The Next Generation Nuclear Plant (NGNP)

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High Temperature, Gas-Cooled Reactor Experience

HTGR PROTOTYPE PLANTS ⟷ **DEMONSTRATION PLANTS**

DRAGON
(U.K.)
1963 1976

AVR
(FRG)
1967 1988

PEACH BOTTOM 1
(U.S.A.)
1967 1974

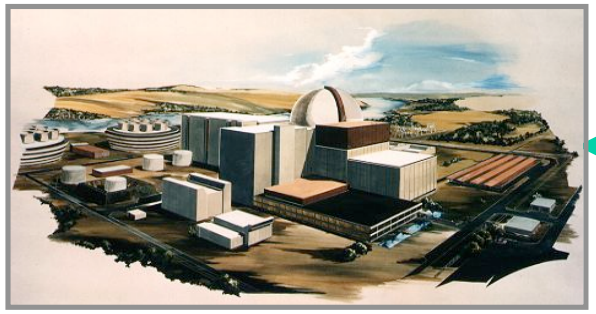
HTTR
(JAPAN)
1999-present

HTR-10
(CHINA)
2000-present

FORT ST. VRAIN
(U.S.A.)
1976 1989

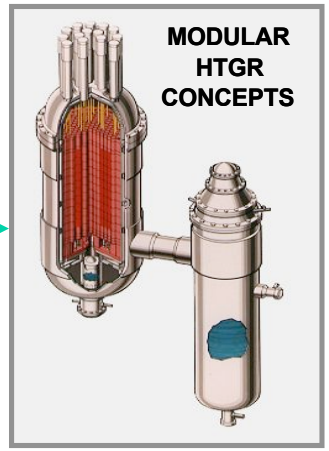
THTR
(FRG)
1986 1989

LARGE HTGR PLANTS



HTGR TECHNOLOGY PROGRAM

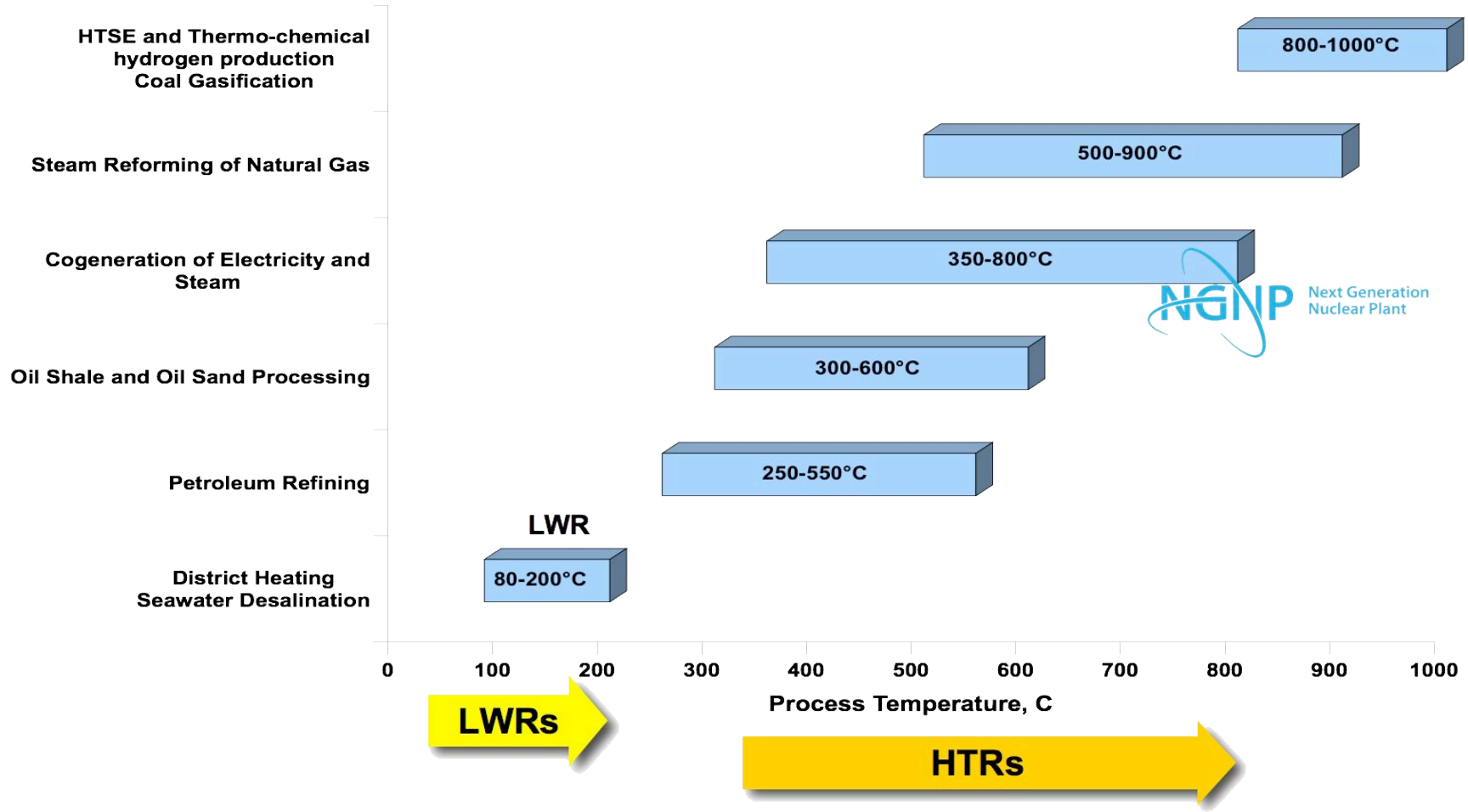
- **MATERIALS**
- **COMPONENTS**
- **FUEL**
- **CORE**
- **PLANT TECHNOLOGY**



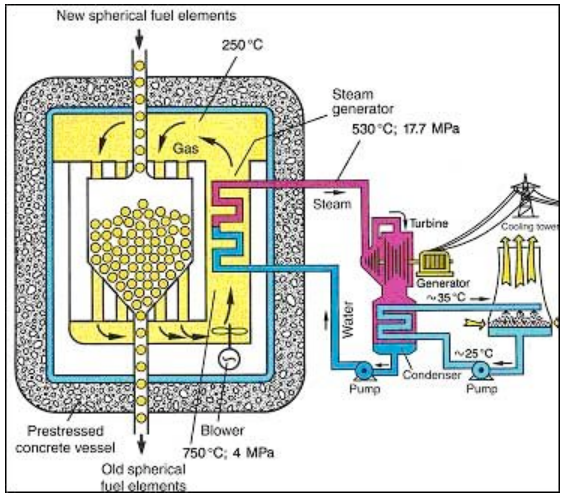
High Temperature Helium Cooled Reactor Operating Parameters

