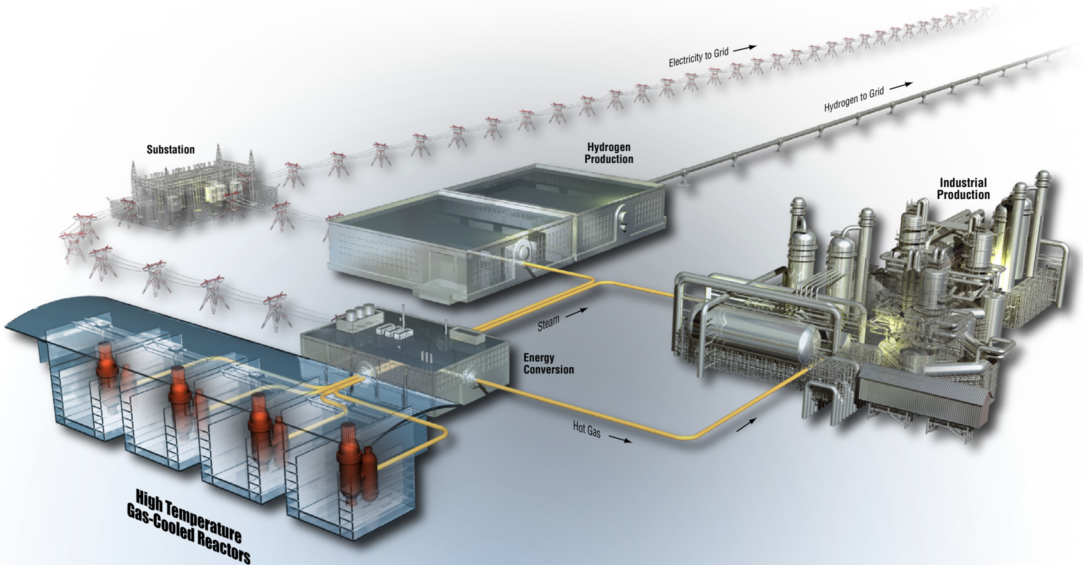


The High Temperature Gas-Cooled Reactor Next Generation Nuclear Energy

Safe, Clean and Sustainable Energy for the Future

The Energy of Industry

NGNP Next Generation Nuclear Plant

The Nuclear Heat Supply System

The High Temperature Gas-cooled Reactor (HTGR) nuclear heat supply system (NHSS) is composed of three major components: a helium-cooled nuclear reactor, a heat transport system, and a cross vessel that routes the helium between the reactor and the heat transport system. The NHSS supplies energy in the form of steam and/or high-temperature fluid that can be used for the generation of high-efficiency electricity and to support a wide range of industrial processes.

The NHSS design is modular with module ratings from 200 MWt to 625 MWt, reactor outlet temperatures from 700ºC to 850ºC, and heat transport systems that provide steam and/or high-temperature fluids. The range of power ratings, temperatures, and heat transport system configurations provides flexibility in adapting the modules to the specific application.

As shown in Figure 1, the three major components are enclosed in metallic pressure vessels that make up the primary helium circuit. Under normal operating conditions, helium flow is maintained by the main circulator and heat is transferred from the reactor to the heat transport system (e.g., the steam generator) and then to an energy conversion

