# Main features of the fixed bed nuclear reactor

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**Abstract:** The Fixed Bed Nuclear Reactor (FBNR) is one of the Small Reactors without On-site Refuelling, which have a capability to operate without refuelling and reshuffling of fuel for a reasonably long period consistent with the plant economics and energy security, with no fresh and spent fuel being stored at the site outside the reactor during its service life. The paper presents some operation and neutronics physics features of the reactor. One of them is a reasonable operation without fuel burn-up poison aimed at lengthening core lifetime of the Fixed Bed Nuclear Reactor.

**Key words:** Spherical fuel element; water layer; reactor vessel; fuel chamber; suspended core; cladding; core lifetime; core limiter; reserve reactivity; FBNR; IAEA.

## I. Description of the fixed bed nuclear reactor

The Fixed Bed Nuclear Reactor (FBNR) is one of spherical fuel element reactors and has been designed by Prof. Dr. Farhang Sefidvash from Federal University of Rio Grande do Sul (Brazil). It is also one of the small nuclear reactors without the need for on-site refueling is adequate for developing countries with small electric grids and limited investment capabilities. Authors of this paper have used the Prof. Dr. Farhang Sefidvash's conceptual reactor design to carry out their neutronics calculation.

### 1.1 Spherical fuel element

*The spherical fuel elements* with the 15 mm diameter, cladded by 0.1 mm thick SiC, are made of compacted-coated particles (figure 1) in a graphite matrix. The coated particles are similar to TRISO fuel with outer diameters of 2 mm. They consist of 1.58 mm diameter uranium dioxide spheres (density is 10.5 g/cm$^3$ and $U^{235}$ fuel enrichment is 5%) coated with 3 layers. The inner layer is of 0.09 mm thick porous pyrolithic graphite (PYC) with density of 1 g/cm$^3$ that is called buffer layer, providing space for gaseous fission products. The second layer is of 0.02 mm-thick dense PYC (density of 1.8 g/cm$^3$), and the outer layer is 0.1 mm thick silicon carbide (SiC, density of 3.17g/cm$^3$). SiC protection layers, manufactured by chemical vapor deposition method, create resistance of graphite components against water and steam at high temperature. Spherical fuel elements are able to confine fission products indefinitely at temperature below 1600°C [2].

**1.2 Description of reactor**

The FBNR is based on the Pressurized Water Reactor (PWR) technology and operates at capacity from 10 to 300 MWe. The reactor is an integrated primary circuit and simple in design. The spherical fuel elements are fixed in the suspended core by the flow of water coolant (see figure 2).

*The reactor core* has a cylindrical shape with the 200 cm height and the 160 cm diameter, cladded by the 0.5 cm zircaloy. At the core center, there is a water column of 20 cm diameter, cladded by a zircaloy pipe of the 0.5 cm thickness. This water column is called region 1. The reactor core (called region 2) is surrounded by a reflector (called region 3) composed of four layers made of different materials with total thickness of 20 cm. FBNR has the main features as follows:

