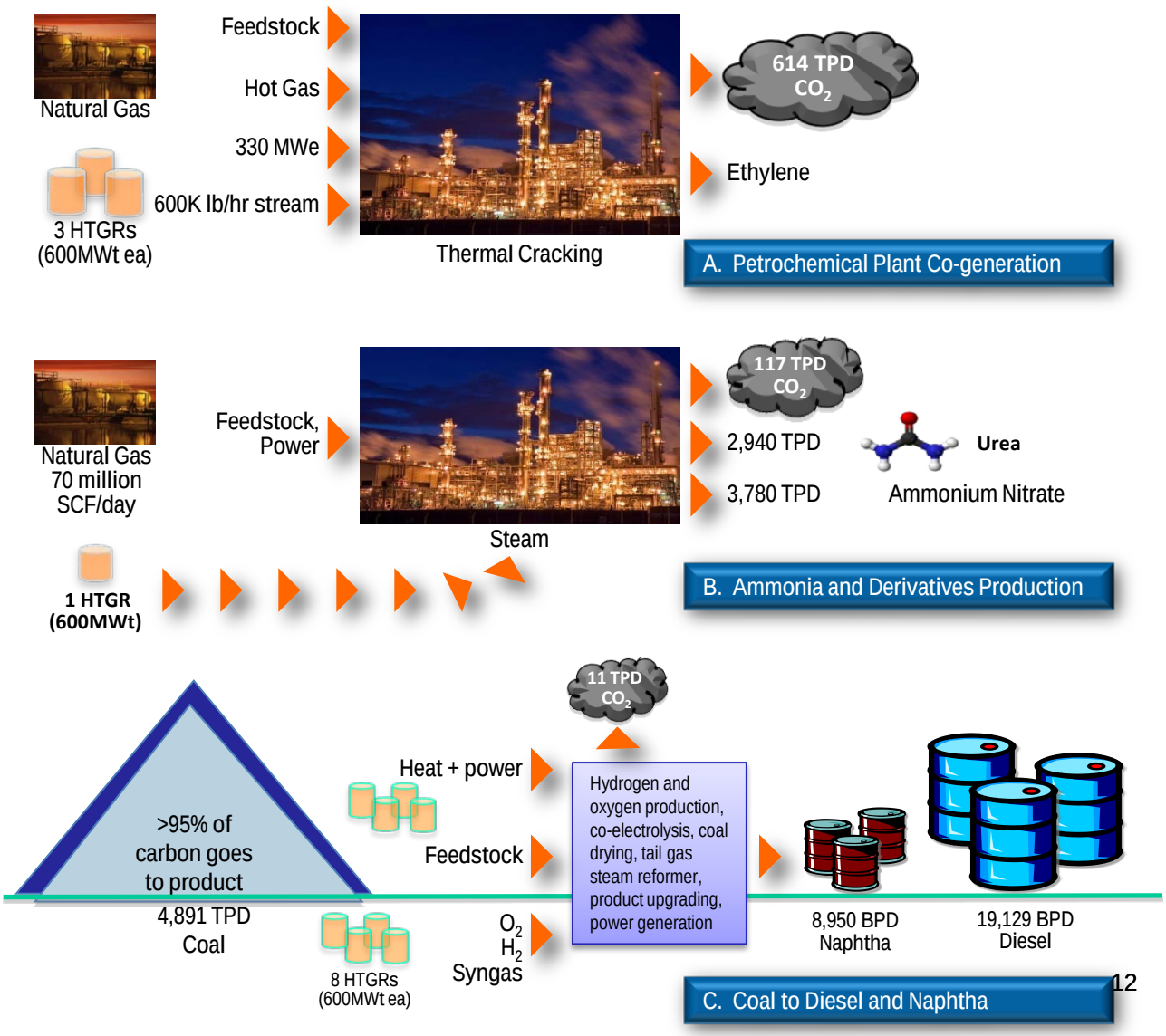


High Temperature Reactors can provide energy production that supports the spectrum of industrial applications including the petrochemical and petroleum industries

