Passive Decay Heat Removal for the Advanced High Temperature Reactor

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INTRODUCTION

This report presents a design concept for a high-capacity decay-heat removal system for the molten-salt cooled Advanced High Temperature Reactor (AHTR) [1]. The design is closely derived from the General Electric S-PRISM reactor, which is a sodium pool-type reactor [2]. The AHTR is distinguished from the S-PRISM by its use of a high-temperature thermal blanket, shown in Fig.1, that allows the vessel to be maintained at a lower temperature than the fuel and primary coolant. This report discusses the design of this thermal blanket and the passive decay heat removal system for the AHTR.

Figure 2 shows the reference decay heat curve for the Next Generation Nuclear Plant [3]. During the first few hours, the decay heat drops rapidly. By 40 hours, the decay heat generation has dropped to approximately (2.5W/588W) = 0.042 of the original full power, or 10.2 MWt for a 2400 MWt AHTR. For fully passive plants like the AHTR, S-PRISM, and GT-MHR, the passive decay heat removal system is sized to remove heat at approximately this rate achieved some 30 to 50 hours after shutdown. Prior to this time, the thermal inertia of the reactor core, internals and coolant is used to absorb the decay heat that exceeds the capacity of the passive decay heat removal system. Figure 3 shows the thermal response of the S-PRISM reactor that results from these design characteristics.

The S-PRISM reactor cavity cooling system (RCCS) is designed to match the decay heat generation rate, at approximately 30 hours, resulting from full-power operation at 1000 MWt. This is significantly smaller than the decay heat removal capability required for the AHTR. Here, the addition of a direct auxiliary cooling system (DRACS) to supplement the RVACS is investigated. Figure 1 shows a schematic diagram of the DRACS, which uses a natural-circulation flow loop to transfer heat from the cool-salt annulus between the reactor vessel and thermal blanket, to a heat exchanger located in the RVACS exhaust chimney.

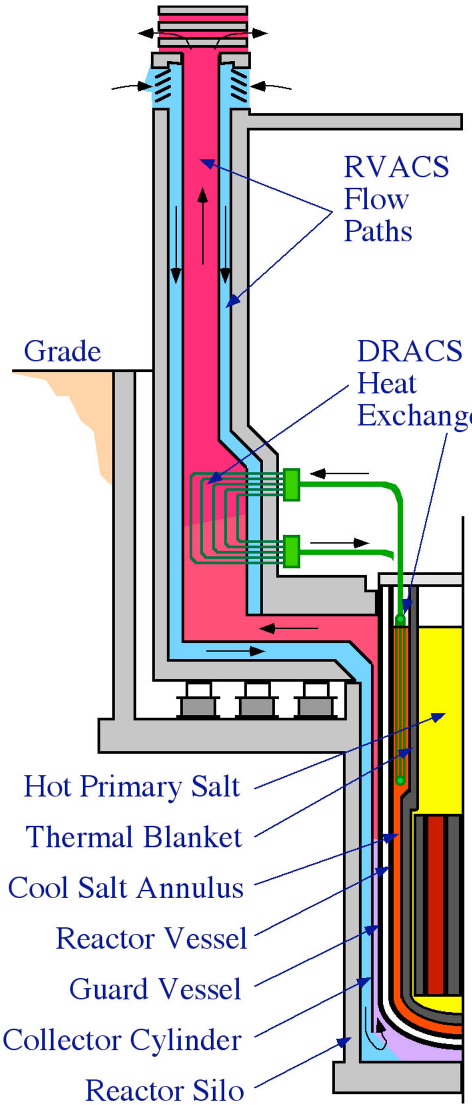

Fig. 1 Schematic of combined RVACS and DRACS system for the ATHR.

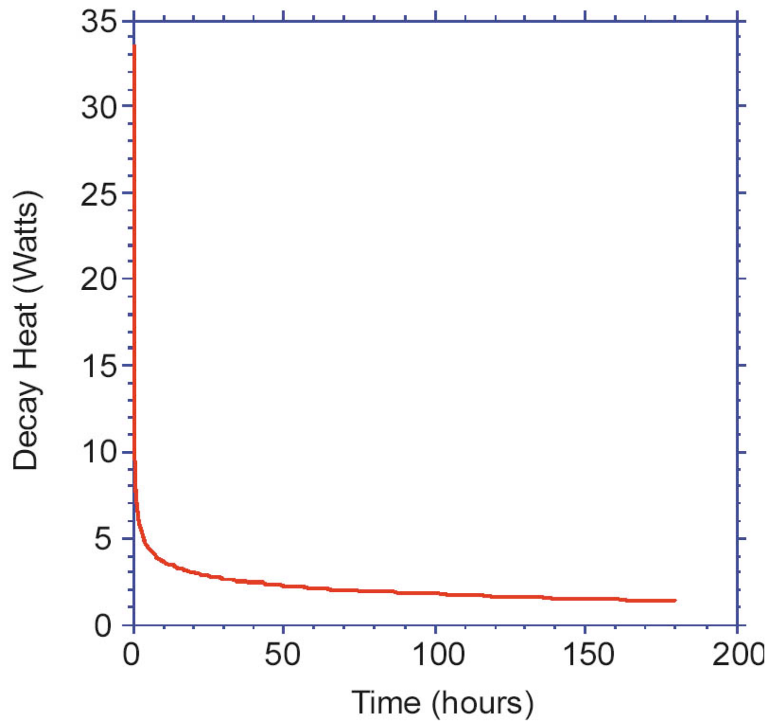

Fig. 2 NGNP equilibrium decay heat curve for a single standard fuel block after 417 EFPD at an average fuel block steady-state power level of 0.588 MWt ([3], pg. 59).

