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Physics characteristics of the fixed bed nuclear reactor

Farhang Sefidvash [a], *Ha Van Thong* [b,*], *Dam Xuan Hiep* [b], *Do Thi Nguyet Minh* [b]

[a] *Federal University of Rio Grande do Sul, Brazil*
[b] *Electric Power University, Hanoi, Viet Nam*

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ABSTRACT

This article is about calculation of fuel burn-up and some physics parameters of the Fixed Bed Nuclear Reactor (FBNR), using spherical fuel elements similar to TRISO fuel, which is investigated by SRAC code. The fuel that was used is a uranium dioxide sphere (UO_2) with U^{235} enrichment of 5%. The main results of this study can be summarized as follows:

(1) Variation of nuclear isotope densities and effective neutron multiplication coefficient in process of fuel burn-up is determined and the reactor can operate during the time of 2.73 years, without on-site refueling. The U^{235} burn-up reaches value 71.84% of its initial density at the end of the reactor fuel cycle.
(2) When the core height is over 120 cm, the reactor control can be carried out by the movement of a core height level limiter, without the fine control rods in the core center.
(3) The kinetic parameters of the reactor (the prompt-neutron lifetime and effective delayed neutron fraction) change in process of reactor operation.

Introduction

The Fixed Bed Nuclear Reactor (FBNR) is a reactor of spherical fuel element, similar to TRISO fuel [1,2]. The reactor was developed under the IAEA coordinated Research Project (CRP) on Small Reactors without On-site Refueling (SRWOR); it is adequate for developing countries with small electric grids, and limited investment capabilities, as well as the weakness of manpower for development of nuclear power plants.

Description of reactor

Based on the Pressurized Water Reactor (PWR) technology, the FBNR operates at the capacity of 70 MWe. The reactor is an integrated primary circuit and simple design. The spherical fuel elements are fixed in the suspended core by the flow of water coolant under 160-bar pressure (Fig. 1). Some of main parameters of the reactor are shown in Table 1, and FBNR has characteristics during the operation as following:

* *Corresponding author*.
E-mail address: hvthong48@gmail.com (H. Van Thong).
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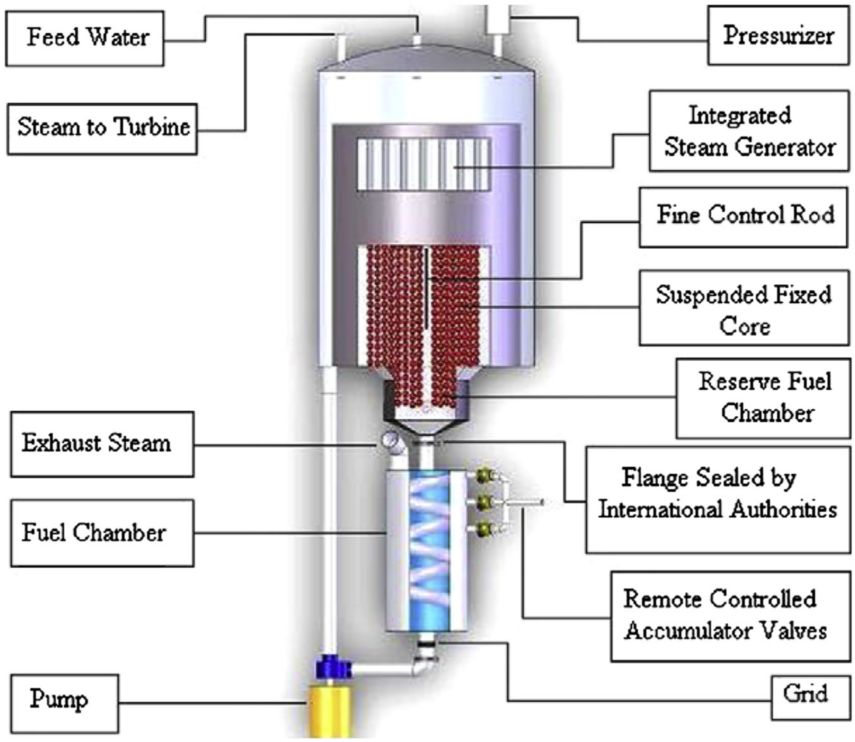

Fig. 1 – Schematic design of the reactor concept.

- The flow by the pump drives the fuel elements from the fuel chamber into the reactor core in its operation process. In the case of any malfunction of the reactor that influences on the reactor' safety operation may happen, the power is cut off and all the fuel elements immediately fall down into the fuel chamber; where they are passively cooled. Therefore, the accidents may not occur with the reactor;
- Adjusting the core height through the core level limiter controls the long-term reactivity. The fine regulating rod located at the core center controls the short-term reactivity. By such adjusting method, the fuel cycle life of FBNR is lengthened because it may avoid a poison of fuel burn-up for neutrons that strongly are absorbed in the core by fission fragments;
- The reactor has the characteristics of proliferation resistance and reduced environment impact because the reactor vessel is fixed and clothed by materials that strongly absorb radioactive rays, and the spent fuel elements are confined in the fuel chamber where it can be sealed by IAEA for inspection in the end of fuel cycle. The fuel chamber needs to be transported from factory to the site and return, when the refueling is necessary to be done and under IAEA inspection.

Spherical fuel element

The spherical fuel elements with the 15 mm diameter, clothed by 0.1 cm thick SiC, are made of compacted-coated particles embedded in a graphite matrix; and they occupy 60% in volume. The coated particles are similar to TRISO fuel with outer diameter of 2 mm; they consist of 1.58 mm diameter uranium dioxide spheres (kernel of UO_2, its density is 10.5 g/cm^3 and ^{235}U fuel enrichment is 5%) coated with three layers. The inner layer is 0.09 mm thick porous pyrolytic graphite (PYC) with density of 1 g/cm^3 that is called buffer layer, providing space for gaseous fission products. The second layer is a 0.02 mm-thick dense PYC (density of 1.8 g/cm^3), and the outer layer is a 0.1 mm thick silicon carbide (SiC, density of 3.17 g/cm^3). SiC protection layers, manufactured by chemical vapor deposition method, create resistance of graphite components against

Table 1 – Main parameters of the reactor.

Parameter	Value	Parameter	Value
Power generation, *MWth*	218	Coolant inlet temperature, °C	290
Net power generation, *MWe*	70	Coolant outlet temperature, °C	326
Pump power, *MWe*	3.4	Average temperature of coolant water, °C	308
Specific density of fuel UO_2, *g/cm^3*	10.5	Core height (cylindrical part), *cm*	200
Enrichment U^{235}, %	5	Inner diameter of the core, *cm*	31
Coolant mass flow, *kg/s*	668	Outer diameter of the core, *cm*	171
Coolant pressure, *bar*	160	Fuel elements occupied in the core volume, %	60