Impact of HTGRs on End User CO_2 Emission

CO_2 Emissions (Mt/day)	A	B	C
Technology Today	5868	1283 (1983)	235 (1646)
Limited HTGR supply of energy only	1534	117 (1953)	11 (742)
HTGR supply of steam, electricity and hot gas	614	28	11

(sequestered values)

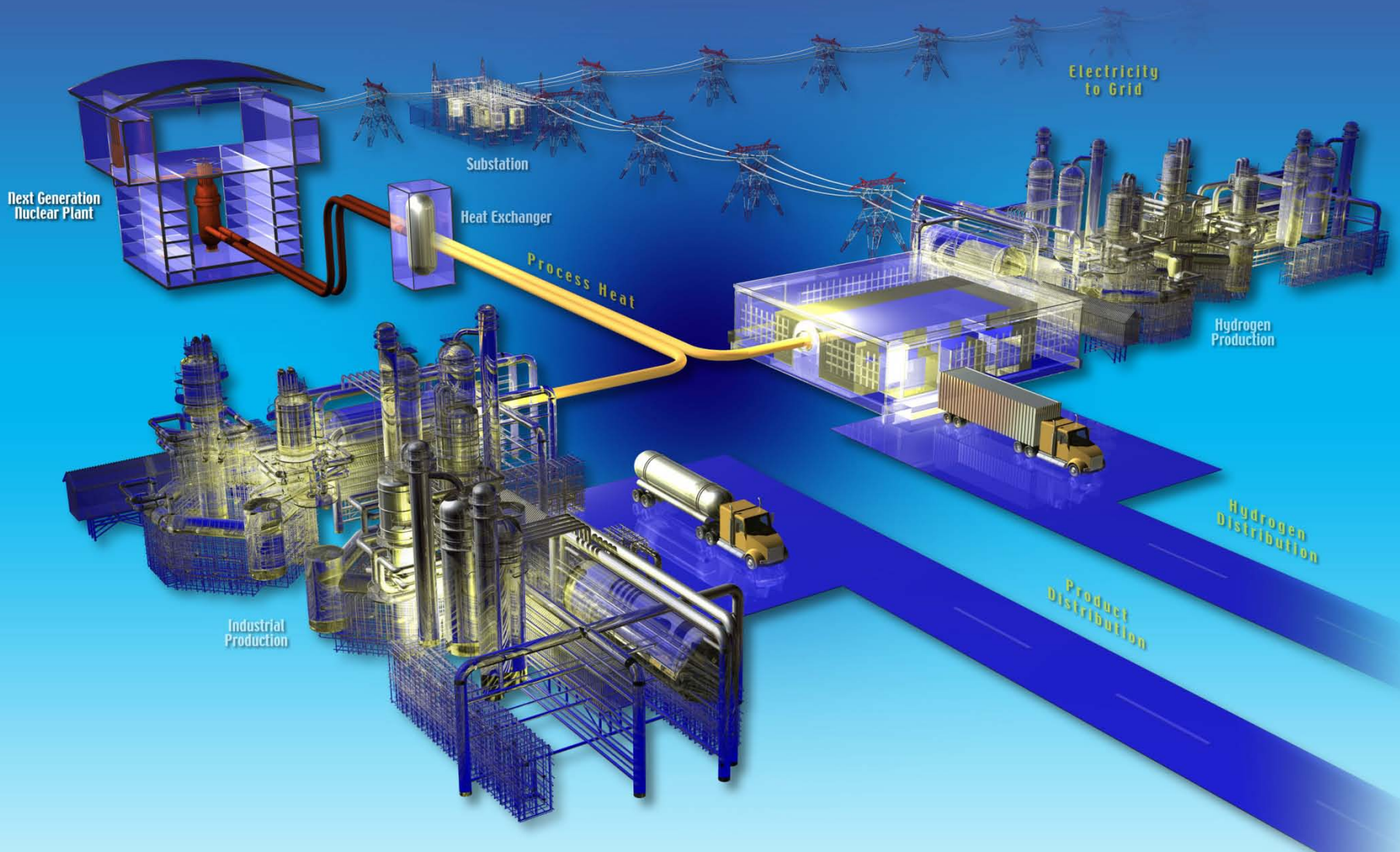


Energy Policy Act of 2005

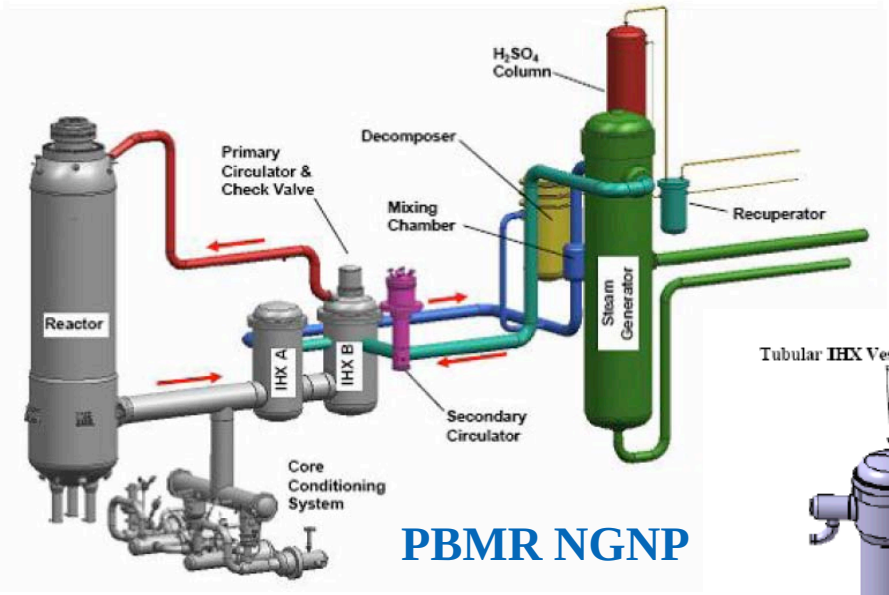
- NGNP Project as authorized by the Energy Policy Act of 2005 to be built
- Use VHTR technology to:
