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PRELIMINARY FEASIBILITY STUDY OF THE HEAT-PIPE ENHS REACTOR

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ABSTRACT

This preliminary study assesses the feasibility of designing an Encapsulated Nuclear Heat Source (ENHS) reactor [1] to have a solid core from which heat is removed by liquid-metal heat pipes (HP). Like the SAFE space nuclear reactor core [2], the HP-ENHS core is comprised of fuel rods and HPs embedded in a solid structure arranged in a hexagonal lattice in a 3:1 ratio. The HPs extend beyond the core length and transfer heat to a secondary coolant that flows by natural-circulation. The HP-ENHS reactor is designed to preserve many features of the ENHS reactor including 20-year operation without refueling, very small excess reactivity throughout life, natural circulation cooling, walk-away passive safety, and robust proliferation resistance. The target power level and specific power of the HP-ENHS reactor are those of the reference ENHS reactor [1].

Compared to previous ENHS reactor designs utilizing a lead or lead-bismuth alloy natural circulation cooling system, the HP-ENHS reactor offers a number of possible advantageous features including: (1) significantly enhanced decay heat removal capability; (2) no positive void reactivity coefficients; (3) no direct contact between the fuel clad and coolant, hence, relatively lower wet corrosion of the clad; (4) a core that is more robust for transportation; (5) higher temperature potentially offering higher efficiency and hydrogen production capability.

The study focuses on four areas: material compatibility analysis, HP performance analysis, neutronic analysis and thermal-hydraulic analysis. Of four high-temperature structural materials evaluated, Mo TZM alloy is the preferred choice; its upper estimated feasible operating temperature is 1350 K. HP performance is evaluated as a function of working fluid type, operating temperature, wick design and HP diameter and length. Sodium is the preferred working fluid and the HP working temperature is 1300 K.

The neutronic analysis found that it is possible to achieve criticality and maintain a nearly zero burn-up reactivity swing for at least 20 EFPY with a linear heat generation rate of 90W/cm. The preferred design uses nitride fuel made of natural nitrogen and loaded with depleted uranium and TRU from LWR spent fuel after a long cooling period and arranged in a very compact lattice of P/D=1.0.

The core is oriented horizontally with a square rather then cylindrical cross section for effective heat transfer to the secondary coolant. The preferred secondary coolant is $LiF\text{-}BeF_2$. The HPs extend from the two axial reflectors in which the fission gas plena are embedded. For effective heat transfer to the secondary coolant it is sufficient to have the HPs extend less then 50 cm; the secondary coolant average outlet temperature is ~ 1090K. The required reactor vessel height is significantly smaller than that of the reference ENHS: 9 vs. ~20 m. The vessel diameter is slightly larger: 4 vs. ~3.5 m.

References

1. E. Greenspan and the ENHS project team, "The Long-Life Core Encapsulated Nuclear Heat Source Generation IV Reactor," ICAPP'02, Holywood, FL, June 9-13, 2002.
2. D.I. Poston, "Nuclear design of the SAFE-400 space fission reactor", Nuclear News, December 2002.