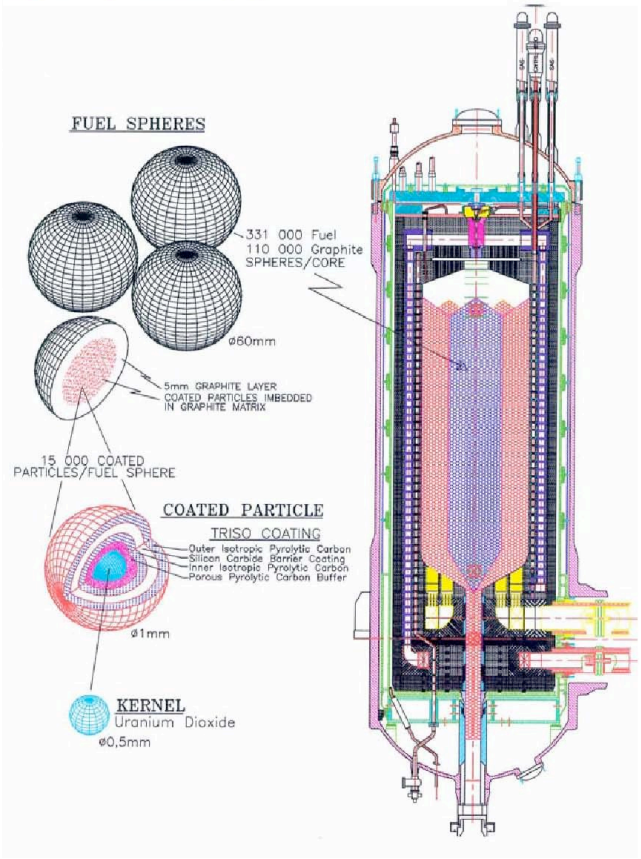
	Dragon	AVR	Peach Bottom	Ft. St. Vrain	THTR-300	HTTR
Country of Origin	OECD	Germany	U.S.	U.S.	Germany	Japan
Thermal Power MW	21.5	46	115	842	750	30
Net Electric Power MW	--	13	40	330	300	10
Core Outlet Temp°C	750	950	725	775	750	950
Helium Pressure MPa	2.0	1.1	2.25	4.8	3.9	4
Steam Temp°C	--	505	538	538	530	--
Reactor Type	Sleeve	Pebble	Sleeve	Block	Pebble	Prism
Vessel Material	Steel	Steel	Steel	PCRV*	PCRV	Steel
Date of Operation	1965-1976	1966-1989	1966-1974	1974-1989	1985-1989	1999

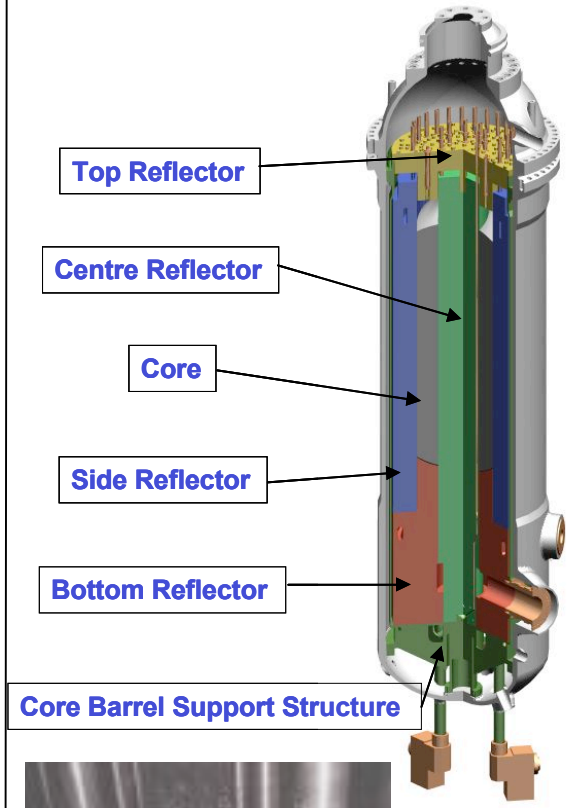
Different Industrial Processes Require Temperatures Only Attainable by VHTRs

