Very High Temperature Reactors (VHTR)

Summary / Objectives:

Among the six Generation IV concepts eventually selected for international cooperative development, the Very High Temperature Reactor (VHTR) was seen as an early favorite among many of the members. Indeed, among the seven original members of the VHTR System Arrangement (SA), three had already operated or tested high temperature gas-cooled reactors. The accession of the People's Republic of China to the VHTR SA in 2008 brought that number to five. This presentation will describe how the continued cooperative development of the VHTR concept as a Generation IV system will deliver on nuclear energy's promises of sustainable, economic, safe, reliable and proliferation resistant power and energy supply.

Meet the Presenter:

Carl Sink has been working for the U.S. Department of Energy (DOE) for 24 years in various roles. Currently a Program Manager for Advanced Reactor Deployment within the Office of Nuclear Energy, he is responsible for coordinating cooperative research, development and demonstration projects conducted by DOE national laboratories and U.S. nuclear industry partners. Since 2004 he has been closely associated with the Next Generation Nuclear Plant Project, the DOE initiative to develop and demonstrate a high temperature gas-cooled reactor (HTGR). From 2006 through 2009 he was the program manager for the Nuclear Hydrogen Initiative, coordinating DOE efforts to develop high temperature water-splitting technologies to take advantage of HTGR outlet temperatures. Within GIF, Mr. Sink has served on the VHTR System Steering Committee since 2008, and currently chairs that group. He holds a Masters Degree in Engineering Management from the Catholic University of America, and is a graduate of the United States Naval Academy. Before joining the DOE, Mr. Sink spent nine years as a qualified Nuclear Engineering Officer in the United States Navy, with reactor operations assignments in a nuclear powered cruiser and a nuclear powered aircraft carrier.

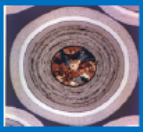
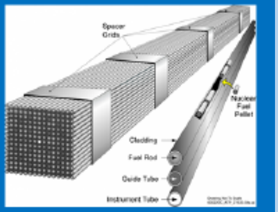
1. Why HTGRs ?:

HTGR is one of the six generation IV concepts, and it has good inherent safety characteristics, diverse industrial applications in addition to electricity, proliferation resistant, and high burnup fuel cycle with growth potential for advanced fuels and cycles.

- **Inherent safety characteristics**
  - Ceramic fuel particles – won't melt
  - Graphite core – stable moderator and thermal buffer
  - Helium coolant – inert gas does not interact with fuel, graphite or structural metals
- **Diverse industrial applications in addition to electricity**
  - High efficiency power conversion capability: modern Rankine cycle (Eff ~40%) to advanced closed cycle Brayton (efficiency up to ~47%)
  - High temperature process steam and process heat capability offer cogeneration opportunities now; very high temperatures in future
- **Proliferation resistant, high burnup fuel cycle with growth potential for advanced fuels and cycles (e.g. Plutonium, Thorium), including deep burn cycles with LWR spent fuel**

2. HTGR / LWR Comparison:

Briefly to compare for those of you who are familiar with Light Water Reactor (LWR) how HTGR is significantly different:

Item	**HTGR**	**LWR**
Moderator	Graphite	Water
Coolant	Helium	Water
Avg coolant exit temp.	700-950°C 	310°C 
Structural material	Graphite	Steel
Fuel clad	SiC & PyC	Zircaloy
Fuel	UO_2,UCO	UO_2
Fuel damage temperature	1600-1800C (design dependent)	1260°C (due to Zircaloy clad properties)
Power density, W/cm³	4 to 6.5	58 - 105
Linear heat rate, kW/ft	1.6	19
Neutron migration length	57 cm	6 cm

