HTR History

(Hans Gougar)

The idea of a nuclear reactor operating at high temperature (>700°C) was first conceived in the early days of nuclear power plant development and government programs were instituted to develop the fuels, materials, and power conversion systems that could withstand these temperatures [1[1]]. Most HTR concepts employed a gas coolant, hence, the term high temperature gas-cooled reactors (HTGRs). A small number of experimental HTRs have been built in Europe and Asia to test these concepts. Unless otherwise stated, the reactors described hereafter are all cooled by helium gas.

Dragon (England)
20 MWth prismatic
750°C
1963–1976

AVR (Germany)
40 MWth pebble bed
>900°C
1967–1988

HTTR (Japan)
30 MWth prismatic
950°C
1998–present

HTR-10 (China)
10 MWth pebble bed
700–950°C
2003–present

Early Prototypes and Test Reactors

The first HTR was the DRAGON test facility built in Winfrith, England and operated by the United Kingdom Atomic Energy Authority. Its purpose was to test fuel and materials for the European HTR research and development program, and was thus managed as an international project under the auspices of the Nuclear Energy Agency of the Organization for Economic Cooperation and Development. Construction commenced in 1959 and was completed in 1962. Operation at 20 megawatts of thermal power (MWt) began in 1965 and continued until 1976; this thermal energy was never used to generate electricity. The reactor was partially decommissioned in 2005.

The AVR (a German acronym for Arbeitsgemeinschaft Versuchsreaktor) was a prototype HTR built and operated at a Research Center in Jülich, Germany. Construction began in 1960. Regular operation began in 1967 and continued until 1988 [2]. The AVR had a thermal output of 40 MWt, of which about 17 were converted to electricity for the local grid. The AVR was used to develop and test a wide variety of fuels and machinery in support of the German HTR development program (http://www.nextgenerationnuclearplant.com/). It was the first so-called pebble bed reactor wherein the fuel was encased in graphite spheres about the size of a tennis ball. The AVR provided the foundation for pebble bed HTR developments later undertaken in South Africa and China.

The HTR-10 is one of two HTRs operating at the beginning of the 21st century. Built in China, the HTR-10 is a small, 10 MWt experimental reactor running on pebbles fabricated to German specifications. The HTR-10 has been used to demonstrate the inherent safety features of the HTR and is a test bed for development of a larger power module under development in China [2].

The other operating HTR is the High Temperature Engineering Test Reactor (HTTR) located in Oarai, Japan. This 30 MWt reactor employs a prismatic core and also features inherent safety characteristics in addition to operating with an outlet temperature of 950°C. The HTTR is being used by Japan as a test bed to develop a larger power reactor based upon HTR technology [3].

Early Commercial Designs and Plants

Power reactor development of the HTGR was pursued by companies in the USA and Germany with plants licensed by state regulatory agencies and operated for commercial use (Figure 3). While much of the early development of light water reactors was conducted by the US Navy in support of their ship propulsion program [5], from the beginning HTGRs were largely a commercial power venture. These early HTGR power plants thus experienced technical challenges typical of first-of-a-kind technology. Although the reliability of these plants did not match the performance of modern LWRs, they did demonstrate that the HTR could evolve into an industrial energy source.

The Peach Bottom Atomic Power Station, was built 50 miles (80 km) southeast of Harrisburg, Pennsylvania. The Philadelphia Electric Company was a pioneer in the commercial nuclear industry when it ordered Peach Bottom Unit 1 in 1958. Peach Bottom Unit 1 operated from 1966 to 1974 with a rated power of 115 MWt. Designed and built by General Atomics, this was the first of the so-called *prismatic* or block fuel reactors in which the fuel was embedded in large blocks of graphite and stacked into a large cylinder to form the reactor core. Although it was considered an experimental reactor, Peach Bottom 1 converted 40 of its 115 MW of thermal power into electricity and supplied the grid with an 88% *capacity factor* (the ratio of actual energy produced to that which could have been generated if operated continuously at full power).

Peach Bottom (U.S.)
115 MWth prismatic
1967–1974

THTR (FRG)
750 MWth pebble bed
750°C
1986–1989

Fort St. Vrain (U.S.)
842 MWth prismatic ~800°C
1976–1989

The THTR-300 (German: Thorium Hoch Temperatur Reacktor) was a pebble bed rated at 300 MWt electric. Located in Hamm- Uentrop, the German state of North Rhine Westphalia and Hochtemperatur-Kernkraftwerk GmbH financed construction of the THTR-300. The plant operated from 1983 to September 1, 1989. The THTR was synchronized to the grid for the first time in 1985 and started full power operation in February 1987. The THTR-300 served as a prototype and, unlike other HTRs, used thorium rather than uranium as its primary fuel. In 1988, however, a combination of political and financial factors led to a decision not to restart the plant after a planned maintenance outage.

The Fort St. Vrain Generating Station was built by near Platteville, Colorado in 1974, the only nuclear plant built in that state. Like its predecessor, Peach Bottom 1, Fort St. Vrain was a prismatic core design built by General Atomics. It ran from 1977 to 1989 with a rated power of 842 MW of thermal energy of which 330 was converted to electricity for the grid. Fort St. Vrain differed from other nuclear plants in that it required no high strength concrete structure to contain its radiological inventory in case it escaped from the primary cooling system. This function was carried out by the reactor vessel and the special coated particle fuel that is the key technical feature of HTRs. Like the THTR, Fort St. Vrain was shut down before the end of its planned lifetime due to technical difficulties that undermined its commercial viability.

The *modular* HTGR concept was introduced the early 1980s with the design of the HTR Modul 200 by the German industrial firms Kraftwerk Union and Siemens/Interatom. Though one was never built, the design was mature enough to be submitted to the German nuclear licensing authorities. The design stressed simplicity and inherent safety even in the most severe of accidents [4]. The HTR Modul 200 would produce 200 MW of thermal energy that could be used to make electricity or drive a heat-consuming industrial process. It featured a recirculating pebble bed core, one in which the fuel pebbles were constantly circulated and reloaded into the core during operation. Modular construction techniques would be used to lower capital costs and large electricity demands could be met by building multiple units of the same (relatively small) 200 MWt plant on the same site. The small reactor vessel combined with the robust coated particle fuel obviated the need for extensive engineered safety systems that drive up costs. The HTR Modul 200 was designed to be able to withstand a complete loss of coolant to the core without sustaining fuel damage.

Also during the 1980s, General Atomics was developing a prismatic version of the modular HTGR. The 350 MWt Modular High Temperature Gas-Cooled Reactor (MHTGR) also featured a passively safe core that would remain intact even in the event of a complete loss of coolant flow to the reactor [7]. Research and development of the MHTGR was supported by DOE into the 1990s. Design and safety analyses [5] were submitted to the U.S. Nuclear Regulatory Commission (NRC) in support of a license application, but this NRC review was discontinued in 1996.

With renewed interest in nuclear power as a safe, carbon-free, and 'home-grown' technology, the HTR has been the focus of new government-sponsored research and development programs around the world. The safety, environmental, and economic features of this heat source have gained the attention of policy makers in Washington and other nations. New designs that build on the fuel and modularity concepts developed in previous decades are now being developed. The following sections explore the technology of the HTR and present some of the new designs that are under development.

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