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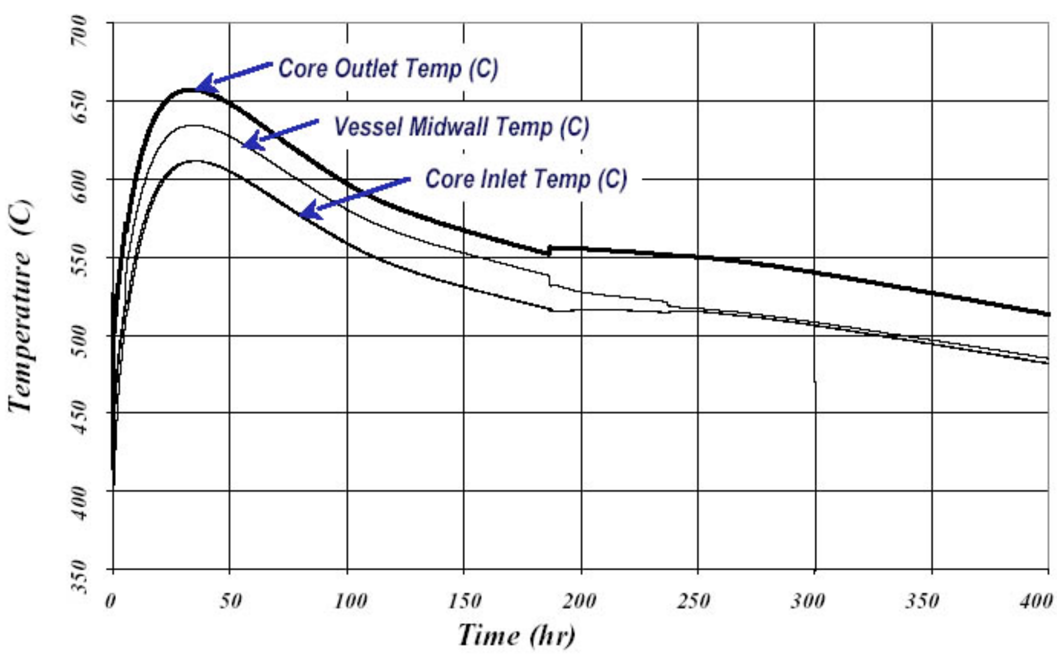

Fig. 3 S-PRISM passive cooling system reaches peak temperature at 30 hours, with very small temperature gradients in the vessel due to convective heat transfer by the sodium.

TABLE 1

Thermophysical properties of S-PRISM, GT-MHR, and AHTR reactor coolants and materials (approximate values at 700°C), with pressurized water at 290°C shown for comparison (ρ-density, c_p -specific heat, k-thermal conductivity, ν-vicosity). [1]

Material	T_{melt} (°C)	T_{boil} (°C)	ρ (kg/m^3)	c_p (kJ/kg°C)	ρc_p (kJ/m^3°C)	k (W/m°C)	$\nu \times 10^6$ (m/s)
$^7Li_2BeF_4$ (Flibe)	459	1,430	1,940	2.34	4,540	1.0	2.9
0.58NaF-0.42ZrF_4	500	1,290	3,140	1.17	3,670	~1	0.53
Sodium	97.8	883	790	1.27	1,000	62.	0.25
Lead	328	1,750	10,540	0.16	1,700	16.	0.13
Helium (7.5 MPa)	—	—	3.8	5.2	20	0.29	11.0
Water (7.5 MPa)	0	100	732	5.5	4,040	0.56	0.13
Hastalloy C-276	1325-1370	—	8,890	0. 43	3,820	9.8	—
Graphite	—	—	1,700	1.90	3,230	200.	—

REFERENCES

1. C.W. Forsberg, P. Pickard, and P.F. Peterson, "Molten-Salt-Cooled Advanced High-Temperature Reactor for Production of Hydrogen and Electricity," *Nuclear Technology* Vol. 144, pp. 289-302 (2003).
2. C.E. Boardman A.E. Dubberley, D.G. Carroll, M. Hui, A.W. Fanning, W. Kwant, "A Description of the S-PRISM Plant, "Proceedings of the 8th International Conference on Nuclear Engineering, Baltimore, MD, April 2-6, 2000.
3. "NGNP Point Design – Results of the Initial Neutronics and Thermal- Hydraulic Assessments During FY-03," Idaho National Engineering and Environmental Laboratory, INEEL/EXT-03-00870 Rev. 1, September 2003.