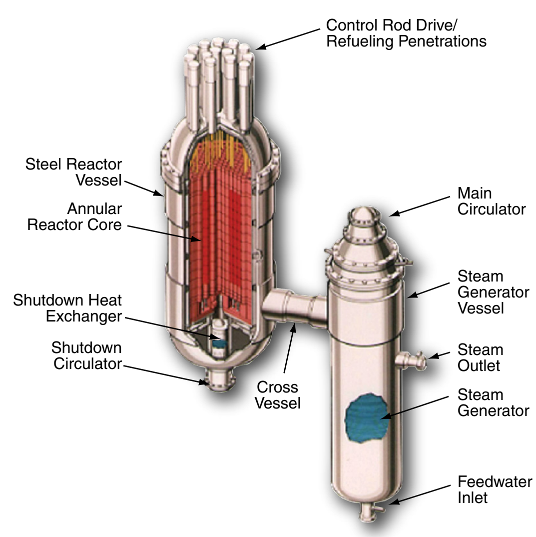
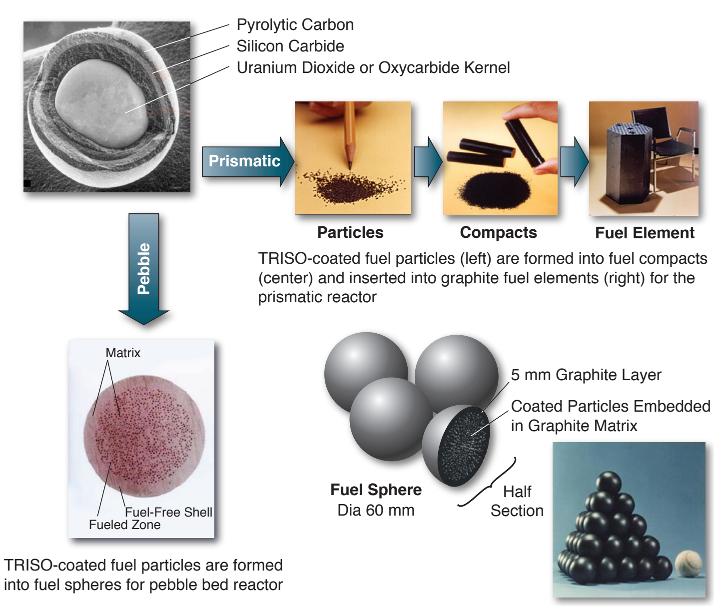


Fig. 1

system (e.g., a steam turbine generator) that interfaces with the industrial process and/or the electrical grid. When the reactor and plant are shut down for maintenance or refueling, reactor temperature is maintained by the shutdown cooling system. In the event the heat transport system and shutdown cooling system are not operational (e.g., on loss of all electrical power), reactor temperature is maintained via a radial heat transfer path through the reactor pressure vessel to an annular cavity formed between the reactor pressure vessel and the reactor building structure, the so-called reactor cavity. The reactor cavity can be actively cooled or cooled by natural circulation. In the event neither of these reactor cavity cooling mechanisms is operational, heat transfer through the reactor building structure to the ground is sufficient to maintain reactor temperatures within acceptable limits.

Achieving the Highest Level of Nuclear Safety

The principal design objective of the NHSS is to ensure that there is no internal or external event that could lead to substantive release of radioactive material from the plant that would require evacuation or sheltering of the public or threaten food and water supplies. This objective is met by provision of:



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

TRISO-coated fuel particles are formed into fuel spheres for pebble bed reactor

Fig. 2

- Multiple barriers to the release of radioactive material from the plant that will not fail under all normal, abnormal, and accident conditions whether affected by internal (e.g., loss of all electrical power, a leak in a steam generator tube) or external (e.g., earthquakes, flooding, tornadoes) events. These barriers include:
  - o A robust carbon-based fuel structure that forms the principal barrier to release and transport of radioactive material. As shown in Figure 2, the fuel is made up of minute (~1 mm diameter) particles that are composed of multiple ceramic layers surrounding the uranium-based kernels. These ceramic layers are designed to retain the products of nuclear fission and limit release to the fuel elements and the helium coolant.
  - o Distribution and containment of the fuel particles in fuel elements (compacts or spheres) of carbon-based material.
  - o Enclosure of the fuel elements in a large graphite core.
  - o Enclosure of the core structure and the helium coolant system in ASME Nuclear Grade metallic vessels.
  - o Enclosure of the NHSS vessels in a robust underground reactor building.

Additional reactor characteristics that prevent release of radioactive materials include:

- Extreme high-temperature capability of the ceramic coated and carbon-based fuel and core structure.
- Reactor materials including the reactor fuel are chemically compatible and, in combination, will not react or burn to produce heat or explosive gases. Helium is inert and the fuel and materials of construction of the reactor core and the nuclear heat supply system preclude such reactions.
- Plant design features limit intrusion of air or water so that the reactor remains shut down and containment of radioactive materials is maintained.
- Single phase and low heat capacity minimizes stored energy in the helium coolant.
- Inherent nuclear and heat transfer properties of the reactor design are continuously functional to ensure that the fuel temperatures remain within acceptable limits under all conditions.
- Inherent properties of the reactor core regulate nuclear power so no electrical power, coolant flow or any other active systems or operator actions are required to limit