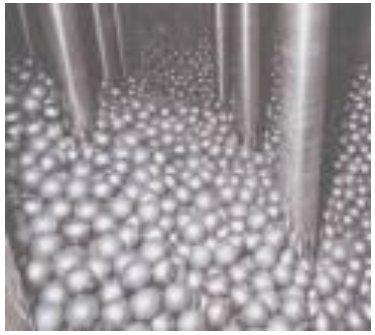


Pebble Bed Reactor

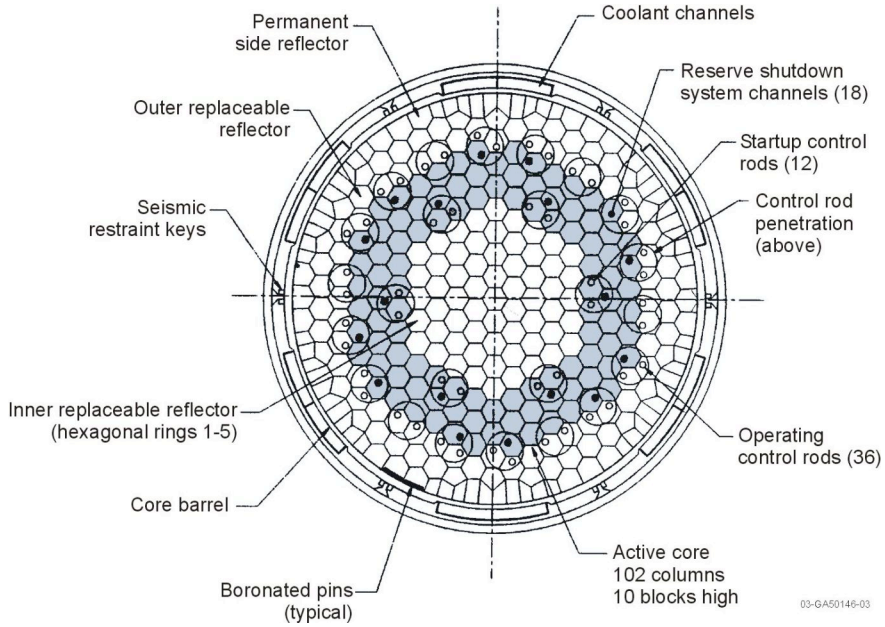


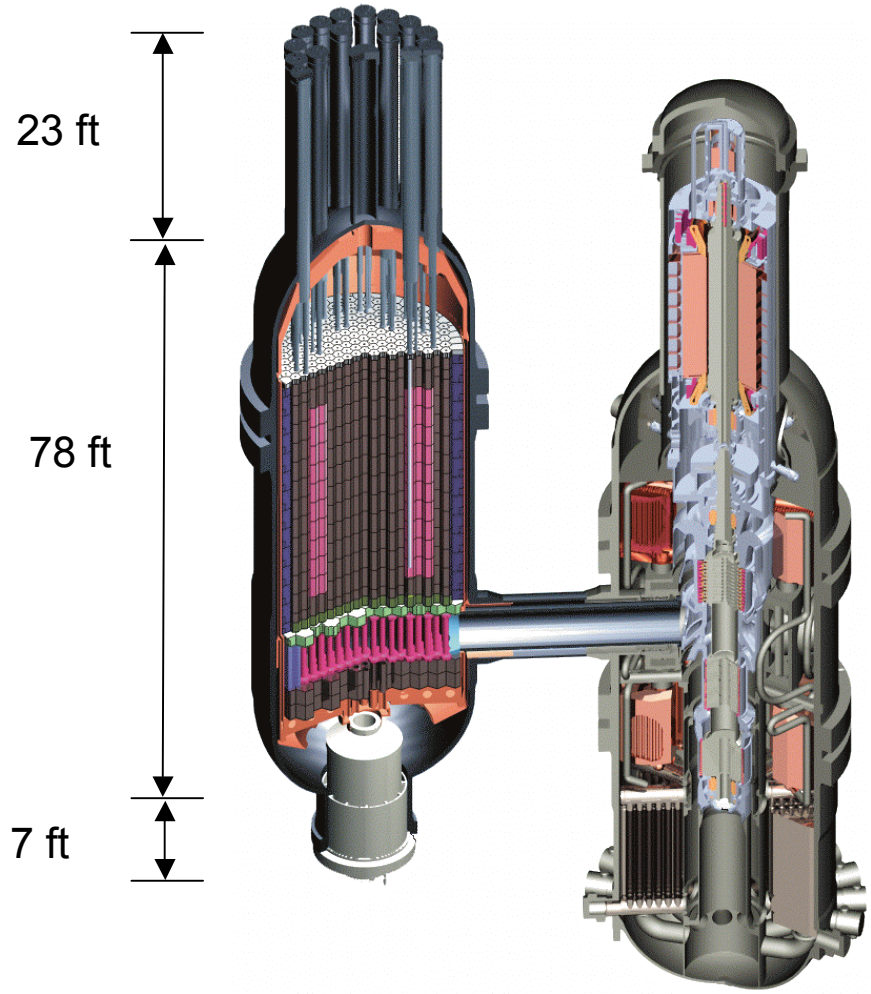




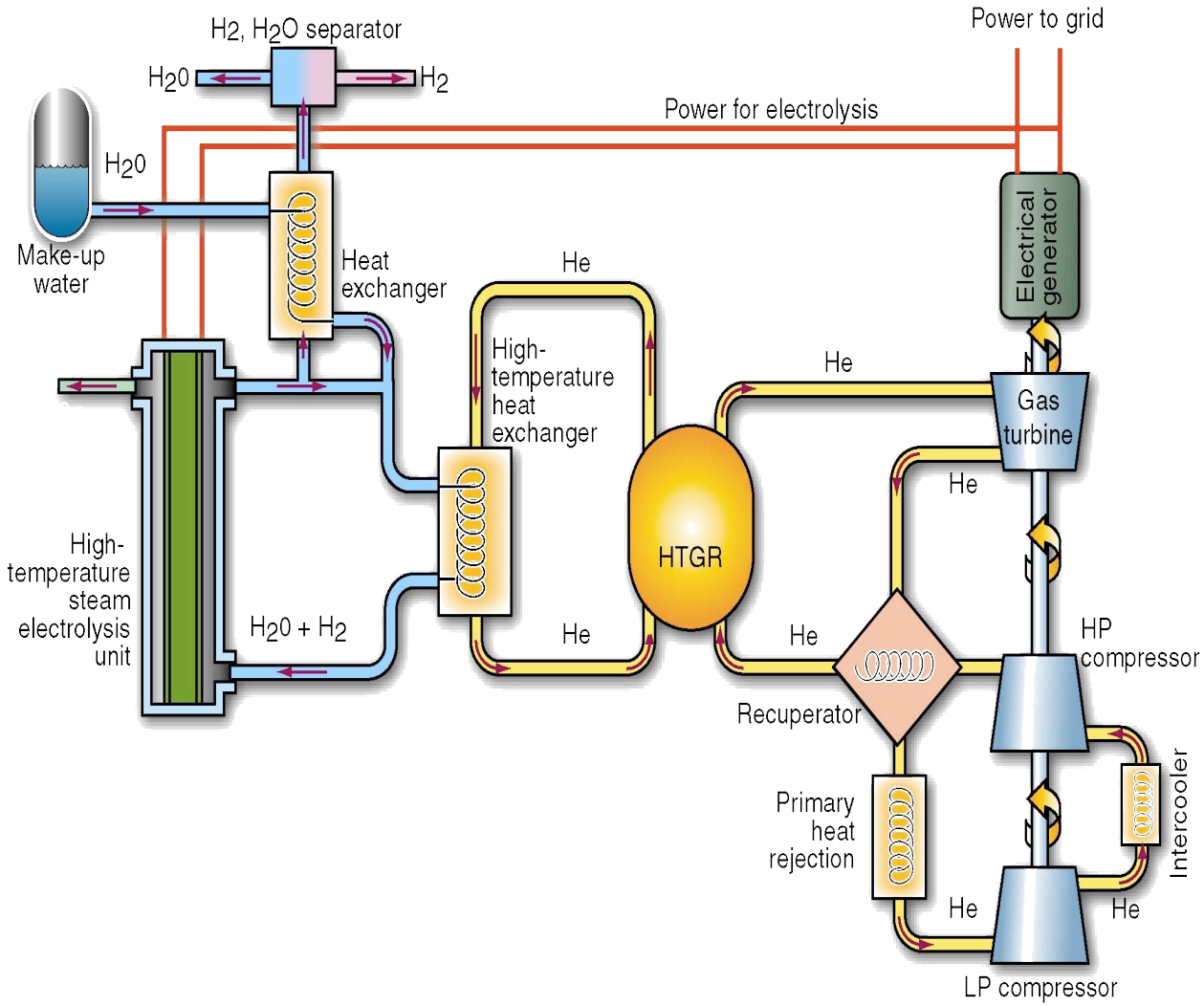


Prismatic Reactor



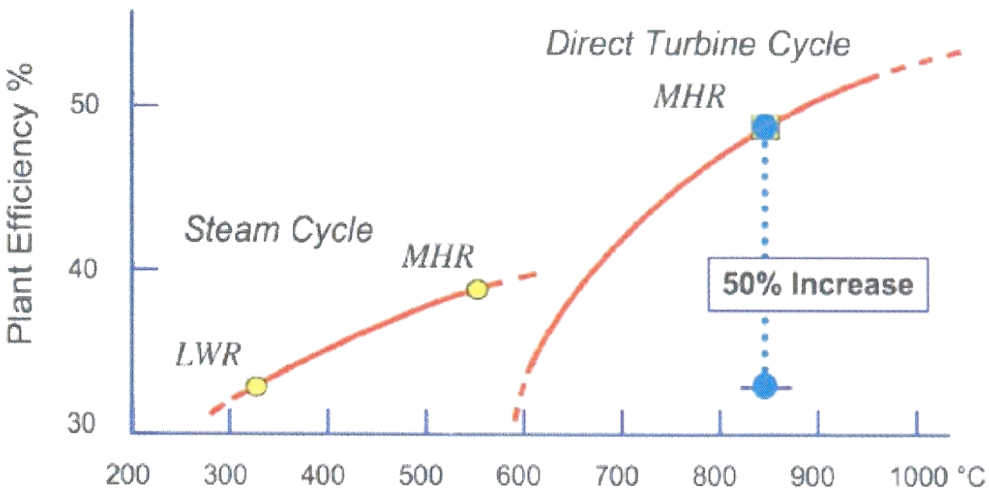


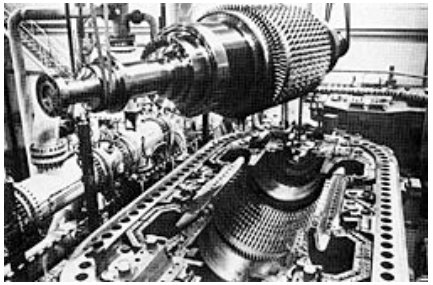
Schematic of VHTR/HTGR to make Hydrogen and Electricity



Advantages of VHTRs: High Thermodynamic Efficiency

- High plant outlet/turbine inlet temperature allows use of gas turbine instead of traditional steam cycle
- Efficiency increases to ~45-47% depending on engineering details of power conversion system

