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Fuel Characteristics and Requirements for the Advanced High-Temperature Reactor

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INTRODUCTION

The Advanced High-Temperature Reactor (AHTR) is a large [>2400 MW(t)] liquid-salt-cooled high-temperature reactor with the same safety goals and requirements as the modular very high temperature reactors (VHTR) with helium cooling and power outputs of ~600 MW(t). Within the U.S. Department of Energy Generation IV Program, the AHTR is being developed as a VHTR variant, the liquid-salt-cooled VHTR. The AHTR uses the same graphite-matrix coated-particle fuel as helium-cooled VHTRs. In high-temperature nuclear environments, graphite has been demonstrated to be compatible with only two coolants: liquid fluoride salts and noble gases.

In an AHTR [1, 2], heat is transferred from the reactor core with a liquid salt to an intermediate heat exchanger. A secondary liquid salt then transfers the heat from the intermediate heat exchanger to Brayton power-cycle machinery for electricity production or to a thermochemical plant for hydrogen production. The changes in reactor fuel design with a liquid coolant, rather than a gas coolant are described.

FUEL IMPLICATIONS OF LIQUID COOLING

Liquids are better coolants than gases. For the same power densities, the temperature drop from the solid fuel to the coolant is 50 to 100ºC less in the AHTR than in a helium-cooled VHTR with an equivalent drop in peak fuel temperature [1]. This additional thermal margin can be used to increase coolant exit temperatures or increase the power density and reduce the core size.

Under accident conditions, decay heat must be moved from the reactor core to the reactor vessel surface, where passive systems dump the heat to the atmosphere (Fig. 1). In a helium-cooled VHTR [3], the decay heat is removed by conduction of heat from the fuel to the reactor vessel. Heat can be conducted through a defined thickness of fuel blocks to the reactor vessel without failure of the hottest fuel because of excessive temperature. The thickness of the fuel zone is limited by decay-heat-removal requirements. To build larger reactors, an annular core is used with no fuel in the middle. Pressure vessel and heat conduction limit power output to ~600 MW(t). In the AHTR, natural circulation of liquid salts efficiently moves heat from anywhere in the reactor core to the reactor vessel. Reactor size is thus limited by the ability to move heat from the vessel, not the ability to move heat from the fuel to the vessel wall. This has two implications.

- *Reactor size*. The liquid-salt coolant avoids the size limit intrinsic to passively safe helium-cooled VHTRs. Because of the larger size, the projected capital costs per kW(e) for the larger AHTR are estimated to be ~60% of those for the modular helium-cooled VHTR [2].

- *Fuel geometry*. Fuel pins in the gas-cooled VHTR are distributed through the graphite block to allow conduction of the decay heat from fuel pin through graphite to the reactor vessel surface under accident conditions. In the AHTR with decay heat removal by natural circulation of the salt, there is the option to have fuel bundles in the graphite block—a geometry that may simplify fabrication and aid waste management [4].

FUEL IMPLICATIONS OF A LARGE AHTR

The AHTR fuel burnup is ~50% higher than in gas-cooled VHTRs for similar fuel enrichments [3, 5]. The AHTR is a large reactor [power: 2400 MW(t); burnup: 156 GWd/t; fuel columns: 265; enrichment: 15.3% ; power density: 10.2 MW/m^3] relative to a helium-cooled VHTR [power: 600 MW(t); burnup: 100 GWd/t; fuel columns: 102; enrichment: 14.0% ; power density: 6.6 MW/m^3]. The AHTR core is a large right cylinder, whereas helium-cooled VHTRs have smaller annular reactor cores to assist decay heat removal (Fig. 1). The small annular core of the VHTR implies high neutron leakage (3.5 to 6%) both inward toward a center graphite cylinder and outward toward the reactor vessel. In contrast, the small surface-to-volume ratio of the large AHTR core implies relatively small neutron leakage (1 to 2%). For nuclear criticality to be maintained, the average enrichment of the core of a helium-cooled VHTR must be higher than in an AHTR. If the two reactors have similar initial fuel enrichments, the AHTR can have a lower end-of-life spent-nuclear-fuel (SNF) enrichment and a corresponding higher SNF burnup [3, 5].