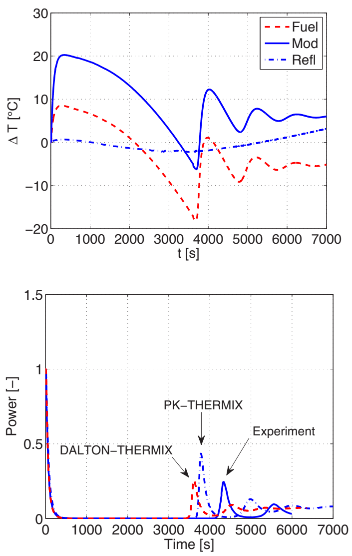


Fig. 3

A loss of flow test on an experimental reactor (HTR-10) with no control system action – reactor power reduced as a consequence of the temperature increase. Calculated differential temperatures are shown for the fuel, moderator, and reflector for first two plus hours after helium flow shutdown. The calculated power response to the temperature variations is shown in comparison with the test data.

B. Boer, D. Lathouwers, J.L. Kloosterman, T.H.J.J. van der Hagen, and G. Strydom, Validation of the DALTON-THERMIX code system with transient analysis of the HTR-10 and application to the PBMR, Nuclear Technology, 170:306-321 (2010)

nuclear power levels and fuel temperatures under any condition (Figure 3).

- Reactors are located underground in reinforced concrete silos (Figure 4), reducing response to earthquakes and providing a natural heat transfer path from the core through the reactor pressure vessel into the silo and ultimately to the passive reactor cavity cooling system under loss of all forced cooling conditions. If the reactor cavity cooling system is unavailable, heat transfer to the ground is sufficient to maintain fuel temperatures in the acceptable range.

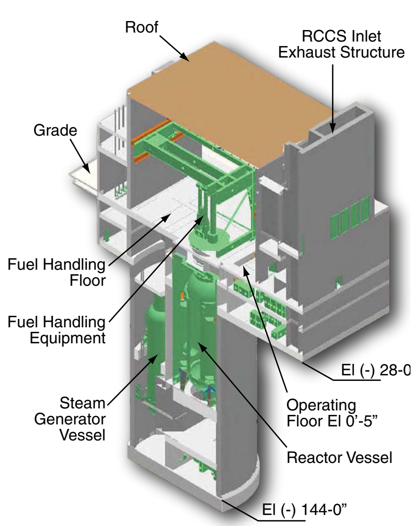


Fig. 4

- The graphite has the ability to absorb large quantities of heat. It takes hours or days to reach peak accident temperatures (still well below temperatures that could cause fuel degradation) independent of whether active cooling systems are working or not.

- The heat transfer path from the core to the reactor cavity cooling system and to the ground is continuously functional and, therefore, available independent of the plant condition.

Spent and Used Fuel Storage

- Spent and used fuel is stored in casks or tanks in underground vaults that can be cooled by naturally circulating air (Figure 5).

- Active systems are not required to maintain acceptable temperatures of stored spent or used (defined as not completely used but removed from the core for maintenance) fuel due to low retained energy and robust carbon-based fuel material.

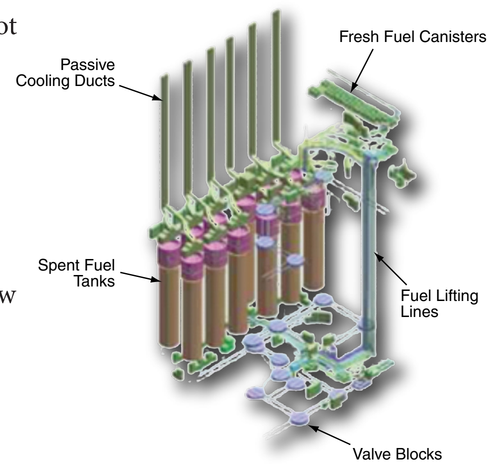


Fig. 5

- Carbon-based material used for the fuel and fuel elements facilitates long-term stable storage.

Clean, Safe Energy with a Wide Range of Applicability:

- A nongreenhouse-gas-emitting source of energy for highly efficient generation of electricity, steam and high-temperature process heat.

- An energy supply that is applicable to a wide range of high-temperature industrial applications beyond production of electricity (Figure 6).