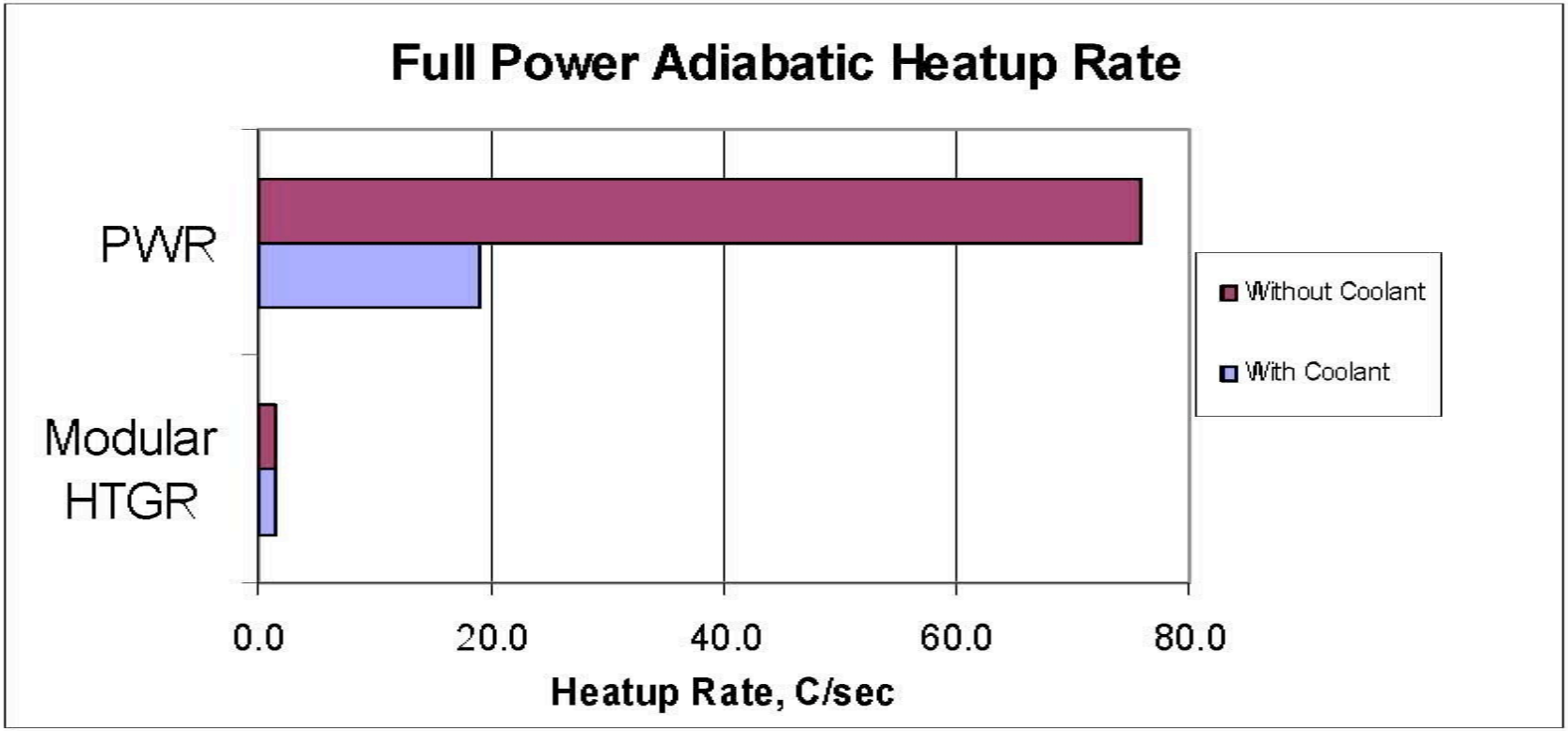




Advantages of VHTRs: Passive Safety Characteristics (Rely on physics instead of operator actions)

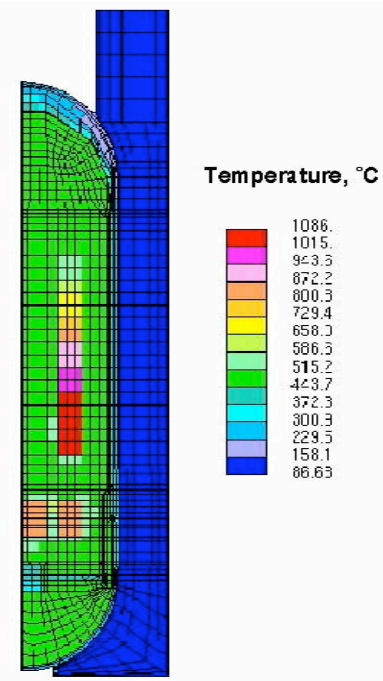
- Inert Helium coolant: no chemical reactions
- High heat capacity of graphite core
- Low power density (1/30th that of LWR)
- Large thermal inertia (very slow transients)
- Large negative temperature coefficient

