Parametric Neutronics Design of a Small and Long-Life HTR

Ming Ding, Jan Leen Kloosterman
Delft University of Technology
Mekelweg, 15, 2629 JB, Delft, The Netherlands
phone: +31-15-2784041, m.ding@tudelft.nl

Abstract – Small and long-life high temperature gas-cooled Reactors (HTRs) are interesting because they can safely produce electricity or heat for remote areas or industrial users in developed and/or developing countries. Small HTRs have the advantages of transportability, modular construction, and flexible site selection. This paper presents the neutronic analysis of the U-Battery®, which is a small, long-life and block-type HTR based on currently mature HTR technologies. The 3.5 meter diameter of the reactor pressure vessel (RPV) is one of the design restrictions in order to secure its transportability. The lifetime of the U-Battery® is chosen to be 5 to 10 years in order to reduce its operating and maintenance costs. Key design parameters and possible core layouts of the U-Battery® were parametrically investigated using the TRITON 6 module in SCALE 5.1. The design parameters analyzed include fuel enrichment, the packing fraction of the TRISO particles, and the thicknesses of the top and bottom reflectors. The external side reflector, located outside the RPV of the U-Battery®, is proposed to improve neutron economy because the U-Battery® adopts a thin internal side reflector located inside the RPV. Nine possible layouts of the U-Battery® covers 7 cylindrical cores and 2 annular cores. The analysis shows that the design of the U-Battery® is feasible and flexible from neutronics point of view. The core layouts of 37*4(4 layers of 37 fuel blocks), 30*4 and 19*4 are promising designs of the U-Battery®. Moreover, the U-Battery® has the negative temperature coefficient of reactivity during its whole lifetime. However, the water ingress risk is obvious from the neutronic point of view because the induced positive reactivity by water or steam in the gas coolant varies in the range from 0 to 0.15 Δk/k.

I. INTRODUCTION

In the past fifty years, the size of nuclear reactors has grown from 60 MWe to more than 1600 MWe in order to make full use of economy of scale [1]. However, because large-size nuclear reactors usually require high capital investment and heavily rely on the infrastructure of reactor sites, this has motivated designers to develop small and medium-size reactors (SMRs), especially for developing countries and remote areas off main grids [2-4].

Compared to large-size nuclear 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, these reactors 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...