Static design of a liquid-salt-cooled pebble bed reactor (LSPBR)

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Abstract
A renewed interest has been raised for liquid-salt-cooled nuclear reactors. The excellent heat transfer properties of liquid-salt coolants provide several benefits, like lower fuel temperatures, higher average coolant temperature, increased core power density and better decay heat removal, and thus higher achievable core power. In order to benefit from the on-line refueling capability of a pebble bed reactor, the liquid salt pebble bed reactor (LSPBR) is proposed. This is a high temperature pebble bed reactor with a fuel design similar to existing HTRs, but using a liquid-salt as coolant. In this paper, the selection criteria for the liquid-salt coolant are described. Based on its neutronic properties, LiF–BeF₂ (flibe) was selected for the LSPBR. Two designs of the LSPBR were considered: a cylindrical core and an annular core with a graphite inner reflector. Coupled neutronic thermal-hydraulic calculations were performed to obtain the steady state power distribution and the corresponding fuel temperature distribution. Calculations were performed to investigate the decay heat removal capability in a protected loss-of-forced cooling accident. The maximum allowable power that can be produced with the LSPBR is hereby determined.

1. Introduction
Because of its high efficiency and inherent safety features, the high temperature gas-cooled reactor (HTGR) attracts a lot of attention worldwide. Despite these promising features, the HTGR concept can be improved by using a liquid-salt as a coolant instead of helium. Promising liquid-salt candidates exist that have excellent heat capacity and heat transfer properties, which allow reactor operation at high power density and high total power without any compromise to safety.

Till now, the Oak Ridge National Laboratory (ORNL) has focused on the advanced high temperature reactor (AHTR) (Forsberg et al., 2004), which can be considered as the liquid-salt-cooled counterpart of the prismatic HTGR. In this paper, we focus on the liquid-salt-cooled pebble bed reactor (LSPBR), which combines the advantages of a pebble-bed HTGR design (e.g. on-line refueling and flexible fuel management) with those of the AHTR (e.g. reactor operation at ambient pressure, high power density, lower maximum fuel temperatures, etc.).

The LSPBR has a core volume of approximately 300 m³ and a core height of 7.5 m. It produces 2500 MWth heat at 1000 °C liquid-salt coolant outlet temperature. Both a cylindrical and an annular core are investigated. The fuel of the LSPBR consists of TRISO coated particles incorporated in regular HTR fuel pebbles. The TRISO particles consist of an UO₂ fuel kernel covered by a porous buffer layer and a combination of an inner pyrolitic carbon (IPyC), a silicium carbide (SiC) layer and an outer pyrolitic carbon layer (OPyC).

There is one major difference between the AHTR and the LSPBR. The first reactor design has some flexibility with regard to the salt volume fraction in the core, as this is a design parameter that can freely be chosen, while the LSPBR has a fixed salt volume fraction of about 39% determined by the porosity of the random packing of the pebble bed.

2. Selection of the liquid-salt coolant
Several criteria are important for the selection of a liquid-salt coolant. Apart from good heat transfer