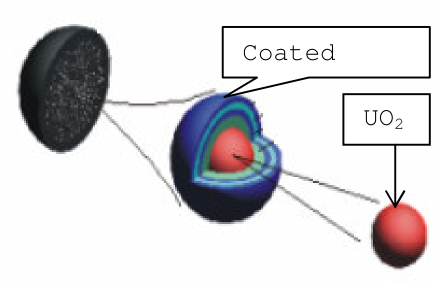


Figure 1. Spherical

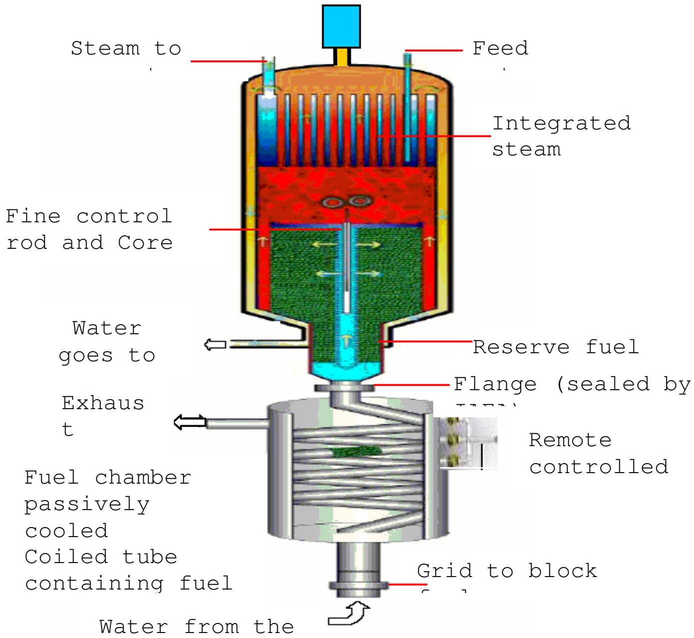


Figure 2. Schematic design of the

- The 15 mm diameter spherical fuel elements made from TRISO type coated particles are cooled by water under 160 bar pressure;
- The flow by the pump drives the fuel elements from the fuel chamber into the reactor core via reserve fuel chamber. Therefore, the fuel cycle life of FBNR is lengthened and there is not positive accident;
- Adjusting the core height through the core level limiter controls the long-term reactivity. The fine regulating

rod located at the center of the module controls the short-term reactivity. The walls of reserve fuel chamber is made of a high neutron absorbing alloy;

- The water heated in the reactor core passes through an integrated steam generator producing steam to drive the turbine;
- The reactor has non-proliferation characteristics as the fuel elements are confined in the fuel chamber where it can be sealed by IAEA for inspection at the end of fuel life. The reactor vessel is cladded by neutron absorbing materials to eliminate the possibility of neutron irradiation to any external fuel. Only the fuel chamber is needed to be transported from factory to the site and return.

Some of main parameters of the regions and the reactor are shown in table 1 and table 2, respectively.

Table 1. Volumetric fraction of the reactor regions.

| | $UO_2$ | $H_2O$ | C | Stainless steel | Zirconium alloy | SiC | Fuel | Total |
|---|---|---|---|---|---|---|---|---|
| Region 1 | 0 | 95 | 0 | 0 | 5 | 0 | 0 | 100% |
| Region 2 | 11.58 | 40 | 21.12 | 0 | 0 | 27.3 | 60 | 100% |
| Region 3 | 0 | 95 | 0 | 5 | 1 | 0 | 0 | 100% |
| Reactor vessel | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 100% |

Table 2. main parameters of the reactor

| **Parameter** | **Value** | **Parameter** | **Value** |
|---|---|---|---|
| Power generation, *MWth* | 134 | Coolant inlet temperature, $^oC$ | 290 |
| Net power generation, *MWe* | 40 | Coolant outlet temperature, $^oC$ | 326 |
| Pump power, *MWe* | 3.4 | Average temperature of coolant water, $^oC$ | 308 |
| Specific density of fuel $UO_2$, $g/cm^3$ | 10.5 | Core height, *cm* | 200 |
| Enrichment $U^{235}$, % | 5 | Inner diameter of the core, *cm* | 20 |
| Coolant mass flow, *kg/s* | 668 | Outer diameter of the core, *cm* | 160 |
| Coolant pressure, *bar* | 160 | | |

## II. Some neutronics physics features of the FBNR

### 2.1 Lengthening of fuel cycles by operation without fuel burn-up poison

*a. Traditional operation (by control rod system)*

With the reactor core data given in tables 1 and 2, the reactor operates at the power generation of 134 MWth and with the reserve reactivity calculated, ρ, equal to 0.16886 (1688.6 pcm). At this reserve reactivity, if the reactor operates thanks to a control rod system strongly absorbing neutrons in the core, the reactor operation time, according to calculation, is 1091 days, it means, about 3 years (see figure 3)