Passive Safety Characteristics: Very Long Response Time

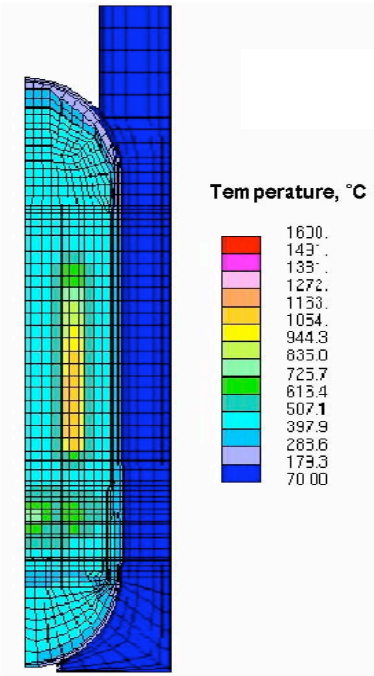


Courtesy Global Virtual LLC

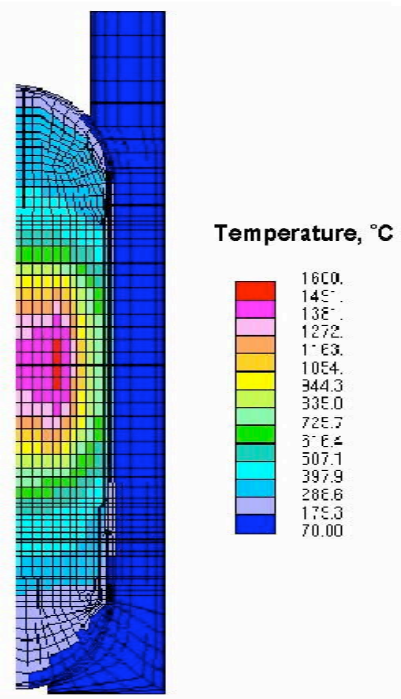
Long Time to Reach Peak Temperature



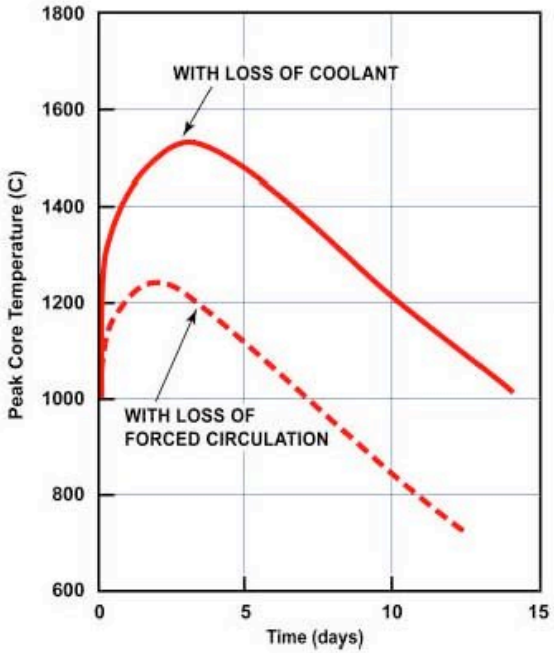
T = 0 Hours



T = 5 Hours

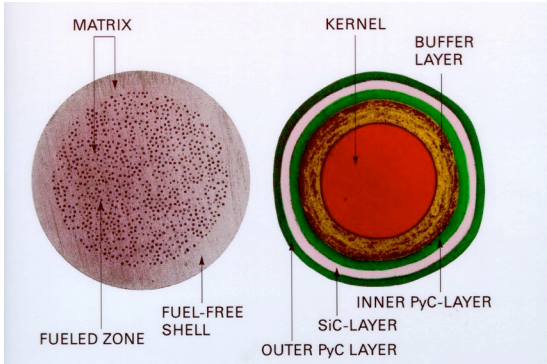


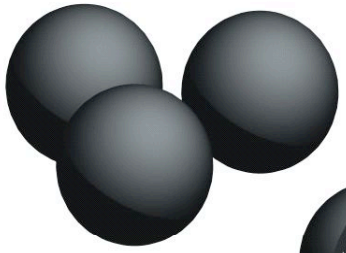
T = 71 Hours



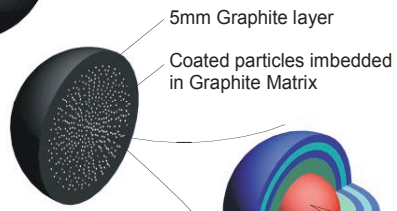
VHTRs Share a Common Coated Particle Fuel

For Pebble Bed

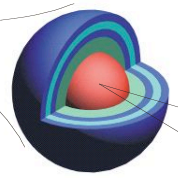




Dia. 60mm
Fuel Sphere

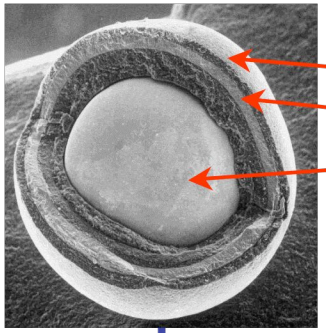


Half Section



Dia. 0,92mm
Coated Particle

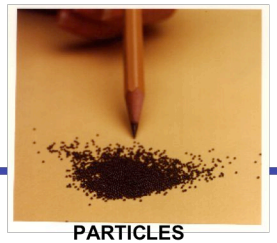
Dia.0,5mm
Fuel



Pyrolytic Carbon

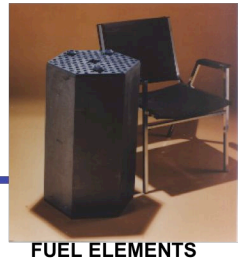
Silicon Carbide

Uranium Oxycarbide Kernel



PARTICLES

COMPACTS

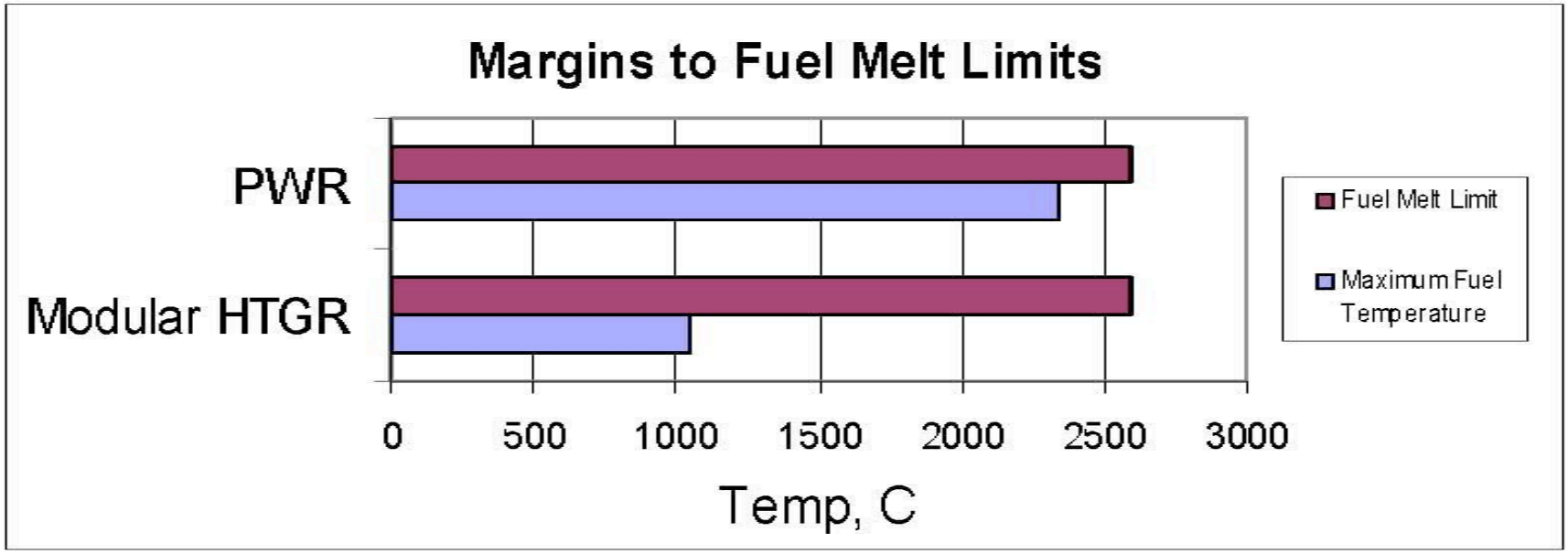


FUEL ELEMENTS

For Prismatic

TRISO-coated fuel particles (left) are formed into fuel compacts (center) and inserted into graphite fuel elements (right)