- An energy supply that can be substituted for the burning of fossil fuels; preserving these natural resources for more beneficial application (e.g., natural gas feedstock for petrochemical processing).

- Standardized nuclear heat supply system modular configurations with a range of power ratings that provide flexibility in adapting the technology to the application.

- A long-term indigenous energy supply system that supplies energy at a stable price; eliminating the high volatility in energy prices experienced over the last several decades.

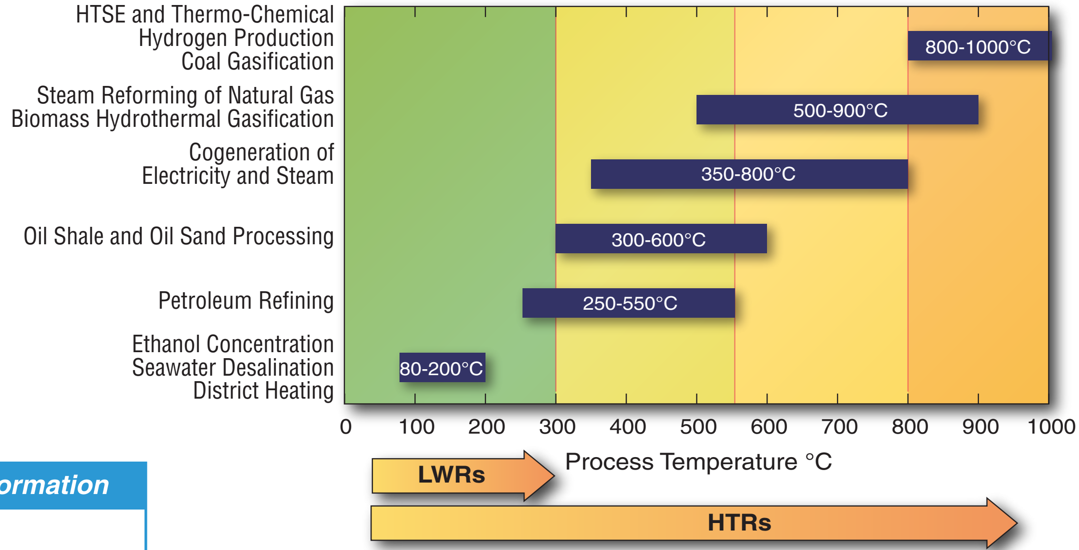


Fig. 6

For more information

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The Market

A potential for deployment of 510 GWt of HTGR technology by 2050 has been identified to fulfill the following industrial energy needs (Figure 7):

CO-GENERATION supply of electricity and steam to major industrial processes in petrochemical, ammonia and fertilizer plants, refineries and other industrial plants.

HYDROGEN production and supply to industrial plants and to the merchant hydrogen market.

ENHANCED RECOVERY and UPGRADING of Bitumen from oil sands (e.g., Alberta, Canada) requiring supply of steam, hydrogen, and electricity.

CONVERSION OF COAL AND NATURAL GAS TO LIQUID FUELS AND FEEDSTOCK requiring the supply of steam, electricity, and hydrogen.

ELECTRICITY generation and supply to the electrical grid.

The opportunity – integrating nuclear high temperature process heat with industrial applications

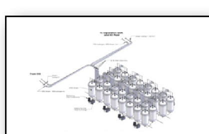
Existing plants – assuming 50% penetration of likely combined heat and power market (2.2 quads*)

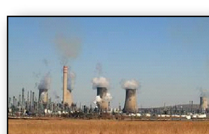

Fertilizers/Ammonia
(23 plants in U.S. – NH3 production)

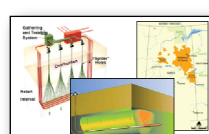

Petrochemical
(170 plants in U.S.)


Petroleum Refining
(137 plants in U.S.)

Growing and new markets – potential for 13.6 quads of HTGR process heat and power and electricity generation


Hydrogen Production
(14 - 719 tpd plants)


Coal-to-Liquids
(24 - 100,000 bpd plants)


Oil Sands/Shale
(60 - 56,000 bpd plants)

Electricity Generation
(40 GWe capacity)

*Quad = 1×10^{15} Btu (293×10^{6} MW_{th}) annual energy consumption

Fig. 7