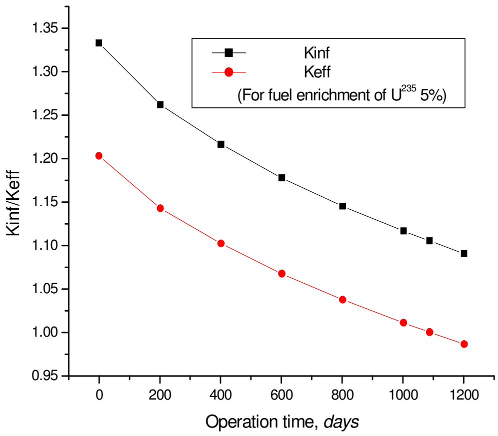


Figure 3. Change of neutron

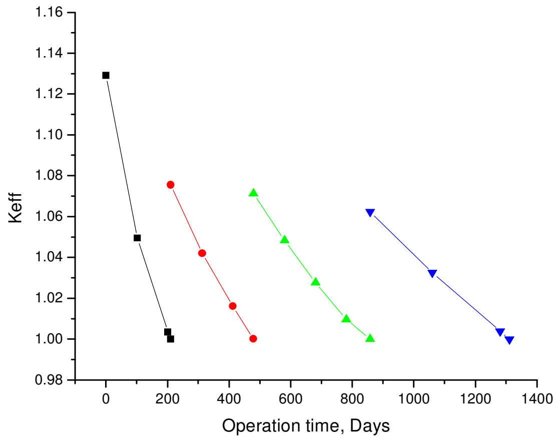


Figure 4. Process of reactor operation with 4 times of inserting

*b. Operation by change of core height (without fuel burn-up poison)*

In case of the reactor controlled by core height, the reactor operation is assigned by core height through the core limiter (without any control rod system that strongly absorbs neutrons). In this case, the fine control rod placed in the core center adjusts small reactivity so that the reactor becomes critical. By this control method, the fuel cycle will be longer than by the traditional operation mentioned above because there is not fuel burn-up poison in the reactor core. This phenomenon is explained that the spherical fuel elements in the reserve fuel chamber almost do not contribute to the reactor reactivity. When the core limiter is adjusted higher, some fresh spherical fuel elements from the reserve fuel chamber enter into the core to make it critical after compensation of fuel burn-up. Thus, with a number of spherical fuel elements from the reserve fuel chamber and by the operation of core height change, the core lifetime lengthens more than by the traditional method. It sees that if in the process of reactor operation, its height is changed four times, for our example (see figure 4), it is 60 cm, 100 cm, 140 cm, and 200 cm in step by step. At those 4 times, new spherical fuel elements that enter the core are mixed with the spent fuel elements existing there, all the core lifetime would be lengthened to 1311 days (3.6 years, equivalently). Therefore, when the spherical fuel elements always enter the core in the above method to make it critical after compensation of fuel burn-up, the core lifetime would be lengthened much more (than 3.6 years); and in point of economical view, using the FBNR is useful.

**2.2 Same other physics features**

*a. Fuel conversion ratio*

According to calculation, the fuel conversion ratio of the FBNR is 0.41. Thus, in comparison with existing fast reactors ($K_{TS}$ = 1.5 - 1.7) and thermal reactors ($K_{TS} \leq 0.8$), the FBNR has a smaller fuel conversion ratio.

*b. Temperature coefficient of reactor reactivity*

The temperature coefficient of reactor reactivity here is calculated under condition of the moderator water and fuel temperatures changed from 290°C to 330°C and its result is

$$\rho_t = -4.057 x 10^{-4} / {}^oC = -40.567\, pcm/{}^oC\ .$$

As known, temperature coefficient of reactivity for the existing water-water reactors is in interval - (1 ÷ 4) x $10^{-4}/{}^oC$ while one for the FBNR is -4.057 x $10^{-4}/{}^oC$. Therefore, the FBNR has the inherent safety higher than the existing water-water reactors.

## III. Conclusion

In framework of this paper, authors present some main features of the FBNR and their results calculated such as: if carrying out reactor operation without fuel burn-up poison, the FBNR's core lifetime will be lengthened more than in case of reactor operation by any control rod system; the FBNR has a fuel conversion ratio smaller and the inherent safety higher than the existing water-water reactors. The authors would like to express a great gratitude to. The work is supported in part by the National Basic Research Programm in Natural Science to which the authors would like to express the thanks.

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