The larger AHTR has more fuel than the helium-cooled VHTR. Consequently, there are strong incentives to increase the size of the fuel block to reduce refueling time.

CONCLUSIONS

The liquid-cooled AHTR and gas-cooled VHTR have the same functional requirements and use graphite-matrix coated-particle fuel. The use of a liquid-salt coolant enables higher burnups, higher power densities, and potentially a bundle fuel assembly design.

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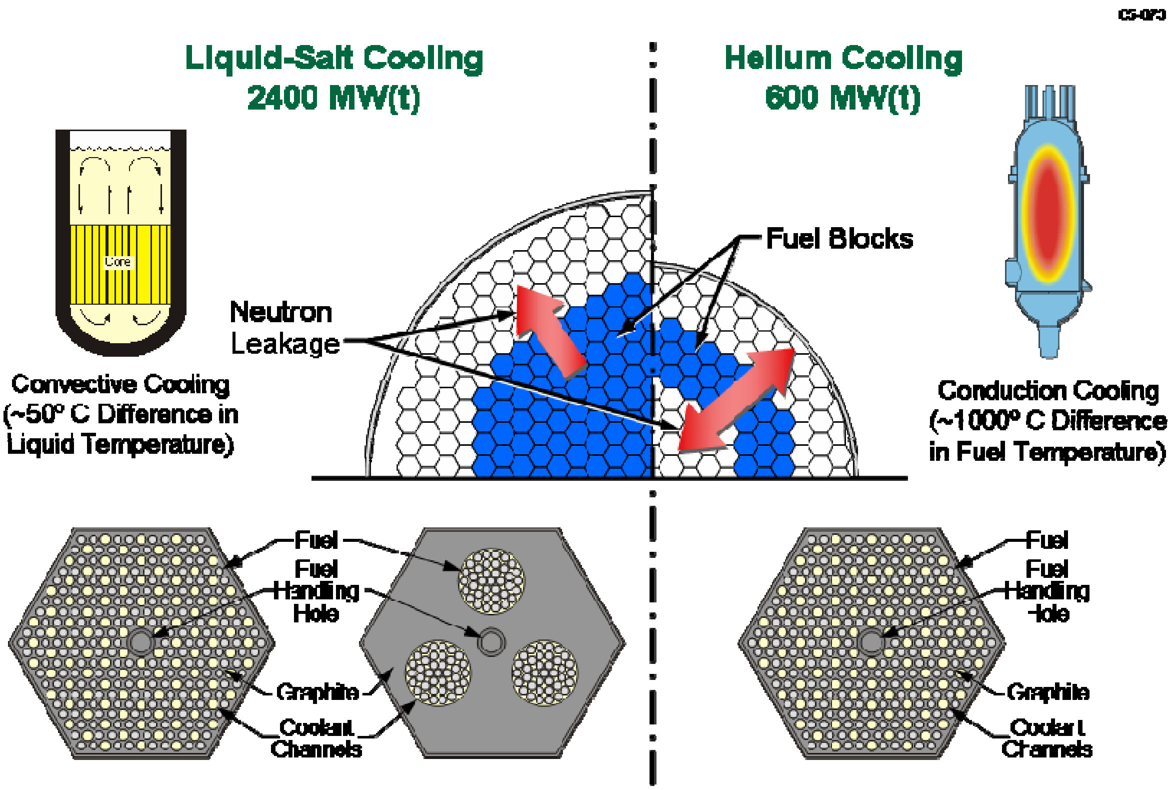

Fig. 1. Differences in liquid-salt-cooled AHTR and helium-cooled VHTR reactor cores.