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Criticality and burnup analyses of a PBMR-400 full core using Monte Carlo calculation method

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ABSTRACT

In this study, the criticality and burnup analyses have been performed for full core model of Pebble Bed Modular Reactors, such as PBMR-400, using the computer codes MCNP5.1.4 and MONTEBURNS 2.0. Three different pebble distributions, namely; Body Centered Cubic (BCC) (packing fraction = 68%), Random Packing (RP) (packing fraction = 61%) and Simple Cubic (SC) (packing fraction = 52%) were selected for the analyses. The calculated core effective multiplication factor, k_{eff}, for BCC, RP and SC came to be 1.2395, 1.2357 and 1.2223, respectively. The core life for these distributions were calculated as ~1200, 1000, and 800 Effective Full Power Days (EFPDs), whereas, the corresponding burnups came out to be ~99,000, ~92,000 and ~86,000 MWD/T, respectively, for end of life k_{eff} set equal to 1.02.
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1. Introduction

In today's technological advances, nuclear reactor designs are tending towards smaller, safer, friendlier to environment and more economical. According to these criteria, Pebble Bed Reactors (PBRs) have great advantages over the other traditional fission reactors. PBRs have increased safety associated with the fuel type that is used in these reactors. In PBRs TRISO type fuel is used. In a TRISO particle fuel is packed in a silicon carbide and three pyrocarbon layers. These layers prohibits the leakage of the fission products from the fuel. This safety feature enables us to store the spent fuel in the places that have less radiation protection compared to the traditional reactor fuel waste storages. Low construction costs, high efficiency and online refueling features make these reactors economical (Kadak, 2005). In addition to this, by using helium, a noble gas, as coolant, very high reactor outlet temperatures can be achieved without increasing the pressure in these reactors. This high outlet temperature of the coolant would result in increased efficiency of the power station and/or can be used for the other applications such as hydrogen production.

Because of the peculiar nature of the fuel and core geometry, special modeling and computational techniques are required for the design and analysis of PBRs. Various worldwide research centers are developing and testing models and methods against the PBR's benchmarks (Bakhshayesh and Vosoughi, 2009; Şeker and Çolak, 2003). Kim et al. (2007) performed benchmark calculations for PBMR-400, reactor developed in South Africa, by using the Monte Carlo method. Bomboni et al. (2010) carried out the depletion calculation for the same reactor by making use of the computer codes MONTEBURNS 2.0, MCNPX2.6 and BGCore. It was observed that the BGCore code exhibits good computational performance.

In present study the analytical methodology and the validity of the computer codes MONTEBURNS 2.0 (Trellue, 2003), MCNP5.1.4 (X-5 Monte Carlo Team, 2005) and ORIGEN2 (Croff, 1980; Ludwig, 2002) has been analysed. The PBMR-400 was taken as reference reactor. Time dependent variations of multiplication factor k_{eff} and other parameters were investigated for 9.6% enriched UO_2 for different packing fractions. The calculated results were compared with those available in the literature.

2. Reactor description

PBMR is a 400 MW_{th} reactor, that utilize TRISO type fuel, has a vertical steel reactor pressure vessel, 6.2 m in inner diameter (Kim et al., 2007). Reactor core is composed of an inner graphite moderator surrounded by an annular fuel zone. The fuel zone is surrounded by an annular graphite zone as shown in Figs. 1 and 2. The main characteristics of the reactor are given in the Table 1. A

