HTR Basics

(Hans Gougar)

The High Temperature Reactor (HTR) and Very High Temperature Reactor (VHTR) are types of nuclear power plants that, as the names imply, operate at temperatures above those of conventional nuclear power plants currently generating electricity in the United States (U.S.) and other countries. Like existing nuclear plants, heat generated from the fission of uranium or plutonium atoms is carried off by a working fluid and can be used to generate electricity, as shown in Figure 1. The very hot working fluid also enables the VHTR to drive other industrial processes requiring high temperatures not achievable by conventional nuclear plants. For this reason, the VHTR is being considered for non-electrical energy applications. The reactor and power conversion system are constructed using special materials that make a core meltdown virtually impossible.

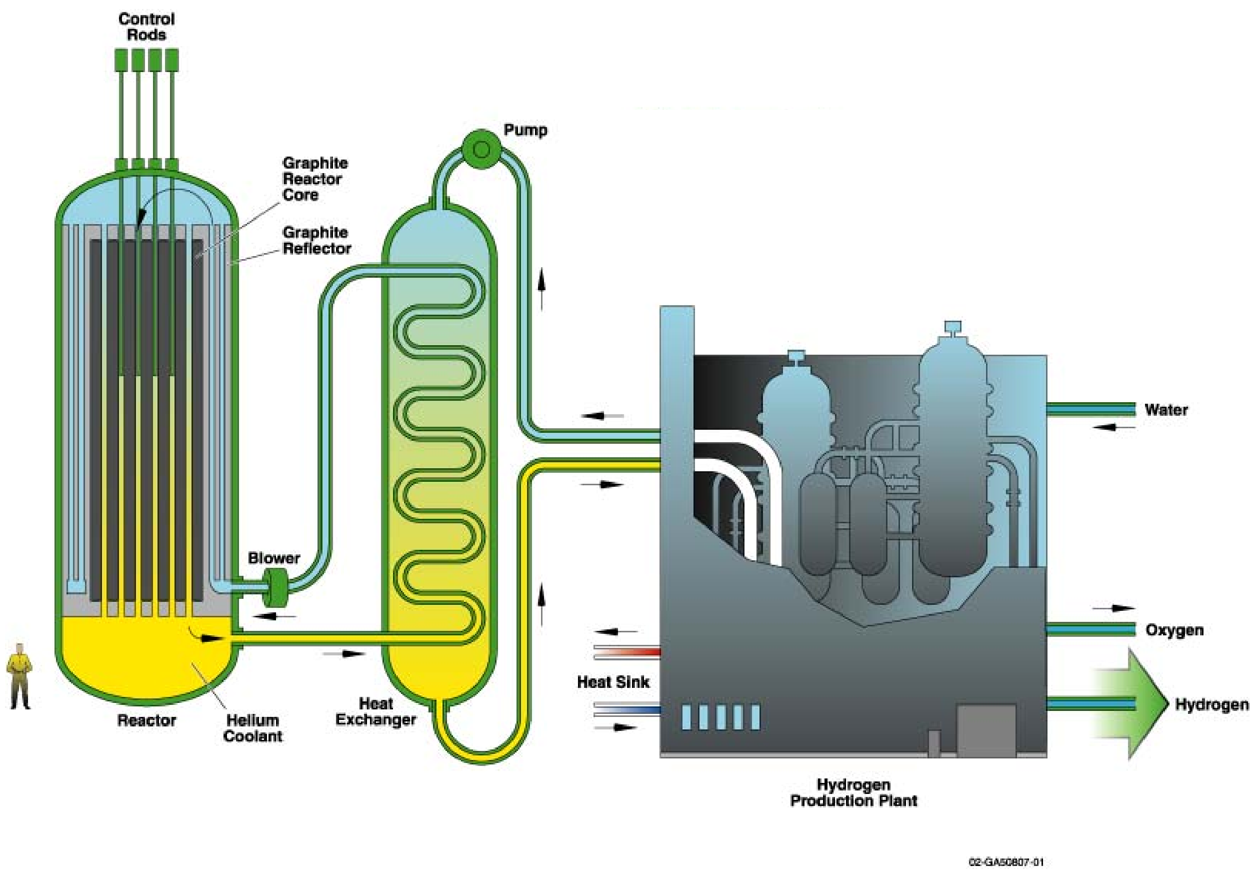


Figure 1. Hydrogen plant driven by a VHTR (Source: U.S. Department of Energy).

Figure 2 shows how HTR safety is based upon three pillars:

- Coated particle fuel form retains its radioactive contents under the worst anticipated conditions.
- A large quantity of graphite in which the fuel particles are embedded. The graphite absorbs the heat from the nuclear reaction and transmits it safely to the coolant or to the surrounding environment in case the cooling is lost.
- The low power density of the core.

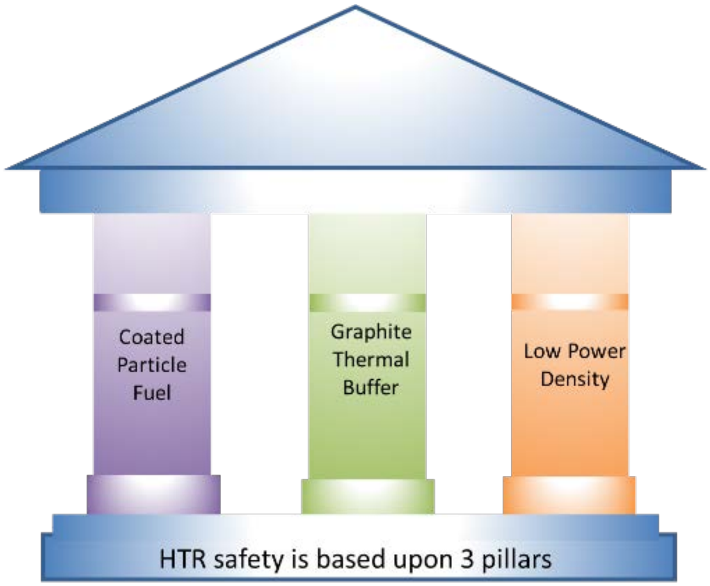


Figure 2. The three pillars of HTR safety.

