Development approaches for the Advanced High Temperature Reactor

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INTRODUCTION

This report outlines and compares two different development paths for the Advanced High Temperature Reactor (AHTR)—termed "dual-path" and "single-path" approaches.

The AHTR is a pool-type reactor with graphite matrix coated-particle fuel and a clean molten salt coolant [1]. Due to the very high thermal inertia provided by the pool configuration and molten-salt coolant of the AHTR, the thermal power of the AHTR can be substantially higher than an equivalent gas-cooled reactor, likely exceeding 2000 MW(t). The AHTR, with a molten-salt intermediate loop and air-cooled reactor cavity cooling system (RCCS), eliminates all stored energy sources that could pressurize its containment (high-pressure gases, volatile liquids, and chemically reactive liquids and gases). By transporting heat with low pumping power, the AHTR permits multiple-reheating in closed gas cycles, raising thermal efficiency by 4 to 8 percent for the same turbine inlet temperature. All of these characteristics suggest that the AHTR will have low capital costs, while achieving robust passive safety.

The Next Generation Nuclear Plant (NGNP) provides the opportunity to develop technology for the high-temperature production of electricity and hydrogen. The NGNP is intended to provide a commercial scale demonstration of electricity production, and to demonstrate hydrogen production at engineering scale using approximately 10% of the reactor thermal power [2]. Two primary routes exist to develop the AHTR as a part of the NGNP project:

1) **"Dual-path" — Helium primary coolant NGNP (H-NGNP).** Under this approach, the NGNP is a commercial-scale prototype of a helium-cooled reactor using prismatic fuel of the same type required for the AHTR, and molten salt is used as the intermediate heat transfer fluid for hydrogen production. Under this dual-path approach, molten salt heat exchanger and pumping technology for the AHTR is developed and demonstrated for use in the 50 MW(t) NGNP intermediate-loop coolant for hydrogen demonstration, and a separate conceptual design and separate-effects experimental program to develops other key AHTR technology elements (in particular the AHTR vessel and RCCS systems).

2) **"Single-path" — Molten-salt primary coolant NGNP (MS-NGNP).** Under this approach, the NGNP is a 200 to 600 MW(t) pool-type reactor with a molten-salt primary coolant.

Under both development paths, technology for the NGNP would be demonstrated at a power level substantially below the anticipated commercial power level of the AHTR, and thus the subsequent construction of a commercial-scale (>2000 MW(t)) demonstration AHTR plant would be required. Thus both routes will require scaling of technology demonstrated on the NGNP to that required for a commercial AHTR.

The routes can be compared in several areas.

Materials technology. The candidate materials for heat exchangers and other salt-handling components for the AHTR are high-temperature nickel alloys (e.g. Hastelloy X) capable of reaching peak operating temperatures of around 800°C, and melt infiltrated carbon-carbon composites capable of temperatures up to and beyond 1000°C [3]. For the H-NGNP, the primary materials demonstration would occur in the 50 MW(t) molten salt intermediate loop. This loop would include all of the types of heat exchangers required for the AHTR, including helium-to-salt and salt-to-S-I-process-fluid heat exchangers, as well as pumps and piping systems. Because the 50 MW(t) helium bypass system would be designed to be isolated from the primary helium circuit, the intermediate helium-to-salt heat exchanger would not be required to be qualified for service as a part of the primary pressure boundary (just as a BWR turbine condenser is not a part of the primary pressure boundary). This would simplify the process of demonstrating the use of compact high-temperature composite heat exchangers, which currently do not have ASME code certification.

