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# Neutronic calculations of AFPR-100 reactor based on Spherical Cermet Fuel particles

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ABSTRACT

The Atoms For Peace Reactor (AFPR-100), as a 100 MW(e) without the need of on-site refueling, was originally based on UO2 TRISO fuel coated particles embedded in a carbon matrix directly cooled by light water. AFPR-100 is considered as a small nuclear reactor without open-vessel refueling which is proposed by Pacific Northwest National Laboratory (PNNL). An account of significant irradiation swelling in the silicon carbide fission product barrier coating layer of TRISO fuel element, a Spherical Cermet Fuel element has been proposed. Indeed, the new fuel concept, which was developed by PNNL, consists of changing the pyro-carbon and ceramic coatings that are incompatible with low temperature by Zirconium. The latter was chosen to avoid any potential Wigner energy effect issues in the TRISO fuel element. Actually, the purpose of this study is to assess the goal of AFPR-100 concept using the Cermet fuel; undeniably, the fuel core lifetime prediction may be extended for reasonably long period without on-site refueling. In fact, we investigated some neutronic parameters of reactor core by the calculation code SRAC95. The results suggest that the core fuel lifetime beyond 12 equivalent full power years (EFPYs) is possible. Hence, the adoption of Cermet fuel concept shows a core lifetime decrease of about 3.1 EFPY.


## 1. Introduction

According to the currently used classification in the IAEA, small reactors are those with an equivalent electric power less than 300 MW; also, medium sized reactors are those with the equivalent electric power between 300 and 700 MW (Technical meeting report, 2005; IAEA, 1997, 2006). Therefore, the Atoms for Peace Reactor (AFPR-100), as a 100 MW(e) without the need of on-site refueling, is a small reactor concept being developed by the Pacific Northwest National Laboratory (PNNL). The reactor system is envisioned to be resistant of nuclear proliferation, passively-safe, and economical for potential deployment to nations with emerging economies (Senor et al., 2007). The enabling feature of this reactor concept is the particulate fuel form. The fuel form provides fission product containment, low stored energy, and long core life. The AFPR-100 was originally using the confined TRI-Structural ISOtropic (TRISO) micro-fuel particles directly cooled by boiling water with average coolant temperature around 266 °C. The TRISO particle consists of a central spheroid kernel of uranium dioxide coated with multiple layers of carbide materials (Fig. 1). The inner and second layers are respectively porous (IPyC) and dense (OPyC) pyrolitic carbide and the outer layer is silicon carbide (Benchrif et al., 2009). However, during in-pile testing of the TRISO particles conducted by the All-Russian Institute of Atomic Machine Building (VNIIAM), it was found that pyro-carbon and silicon carbide could experience integrity problems under low temperature irradiation, related to the accumulation of atomic displacements in the graphite lattice structure (Wigner energy), owing to insufficient annealing at temperatures below ~260 °C (Final report of an IAEA coordinated research project, 2010). Thus, an alternative particulate fuel form was proposed. It consists, basically, of a spherical Cermet UO2 kernels embedded in a zirconium matrix coated with an outer zirconium layer as shown in Fig. 2. In fact, is divided into two regions: The inner region consists of coated fuel particles (kernels) embedded in a zirconium matrix. The outer region is made of a 300 μm thick protective zircaloy cladding (Senor et al., 2007; Chetaine et al., 2012). The dimension of the coated UO2 kernels (500 μm) is significantly smaller than the neutron mean free path in the fuel so that the inner region can be homogenized for numerical calculations (Sahin et al., 2009).