Advantages of VHTRs: Large Margin to Fuel Integrity Limits



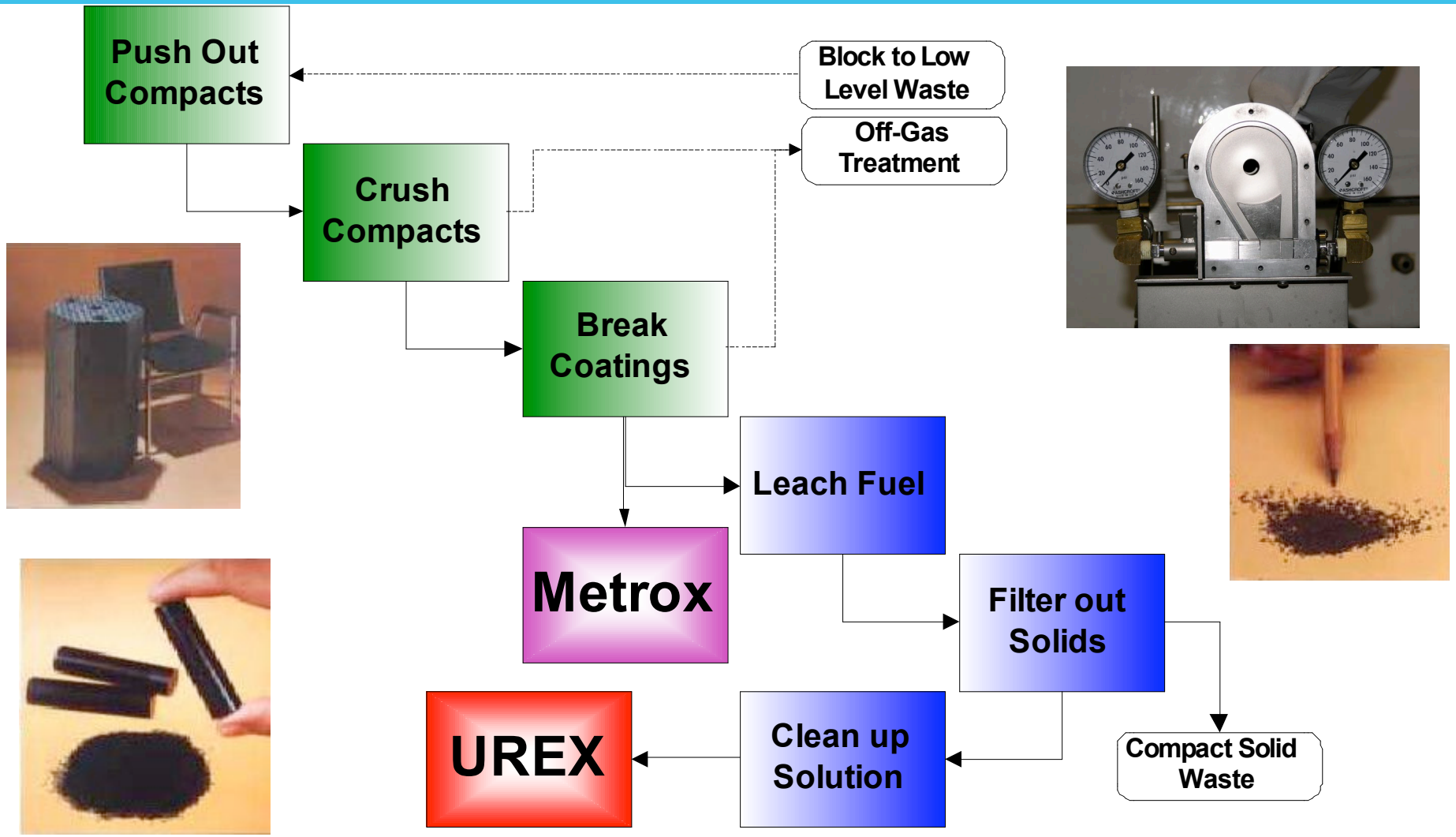
Courtesy Global Virtual LLC

Advantages of VHTRs: Robust High Performance Fuel

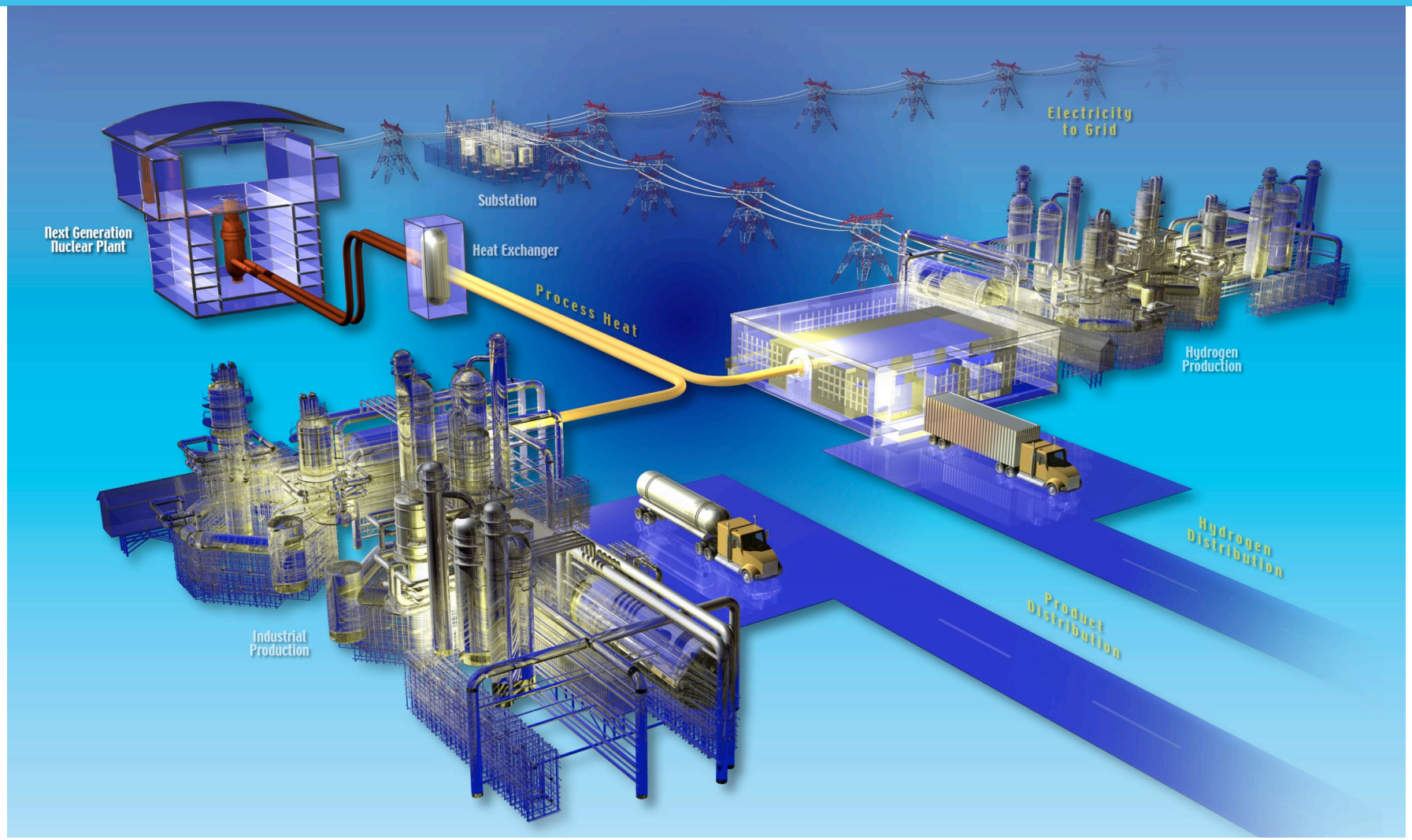
- High burnup fuel
  - Less waste
  - More energy produced per unit mass of uranium
  - Better fuel utilization
- Robust
  - Ultra high quality, very low fabrication defects
  - Large margins to fuel failure
  - High fission product retentiveness
- Flexible fuel cycle
  - U, Th, or Pu

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

Recycle path for VHTR fuel



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



Energy Policy Act of 2005

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

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

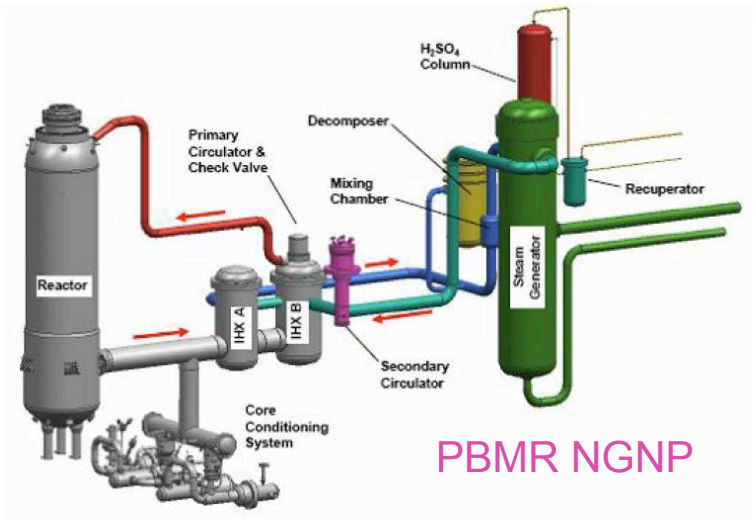
Schedule – 2021 operational date for NGNP demonstration at far end of acceptable schedule

Next Generation Nuclear Plant (NGNP)