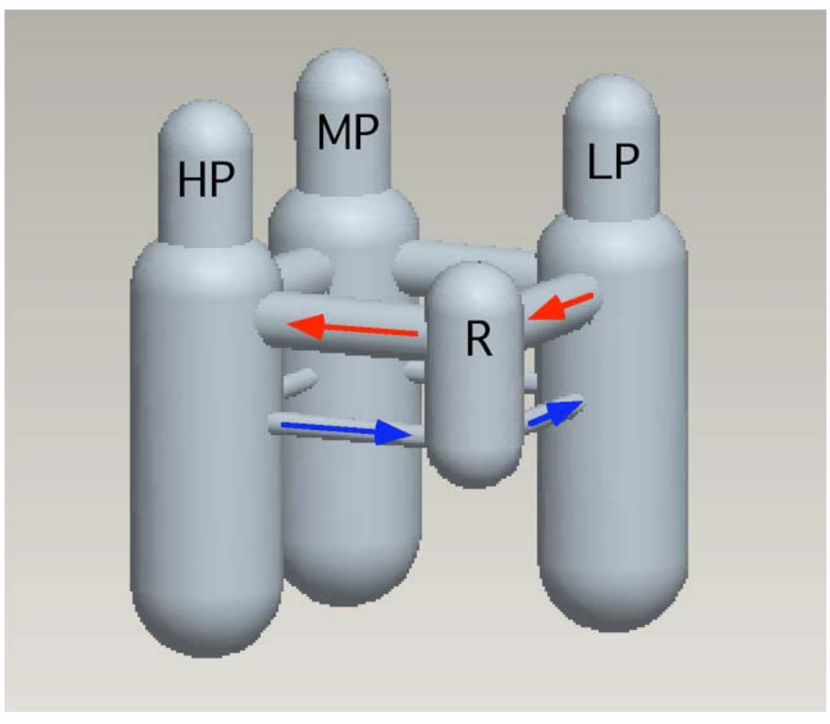

Fig. 1 Arrangement for a three-expansion-stage, 2400 MW(t), 1300 MW(e) AHTR power conversion, using three PCU modules (HP, MP, and LP), with a recuperator (R) located in a fourth vessel. With a maximum pressure of 10 MPa and turbine inlet temperature of 900°C, the power density is 290

kW(e)/m^3, compared to 184 kW(e)/m^3 for the GT-MHR PCU (7 MPa, 850°C) [4].

Power conversion. The baseline power conversion system for the AHTR is a multiple-reheat helium Brayton cycle. The NGNP power conversion unit (PCU) will demonstrate key helium Brayton cycle technologies, including helium turbines and compressors, magnetic bearing systems, and high-effectiveness, low pressure loss recuperators. The PCU's developed for the NGNP can be used for the multiple reheat AHTR power conversion cycle; for example, a 2400 MW(t), 1300 MW(e) design based on three GT-MHR PCU's, shown in Fig. 1, allows compact composite salt-to-helium heat exchangers to be arrayed to be arrayed in an annulus around each turbine, giving a hot-gas flow length under 2 meters [4]. Under the dual-path approach, the MS-to-He heat exchangers needed for power conversion in the AHTR would be demonstrated as the He-to-MS IHX for the NGNP.

Reactor vessel and RCCS technology. The primary limitation upon the thermal power of the AHTR will be determined by the maximum heat removal rate that can be achieved by the RCCS, while maintaining acceptable vessel and fuel temperatures. Multiple functional requirements for the AHTR RCCS must be met, including inspectability, seismic, and material temperature and stress limits. Both the H-NGNP and the MS-NGNP would provide useful information on RCCS performance, but both would also suffer scale distortions relative to a RCCS system designed for a reactor thermal power > 2000 MW(t). Thus the AHTR development will require a parallel RCCS and reactor vessel development program, to identify, design, license and demonstrate technology for the large AHTR vessel and RCCS systems.

NGNP Functions and Requirements. The dual-path H-NGNP will meet several of the functional requirements that have been established for the NGNP. This includes the demonstration of commercial-scale electricity generation, allowing immediate subsequent construction of similar plants for the commercial market of 2015-2025. The requirement of a 1000°C core outlet temperature is close to values that have been demonstrated in smaller gas cooled reactors. To support the dual-path development of the AHTR, the H-NGNP should include the following design requirements:

1) **Molten-salt intermediate fluid.** Molten-salt should be selected as the baseline intermediate coolant for hydrogen production, with an appropriate technology and materials development program. Here it is important to note that molten salt provides lower technical risk than high-pressure helium, and is the appropriate baseline intermediate coolant to choose for the NGNP in any case [5].

2) **Air-cooled RCCS system.** Water is not acceptable as a reactor-cavity cooling system (RCCS) coolant for the AHTR, because as a volatile liquid, water introduces a mechanism to release the stored thermal energy in the primary molten salt, through steam explosions. Air, on the other hand, is essentially chemically inert and cannot generate high containment pressures if it interacts with the primary molten salt coolant. ("Direct containment heating," of the type studied for LWRs, results from the blowdown of molten core material from a pressurized vessel, and no comparable energy source exists to aerosolize molten-salt primary coolant of the

AHTR to generate rapid air heating.) The RCCS system performance is the key factor that will limit the AHTR thermal power, and thus a strong R&D program to improve and optimize air-cooled RCCS systems, and to demonstrate the licensing of an air-cooled RCCS system, is a key need for the AHTR development.

3) **Prismatic fuel.** While pebble fuel could conceivably be used for the AHTR, the ability to control the coolant flow channel geometry is important to obtaining negative void coefficients. Also, the issue of pebble floating, which would arise for some primary salt compositions (particularly ZrF_4-based salts), is avoided with prismatic fuel.

REFERENCES

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