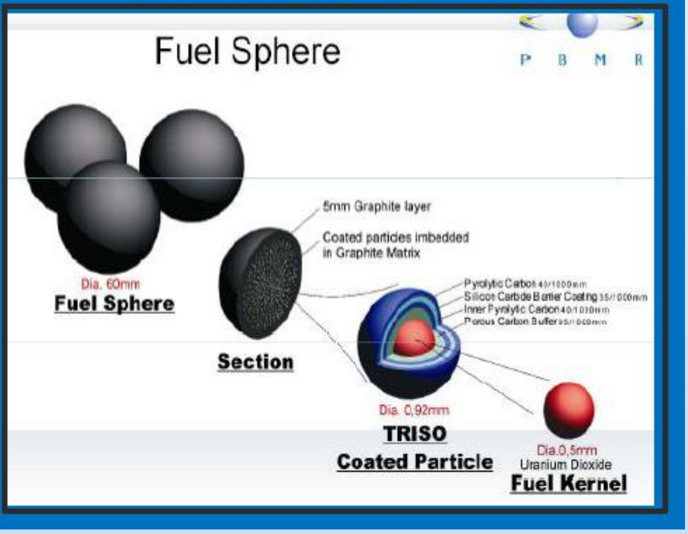
TRISO Coated-particle Fuel:

TRISO coated-particle fuel as the basic element is used for both prismatic and pebble bed type HTGRs. In the prismatic type HTGR, TRISO coated fuel particles are formed into fuel rods and inserted into graphite fuel elements, and in the pebble bed type HTGR, TRISO coated fuel particles are formed into fuel spheres.

Prismatic Fuel

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

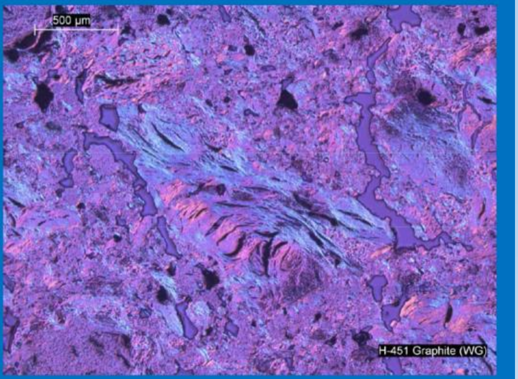
Pebble Bed Fuel



Role of Graphite in HTGRs:

Graphite plays a key role in the core of HTGR as shown in the figure. The other roles are as follows: in prismatic cores, graphite fuel element blocks retain the nuclear fuel compacts, and in a pebble bed reactor, a graphite reflector structure retains the fuel pebbles; the graphite reflector structure contains vertical penetrations for reactivity control; reactivity control channels are also contained in prismatic graphite fuel elements.

- **Neutron moderator (carbon & graphite)**
  - Thermalize fast neutrons to sufficiently low energies that they can efficiently fission U-235
- **Neutron reflector – returns neutrons to the active core**
- **Graphite (nuclear grade) has a low neutron capture cross section**
- **High temperature tolerant material**



Important HTGR Safety Paradigm Shifts:

HTGR has some safety paradigm shifts from LWR, and it’s just a different way of thinking about reactor safety and this has been an issue which has caused us to have to rethink how we regulate HTGR and how we think about accident scenarios for HTGR.

- The fuel, helium coolant, and graphite moderator are **chemically compatible** under all conditions
- The fuel has very **large temperature margins** in normal operation and during accident conditions
- Safety is **not dependent** on the presence of the helium coolant
- **Response times** of the reactor are very **long** (days as opposed to seconds or minutes)
- Loss of forced cooling tests have demonstrated the potential for walk-away safety
- There is no inherent mechanism for runaway reactivity excursions or power excursions
- The HTGR has multiple, **nested, and independent** radionuclide barriers
- An LWR-type containment is neither advantageous nor necessarily conservative.

HTGRS for Production of a Wide Variety of Energy and Commercial Products:

HTGR can supply a wide range of heat from law temperature to high temperature, and the various applications such as hydrogen production are proposed to be used in commercial form.