  - Produce electricity
  - Process heat for hydrogen production and other applications
- Conceived as a public/private partnership
  - Demonstrate the basis for commercialization
  - U.S. nuclear industry expected to play integral part in advancing VHTR technologies
- Will be licensed by NRC

NGNP Commercialization

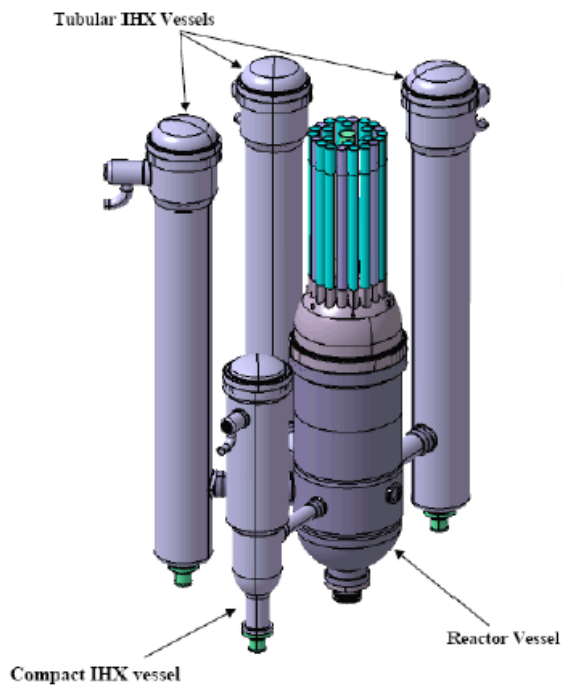
NGNP will enable commercialization of High Temperature Gas-Cooled Reactor technology to provide process heat



