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MHR Design, Technology, and Applications

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1. Introduction

The Modular Helium Reactor (MHR) is one of the Very High Temperature Reactor (VHTR) concepts being proposed for the U.S. Department of Energy (DOE) Next Generation Nuclear Plant (NGNP) project. Other countries, including Russia, Japan, South Korea, China, South Africa, and France are also developing VHTR technology, and large-scale deployment of VHTR technology is a realistic element of future energy-growth scenarios. In this paper, we discuss MHR conceptual designs for electricity, hydrogen production, and other process-heat applications, and their role in a sustainable energy future with significant growth in nuclear energy.

2. MHR Design Features

MHR design features include: (1) Passive Safety, Competitive Economics, and Siting Flexibility. The MHR does not require active safety systems to ensure public and worker safety. The high-energy conversion efficiency of the MHR, combined with the elimination of active safety systems, result in a design that is passively safe and economically competitive with other non-passively safe reactor concepts. Because of its high efficiency, the MHR rejects less waste heat than other reactor concepts. This design feature, combined with passive safety, allows for more flexible siting options for the MHR. (2) High Temperature Capability and Flexible Energy Outputs. The MHR is capable of producing process-heat temperatures of 950°C and higher. This high-temperature capability translates into a high-energy conversion efficiency for a variety of energy outputs, including electricity, hydrogen production, and synthetic fuel production. (3) Flexible Fuel Cycles. The MHR can operate efficiently and economically with several different fuel cycles. MHR designs have been developed utilizing low-enriched (LEU) uranium fuels, high-enriched uranium (HEU) fuels, mixed uranium/thorium and plutonium/thorium fuels, and surplus weapons-grade plutonium fuels. The thermal neutron spectrum of the MHR, combined with robust, ceramic-coated particle fuel, allow for very high burnup in a single pass through the reactor. More recently, an MHR design has been developed to deeply burn plutonium and other transuranic (TRU) actinides recovered from light-water reactor (LWR) spent fuel. The flexible fuel cycle capability of the MHR, combined with its flexible energy output capability (see Fig. 1), result in a design concept that is very well suited for a wide variety of energy-growth scenarios.

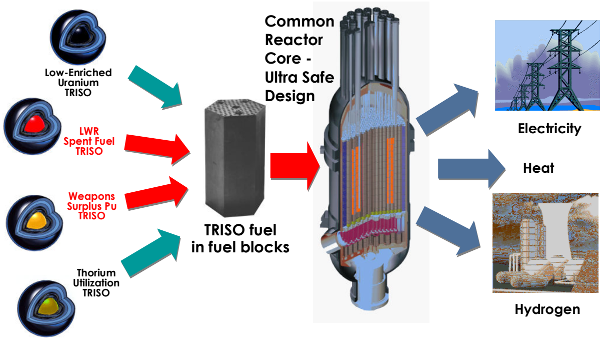

Figure 1. MHR Fuel Cycle and Energy Output Options

3. Electricity Production

The MHR operates with a thermal power level of 600 MW. For electricity production, the MHR is coupled to a direct, Brayton cycle power-conversion system (PCS) [1]. For core outlet helium temperatures in the range 850°C to 950°C the thermal-to-electrical conversion efficiencies are in the range 48 to 53 percent. This concept is referred to as the Gas Turbine MHR (GT-MHR) and is shown in Fig. 2.

