Thermal-hydraulic design and transient evaluation of a small long-life HTR

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HIGHLIGHTS

- We present the thermal-hydraulic evaluations of a small, long-life and block-type HTR using the DALTON/THERMIX code system.
- A cross section generation methodology is developed and verified for the diffusion calculations of the small HTR.
- The thermal-hydraulic characteristics of the small HTR during pressurized loss of forced-cooling loss of forced-cooling ones.
- The thermal-hydraulic characteristics of a cylindrical core are compared with an annular one.
- Thermal power limit of the small HTR is investigated based on depressurized loss of forced-cooling incidents.

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ABSTRACT

Small long-life high temperature gas-cooled reactors (HTRs) may provide electricity or heat for remote areas or industrial users in developed and/or developing countries. Moreover, small HTRs have advantages over large nuclear reactors of demonstrated inherent safety, transportability, modular construction, and flexible site selection. This paper presents the thermal-hydraulic evaluations of the U-Battery, which is a small, long-life and block-type HTR using the DALTON/THERMIX code system. The thermal-hydraulic characteristics of a cylindrical design and an annular design of the U-Battery were evaluated for loss of forced-cooling (LOFC) incidents including depressurized LOFC (DLOFC) and pressurized LOFC (PLOFC) incidents. The calculations show that the stronger natural circulation during the PLOFC makes the reactor core cool faster than during the DLOFC, flattens the radial solid temperature distribution, and transfers more heat from the hot regions (bottom and center of the reactor core) to cold regions (top and periphery of the reactor core). Although the natural circulation in the reactor core is so weak that it is neglected during the DLOFC, the decay heat is removed passively by conduction without any violation of the temperature limits for the 20 MW\textsubscript{th} U-Battery. The comparisons of the cylindrical and annular reactor core configurations show that the latter is a better design with a lower maximum core temperature during the LOFC because of the central graphite reflector. Moreover, it is possible to adopt the current reactor configuration when the thermal power of the U-Battery increases from 20 MW\textsubscript{th} to 40 MW\textsubscript{th}.

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1. Introduction

Compared to large-size nuclear reactors, small and medium-size reactors (SMRs) have some inherent advantages. They can be fabricated in modularity and transported to sites by rail, barge, truck, etc. After a long operation, they can be brought back to factories for refueling or directly replaced by new ones, which would greatly reduce the dependence of nuclear reactors on infrastructure. Thus, SMRs' sites can be chosen more flexibly than large-size reactors. More importantly, SMRs can be inherently or passively safe, because they commonly operate at low power levels. For example, some small reactors, which adopt passively cooling methods during normal operation or accident, have been proposed based on different reactor technologies, such as light water reactors (Modro et al., 2003), high temperature gas-cooled reactors and liquid metal cooled reactors (Sienicki et al., 2007).

Since the inherent safety of modular HTRs has been validated directly by experiments over the last 30 years (Gottaut and Krüger, 1990; Hu et al., 2006; Nakagawa et al., 2004), our previous papers (Ding and Kloosterman, 2010, 2011) presented the neutronic feasibility design of a small long-life HTR called U-Battery, which can be commercialized in the near future. The term U-Battery is used for this small HTR in order to emphasize its long life, transportability and inherent safety. Because the U-Battery is still at the stage...