These features allow a reactor to operate safely at much higher fuel and coolant temperatures than other types of nuclear plants while being immune to a meltdown. The higher temperatures enable electricity production with higher efficiency. The high quality heat can also be used to drive a number of industrial processes currently running on fossil fuels.

Coated Particle Fuel

The uranium dioxide or uranium carbide fuel material is formed into tiny spherical particles and coated with layers of high density carbon and silicon carbide that contain the radioactive material, even if the coolant (helium) is lost. Such fuels have been extensively studied around the world over the past four decades. Layers of carbon and silicon carbide surround the uranium core or kernel (the active part of the particle), thus forming the so-called tri-isotropic-coated particle fuel (TRISO). Each HTR core would contain billions of these multilayered coated particles. The particles are mixed with graphite and then pressed into either small cylinders called compacts for the prismatic reactor or tennis-ball-sized spheres called pebbles for the pebble bed reactor, as shown in Figure 3.

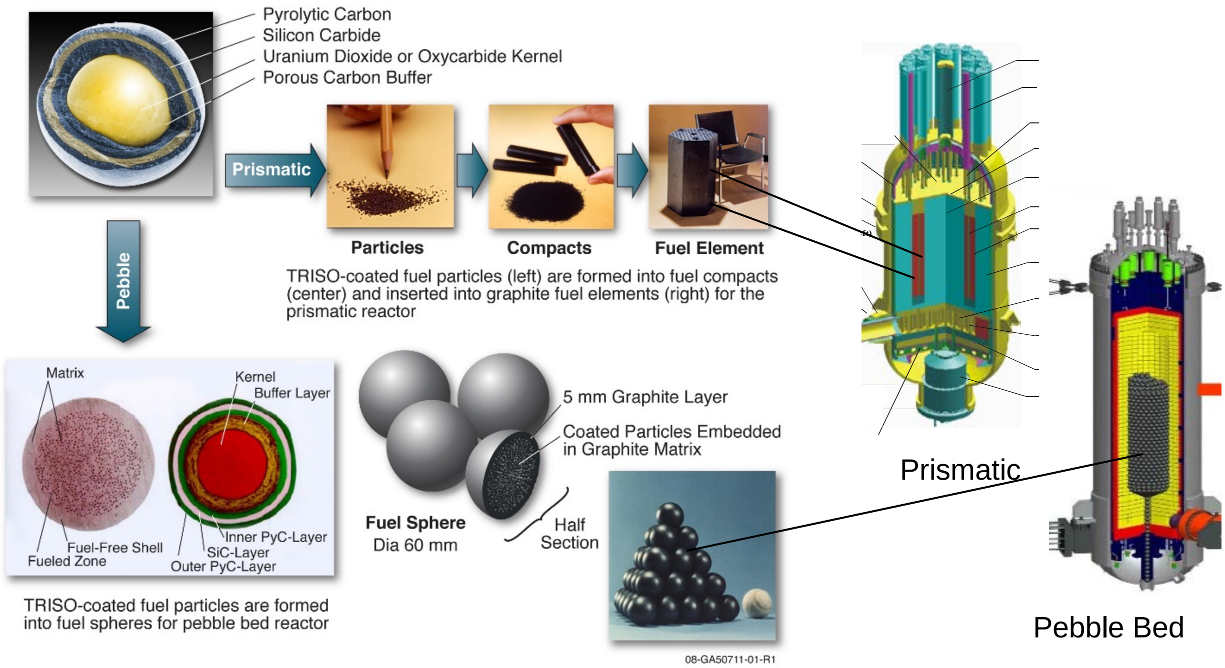
Figure 3. A coated particle with just under a 1-mm-diameter is shown in the upper left quadrant.

Graphite

The bulk of the reactor core consists of graphite, which moderates the neutron energy but also serves to absorb excess thermal energy in the event that coolant flow is stopped. Whether in the shape of blocks or pebbles, graphite makes up the bulk of the mass in the reactor core. It has excellent heat conduction and absorption properties such that in any type of off-normal or over-power condition, it will absorb the heat of the nuclear reactions and passively transmit it to the coolant or the surrounding structures.

Low Power Density

The HTR typically operates with a power density of about 3-8 Watts per cubic centimeter (W/cm^3). A typical light water reactor operates near 100 W/cm^3. While this results in a very large reactor vessel that doesn't generate as much power as other types of reactors, even in the event of a loss of coolant, there isn't enough heat being generated in the fuel to raise the core temperature to dangerous levels.


Pyrolytic Carbon
Silicon Carbide
Uranium Dioxide or Oxycarbide Kernel
Porous Carbon Buffer
Prismatic
Particles
Compacts
Fuel Element
TRISO-coated fuel particles (left) are formed into fuel compacts (center) and inserted into graphite fuel elements (right) for the prismatic reactor
Pebble
Matrix
Kernel
Buffer Layer
Fuel-Free Shell
Fueled Zone
Inner PyC-Layer
SiC-Layer
Outer PyC-Layer
TRISO-coated fuel particles are formed into fuel spheres for pebble bed reactor
5 mm Graphite Layer
Coated Particles Embedded in Graphite Matrix
Fuel Sphere
Dia 60 mm
Half Section
08-GA50711-01-R1
Prismatic
Pebble Bed