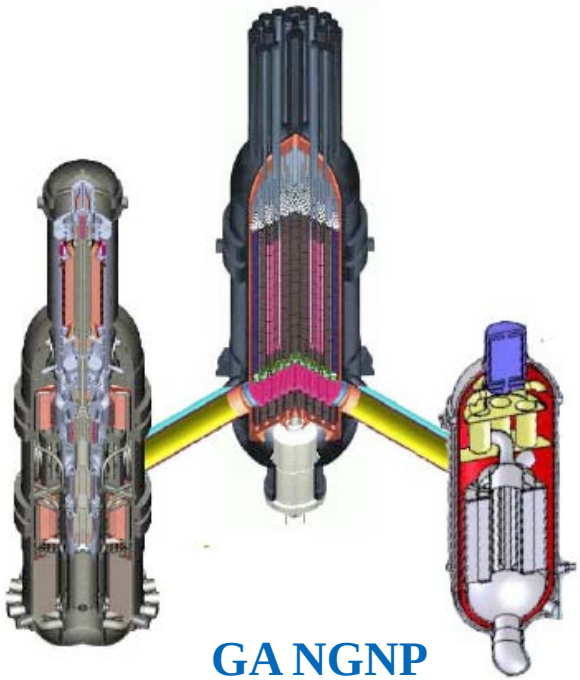
Industry Design Efforts Guide Technology Development



PBMR NGNP



AREVA NGNP



GA NGNP

NGNP Next Generation Nuclear Plant

End-users are Defining the HTGR Commercial Concept

- Energy Delivery
- Co-generation of process steam and electricity of more immediate interest
- Intermediate Nuclear System outlet temperature (~750°C) may suffice
- Hydrogen (and oxygen) production – of interest in selected applications – potentially drives higher Nuclear System outlet temperature requirement

Business Model – nuclear owner/operator in long term business relationship with end-user

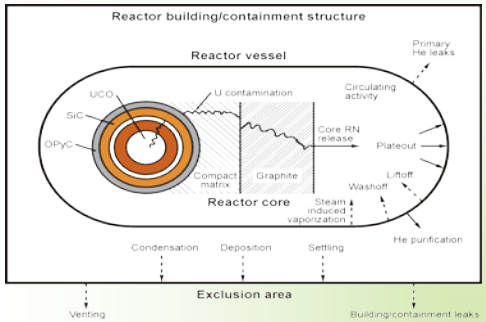
Current NGNP Project Status

- Current plan is for DOE to enter into a financial assistance agreement with private sector to share risks and costs
- Current emphasis is on R&D, reduction of high technical risks and licensing planning issues
- Conceptual design is underway
- Completion of NGNP demonstration plant scheduled for early 2020s

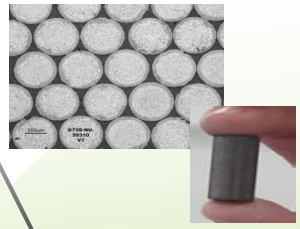
Key Technology Development Areas

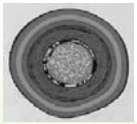
- Fuel Development and Qualification
- Source Term Qualification
- Graphite Materials Qualification
  - Structural (non-fuel) graphite
  - Ceramic composites (Cf/C and SiCf/SiC)
  - Structural ceramics (fused silica, SiC, alumina)
- High Temperature Material Qualification
  - Intermediate heat exchanger (IHX)
  - Hot Duct and hot piping materials
  - Reactor Pressure Vessel (RPV)
  - Core structural metals (core barrel, control rods)
- Design and Safety Methods and Validation

Fuel Development and Qualification

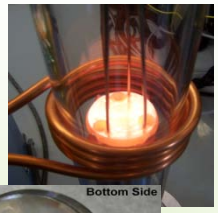


Fission Product Transport & Source Term





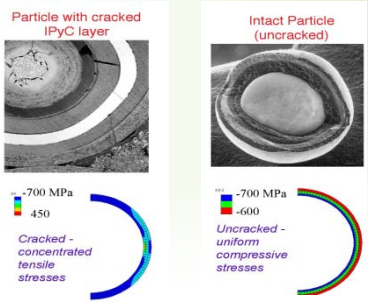
Fuel Supply

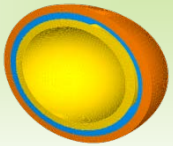


Fuel and Materials Irradiation

- Coated Particle Fuel Fabrication
- Fuel Qualification
- Analysis Methods Development & Validation