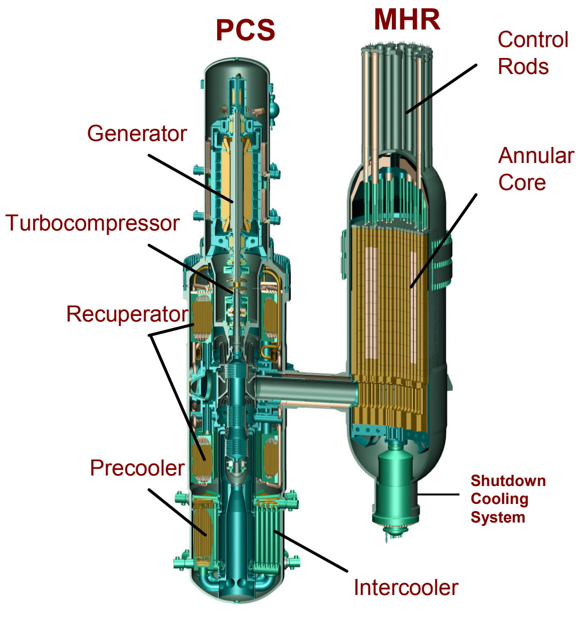

Figure 2. Gas Turbine Modular Helium Reactor

4. Hydrogen Production

Two hydrogen-production technologies have emerged as leading candidates for coupling to the MHR: (1) thermochemical water splitting using the sulfur-iodine (SI) process and (2) high-temperature electrolysis (HTE). These concepts are referred to as the SI-based H2-MHR [2] and the HTE-based H2-MHR [3], respectively. The SI thermochemical water-splitting process involves decomposition of sulfuric acid and hydrogen iodide, and regeneration of these reagents using the Bunsen reaction. Process heat is supplied at temperatures greater than 800°C to concentrate and decompose sulfuric acid. The exothermic Bunsen reaction is performed at temperatures near 120°C and releases waste heat to the environment. Hydrogen is generated during the decomposition of hydrogen iodide, using process heat at temperatures greater than 350°C. The HTE-based H2-MHR couples the GT-MHR to high-temperature, solid-oxide electrolyzer (SOE) modules. Approximately 90% of the heat generated by the MHR modules is used to produce electricity. The remainder of the heat is transferred though an intermediate heat exchanger (IHX) to produce the steam supplied to the SOE modules. Simplified process-flow schematics of the SI-Based and HTE-Based H2-MHR plants are shown in Figs. 3 and 4, respectively. The MHR can also be coupled to a conventional steam-methane reforming plant to produce hydrogen.

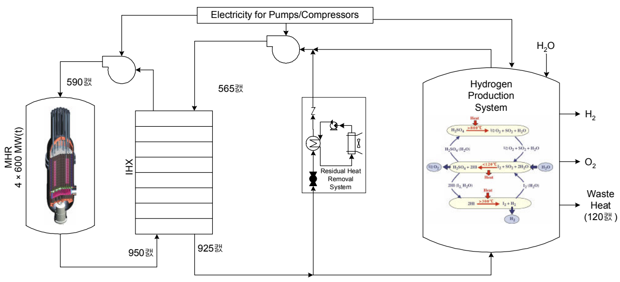

Figure 3. SI-Based H2-MHR Process Schematic

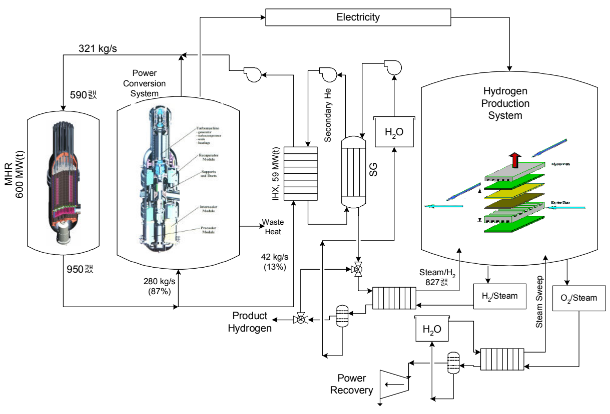

Figure 4. SI-Based H2-MHR Process Schematic

5. Other Process Heat and Steam Applications

The MHR can also be coupled to a cogeneration plant to produce electricity and high-temperature/high-pressure steam to provide the energy requirements for a wide variety of industrial processes [4]. This concept is referred to as the Process Steam/Cogeneration Modular Helium Reactor (PS/C-MHR). Potential applications for the PS/C-MHR include heavy oil recovery, tar sands oil recovery, coal liquefaction, coal gasification, and steel and alumina manufacturing. As illustrated in Fig. 5, the flexible energy outputs of the MHR are well suited for coal liquefaction. The use of MHR-supplied nuclear energy to manufacture synthetic fuels can provide a bridge to the future when the direct use of hydrogen as a fuel is both practical and economical.

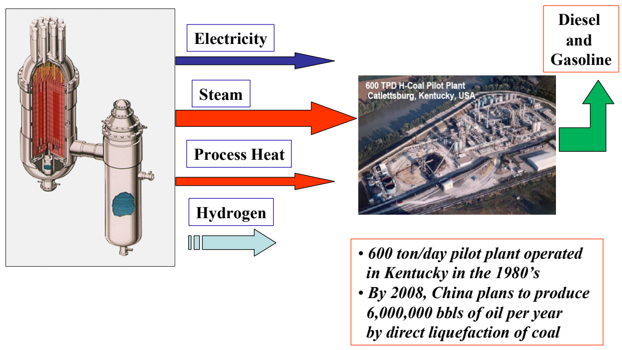

Figure 5. Use of MHR Energy Outputs for Coal Liquefaction

3. Conclusion

Because of its passive-safety features, high-temperature capability, high efficiency, and flexibility with regard to fuel cycles and energy outputs, the MHR is well suited for supplying a wide range of future energy needs, including electricity, hydrogen, synthetic fuels, and other process-heat applications.

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