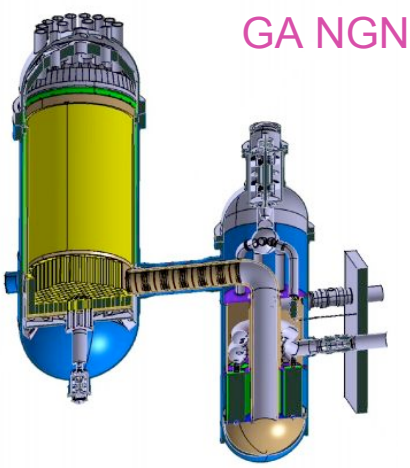
- 600 MWt (upper limit), helium cooled high temperature reactor
- Outlet temperature from 750 to 800°C
- Process heat demonstration - hydrogen production by thermo-chemical cycle or high temperature electrolysis
- Electricity generation
- 60-year design life - however, components can be replaced

NGNP Next Generation Nuclear Plant
E=MC² The Energy of Industry

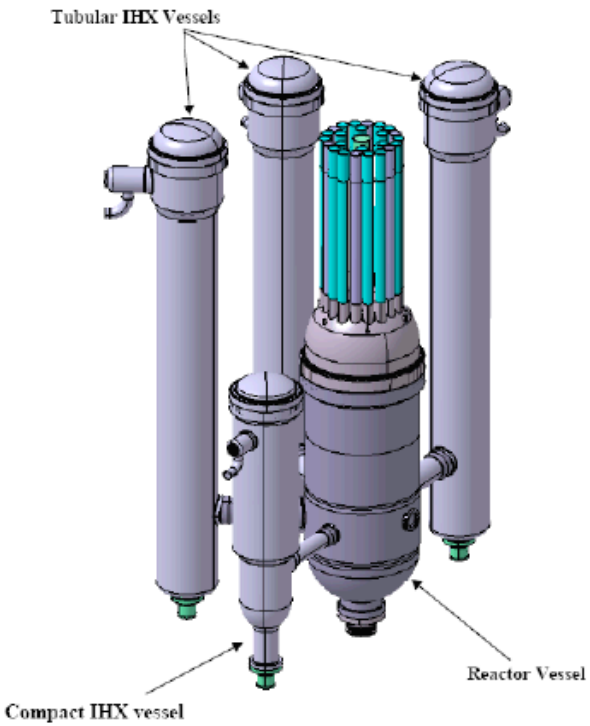
Application of VHTR Technology to NGNP: Preconceptual Designs



PBMR NGNP



GA NGNP

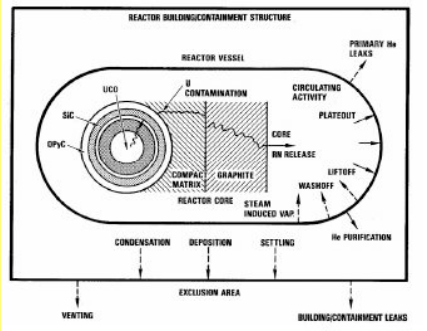


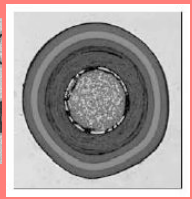
AREVA NGNP

Key VHTR Technology Development Areas

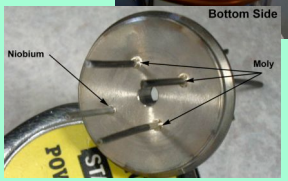
- Fuel Development and Qualification
- Source Term Qualification
- Graphite Materials Qualification
  - Structural (non-fuel) graphite
  - Ceramic composites (Cf/C and SiCf/SiC)
  - Structural ceramics (Fused silica, SiC, alumina)
- High Temperature Material Qualification
  - Intermediate heat exchanger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

NGNP/AGR Fuel Program Elements





Fuel Supply



Fission Product Transport & Source Term

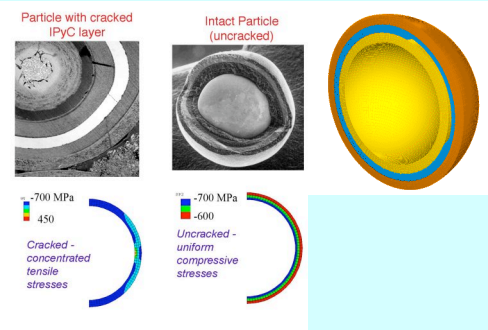
Coated Particle Fuel Fabrication

Fuel Qualification

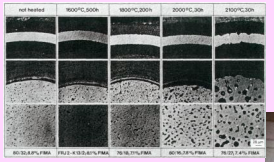
Analysis Methods Development & Validation

Fuel and Materials Irradiation

Fuel Performance Modeling



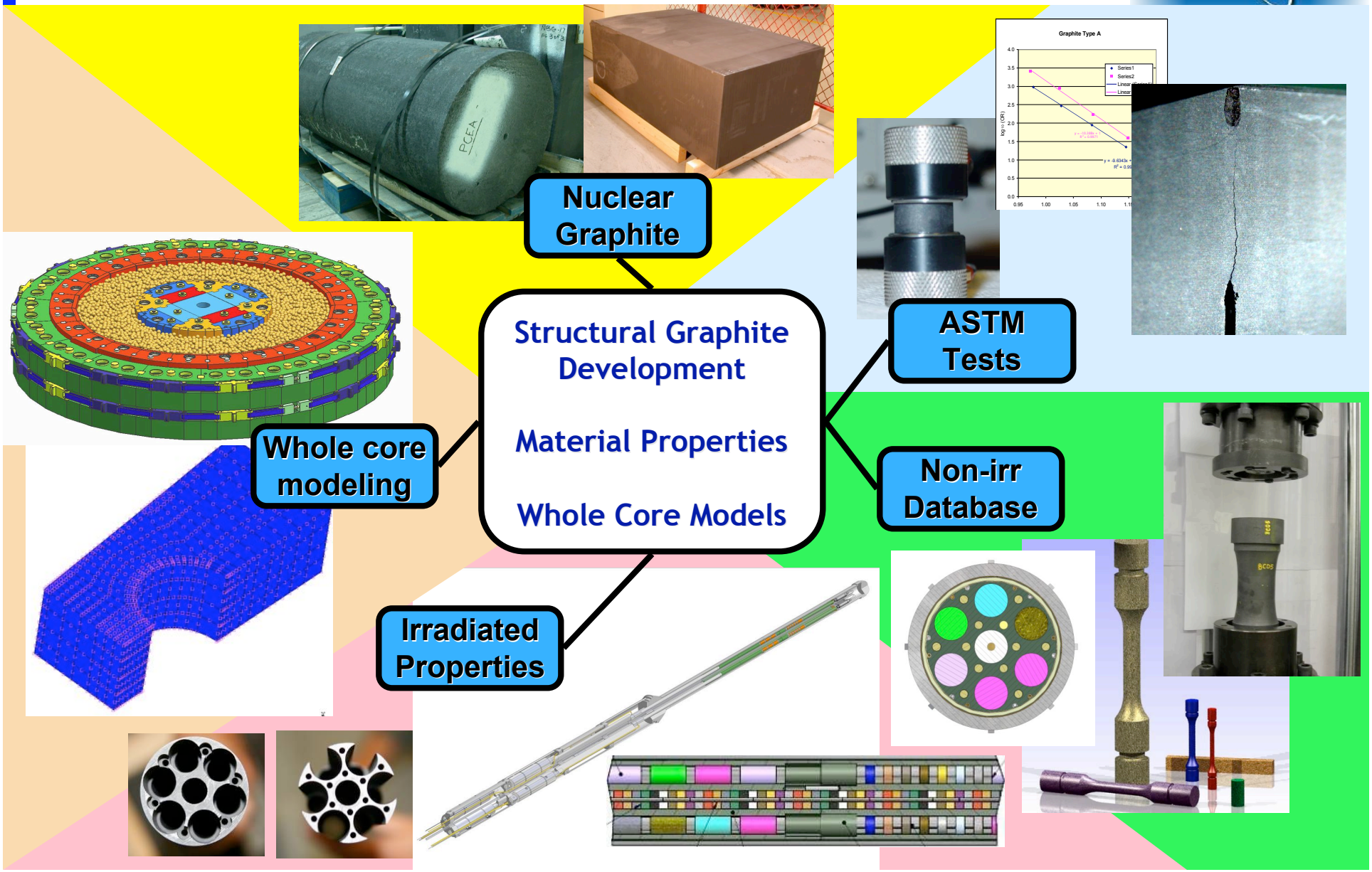
Post Irradiation Examination & Safety Testing