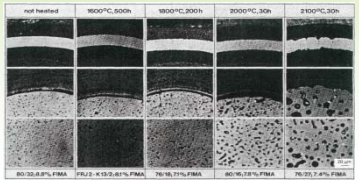
Fuel Performance Modeling





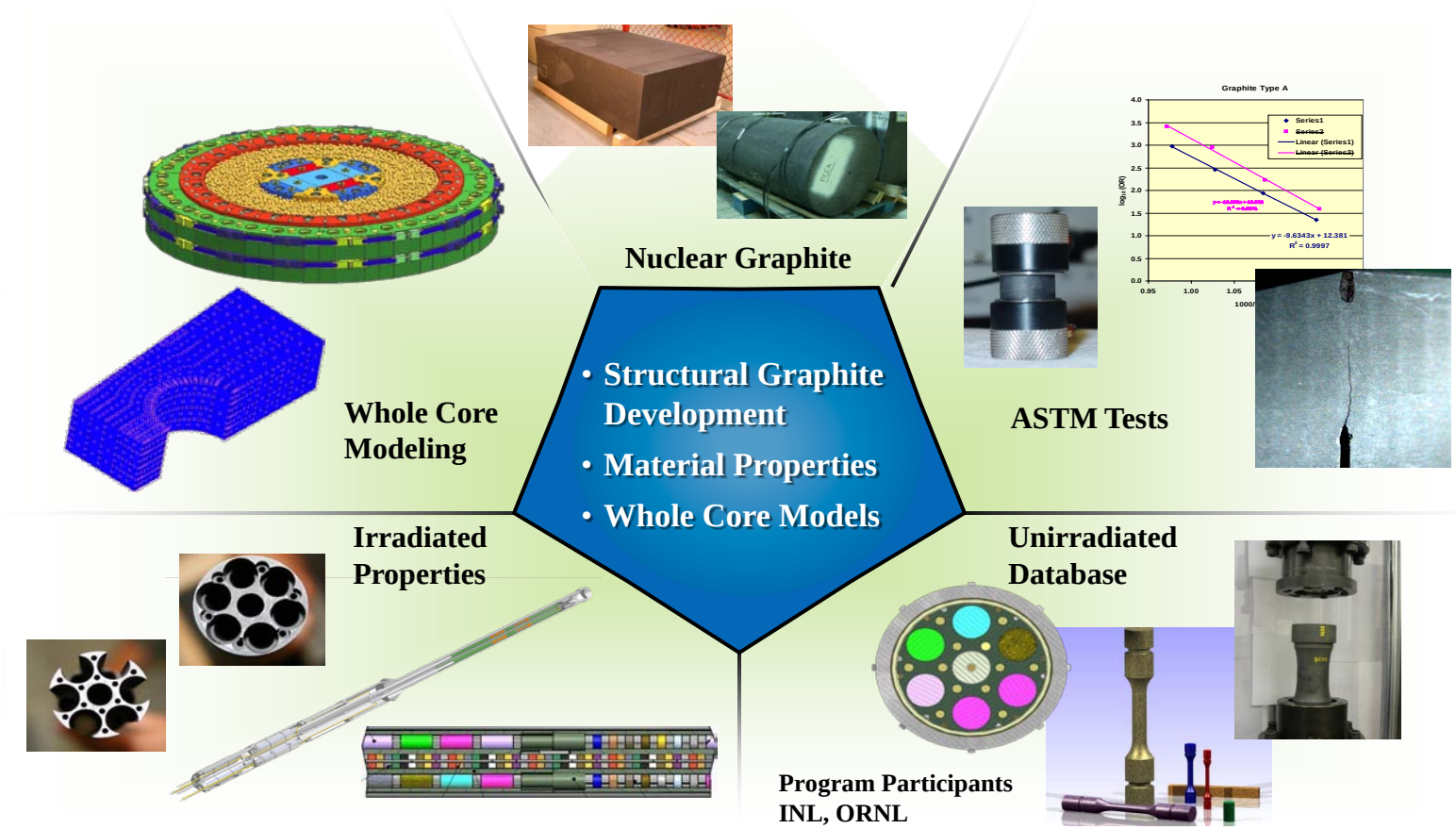
Program Participants
INL, ORNL, BWXT, GA