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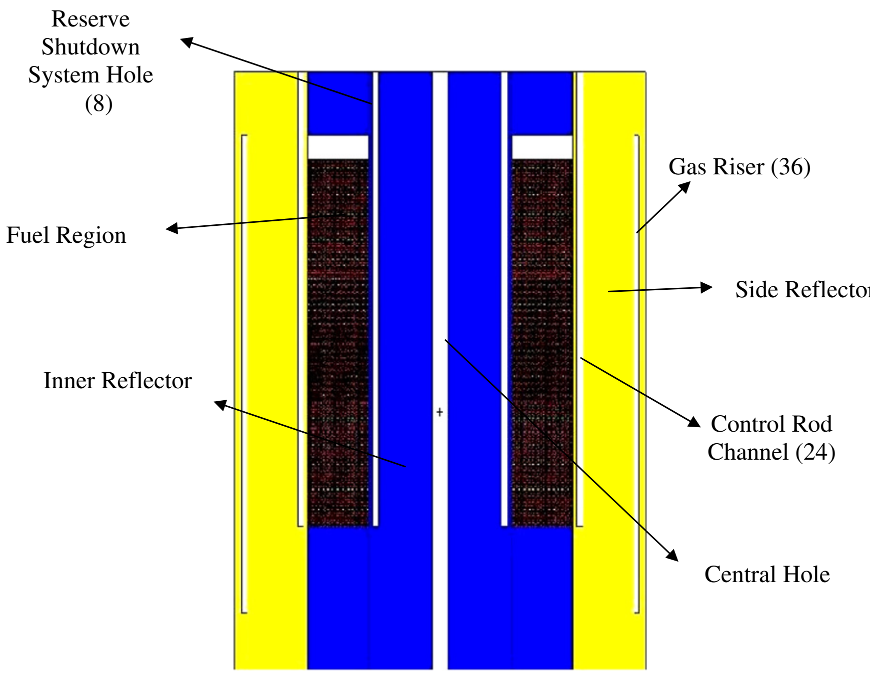

Fig. 1. Vertical view of the PBMR-400 model (Coşkun, 2010).

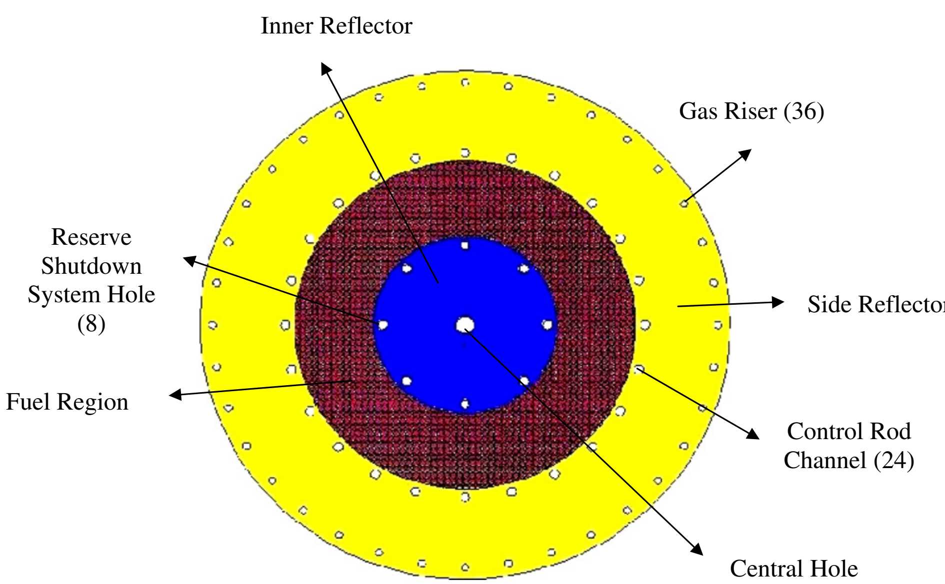

Fig. 2. Horizontal view of the PBMR-400 model (Coşkun, 2010).

fuel pebble contains ~15,000 TRISO fuel particles. Fuel particles are present in 5 cm diameter graphite matrix, which holds the particles together and acts as a moderator. Uranium dioxide fuel in TRISO particles are surrounded by three pyrolitic carbon (PyC) and a silicon carbide layer. The main characteristics of the fuel pebbles and the TRISO particles, used in this study, are given in Tables 2 and 3, respectively.

3. Numerical calculations

The neutron transport calculations were carried out with Monte Carlo methods, using the widely known three dimensional particle transport code MCNP, version 5.1.4 (X-5 Monte Carlo Team, 2005). MCNP5.1.4 allows the simulation of complex geometrical descriptions limited only with available computational power. MCNP5.1.4 simulation and calculations were made by using the ENDF/B-V continuous energy cross-section libraries. The first step of the computational procedure with MCNP were the definition of the geometry, material and the selection of appropriate tallies to obtain k_{eff} value of the reactor core and the flux spectrum.

Time dependent burnup and criticality calculations were made by using MONTEBURNS 2.0. (Trellue, 2003), a burnup code, which is a fully automated tool that links the Monte Carlo transport code MCNP with the radioactive decay and burnup code ORIGEN2 (Croff, 1980; Ludwig, 2002). The principle function of MONTEBURNS 2.0 is to transfer one group cross-section and flux values from MCNP to ORIGEN2, and then transfer the resulting material compositions

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