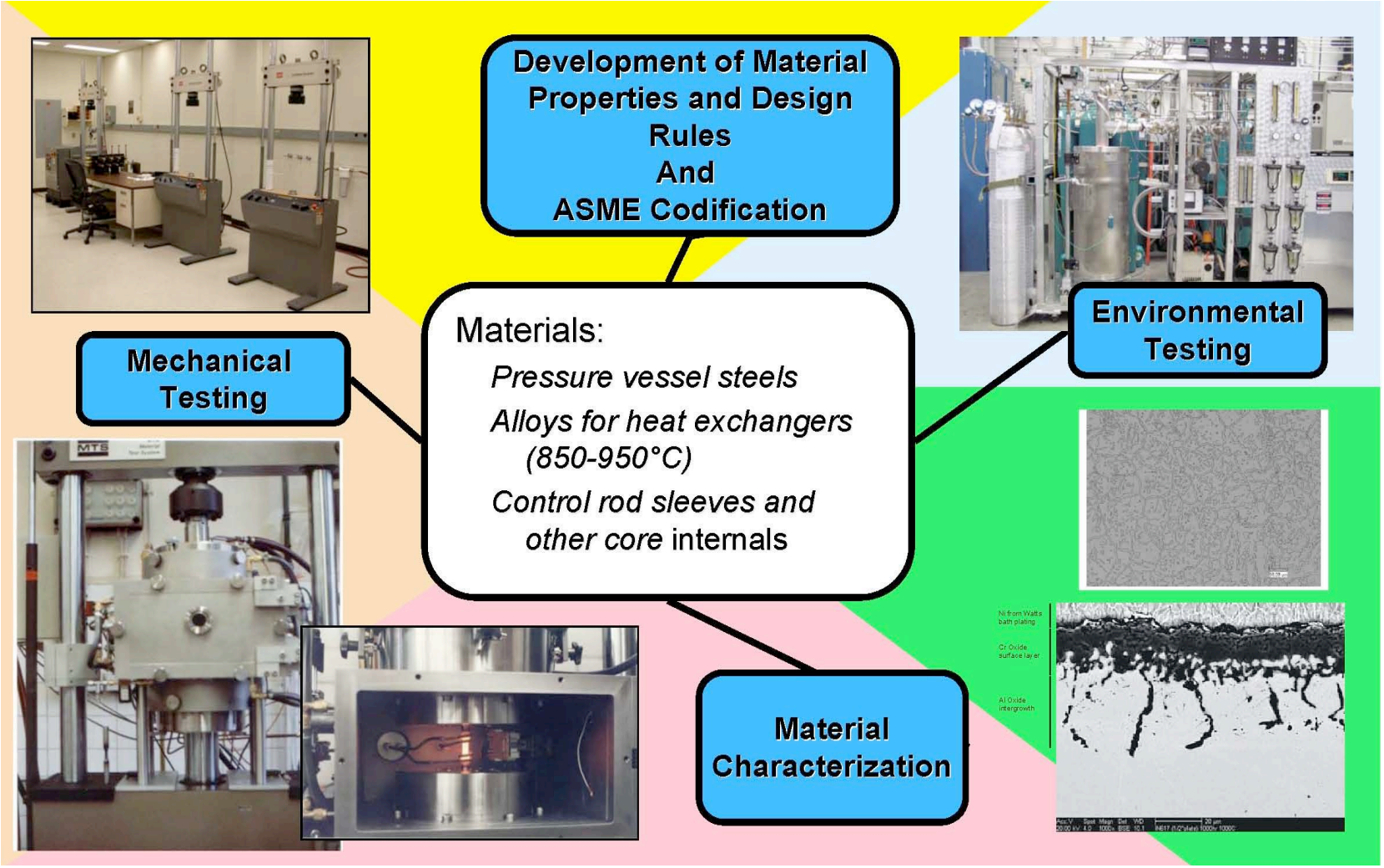
Program Participants

INL, ORNL BWXT, GA

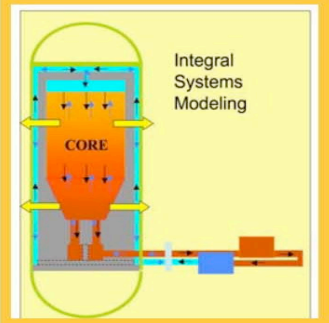
Overview of NGNP Graphite Program



Overview of NGNP High Temperature Materials Program

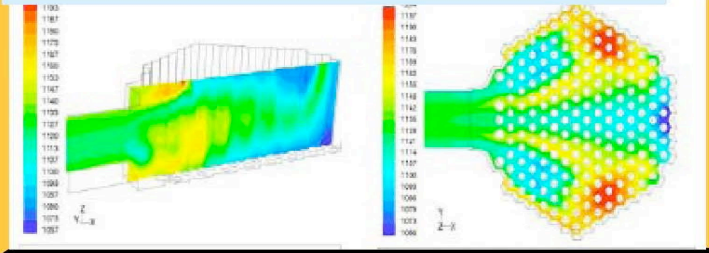


NGNP Methods Program Elements

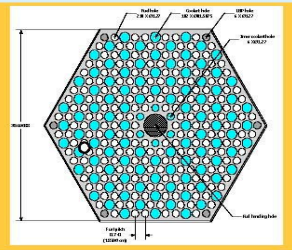


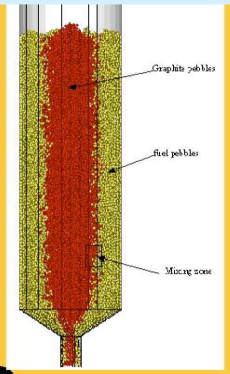
Integral Systems Modeling

Multi-dimensional CFD Simulations



Pebble and Prismatic Physics Methods

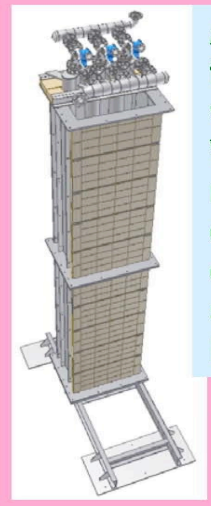




Physics, Thermal and System Safety Methods & Code Development and Application

Design and Safety Analysis Methods Development & Validation

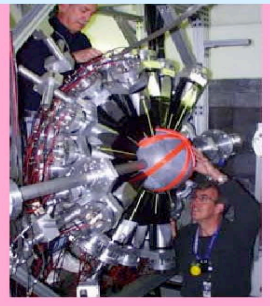
Separate Effects & Integral Testing Under Normal & Off-Normal Conditions



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



Graphite/air reaction rate testing

Scaled Vessel Testing

The NGNP Project Will…

Develop and implement technologies important to achieving design and performance requirements through collaboration with commercial end-users

Demonstrate the basis for commercialization of the nuclear system, hydrogen production facility and power conversion concepts

Establish the basis for licensing the commercial version of NGNP by NRC by licensing the prototype