Post Irradiation Examination & Safety Testing



Next Generation Nuclear Plant

Graphite Development and Qualification

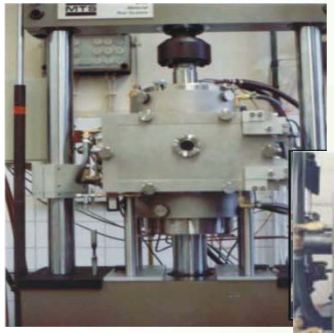


High Temperature Materials

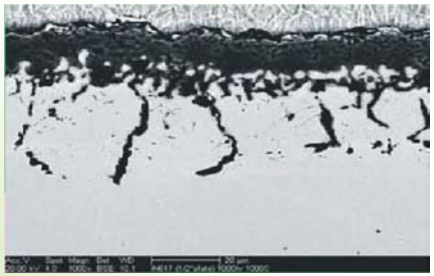
Development of Material Properties, Design Rules, and ASME Codification

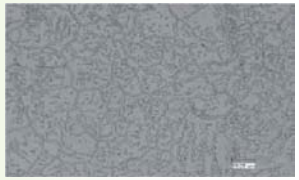
Materials:
- **Pressure vessel steels**
- **Alloys for heat exchangers (up to 800°C)**
- **Control rod sleeves and other core internals**

Mechanical Testing



Material Characterization

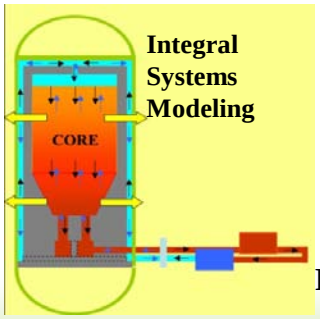




Environmental Testing

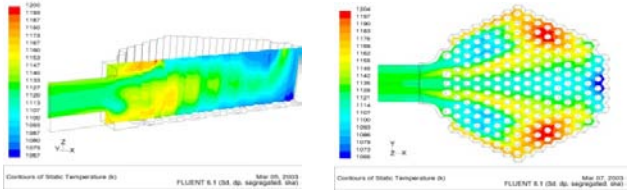
Program Participants INL, ORNL

NGNP Methods Program Elements

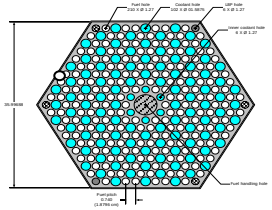


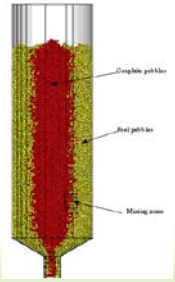
Integral Systems Modeling

Multi-dimensional CFD Simulations



Pebble and Prismatic Physics Methods





Physics, Thermal and System Safety Methods & Code Development and Application

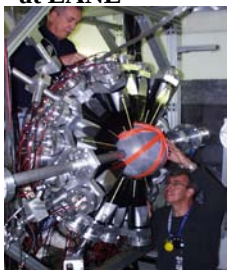
Design and Safety Analysis Methods Development & Validation

Separate Effects & Integral Testing Under Normal & Off-Normal Conditions

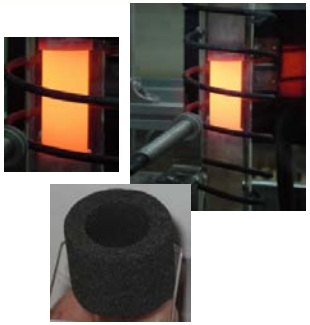
ANL Facility to Validate VHTR Reactor Cavity Cooling System Behavior

INL's Matched Index of Refraction (MIR) Facility to Study 3-D Flow Effects in Plena

Cross-section Measurements at LANL



Program Participants LANL, ANL, INL



Graphite/Air Reaction Rate Testing

Scaled Vessel Testing

Summary

- Prior experience demonstrates HTGR technology offers unique safety and economic benefits
  - High efficiency power production
  - High temperatures for process heat and hydrogen production
  - Inherent safety
- The U.S. NGNP Project defined to:
  - Develop and implement technologies important to achieving design and performance requirements through collaboration with commercial end-users
  - Demonstrate basis for commercialization of nuclear system, hydrogen production facility and power conversion concepts
  - Establish basis for licensing commercial version of NGNP by NRC by licensing prototype
- R&D focused to address technical risks identified in industry / regulatory / laboratory interactions