The previous TRISO particles contain the nuclear fuel inside porous pyrolitic carbide, called buffer layer, where the gaseous fission products will be accommodated easily (Sefidvash and Da Silva, 2008). It may perhaps appear speculative to extrapolate that

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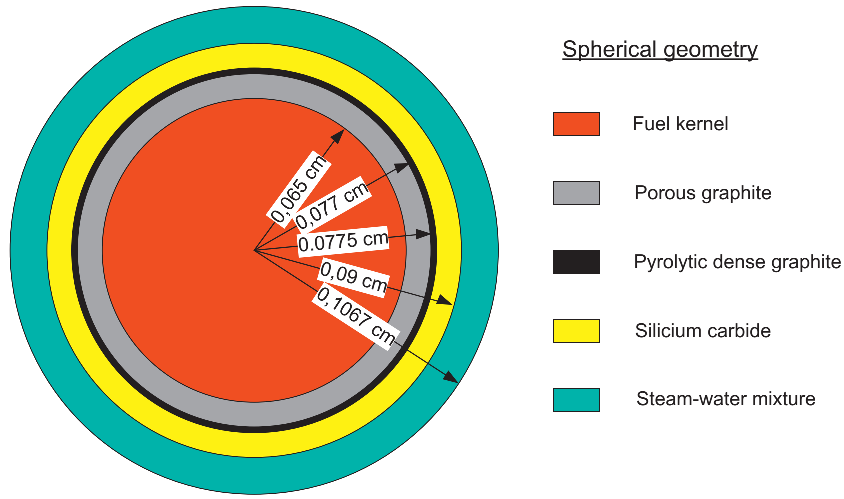


**Fig. 1.** Structure of TRISO coated particles with surrounding layer of steam–water.

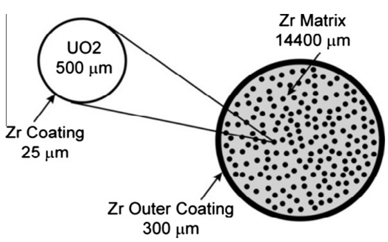


**Fig. 2.** Cermet fuel particle.

Cermet fuel inside the zirconium matrix and coating would withstand similarly high burn ups, although the sintered zirconium matrix may also offer a buffer for the gaseous fission products. But, of course it is to be preferred that they are already retained in the coating of particles (Senor et al., 2007; Sahin et al., 2010).

The present paper will focus on the evaluation of some neutronic parameters of AFPR-100 core using the new Cermet fuel element. The main objective of this neutronic analysis is to determine the impact of adoption of Cermet fuel, specially, on core lifetime, instantaneous conversion ratio, Spent Fuel Isotopic Composition and Neutron Energy Spectra.

## 2. Reactor design description and methodology used

The AFPR-100 is one of an evolutionary small reactor concept (Senor et al., 2007). It is a 100 MW(e) boiling water reactor. The core height is 3.0 m and its diameter is 3.1 m. Table 1 summarizes the core reactor parameters. The AFPR-100 incorporates fresh and used fuel storage tanks inside the reactor vessel and could operate for long duration before recharging the fuel storage tanks. The design of AFPR-100 core is depicted in Fig. 3. The micro-fuel elements were immobilized in four concentric cylindrical regions of the core. The latter were separated by steel partition with a thickness of 5.0 mm. Each fuel region was divided into four sub-regions, allowing the separation of fuel compositions in each of the different fuel regions as shown in Fig. 4. Control rods, filled with coolant water, were included in four radial fuel regions. In the fuel region, each Cermet fuel element is dispersed by mixture steam–water. The volume fraction of fuel particles to the fuel region is 60.0%. These three regions (fuel, zircaloy and steam–water) create one homogenized fuel–water region.

The distinctive features of the AFPR-100 reactor are as follows:

**Table 1**
AFPR-100 core parameters.

| Core parameter | Value |
|---|---|
| Thermal power, MW | 300 |
| Core height, m | 3.00 |
| Core diameter, m | 3.06 |
| Core volume, m | 21.1 |
| Enrichment of U235, % | 14 |
| Pebble bed porosity | 0.35 |
| Fuel zones | 4 |
| Control rods, number | 128 |
| Coolant | Water |
| Average coolant temperature, °C | 266 |
| Average coolant density, g/cm$^3$ | 0.774 |

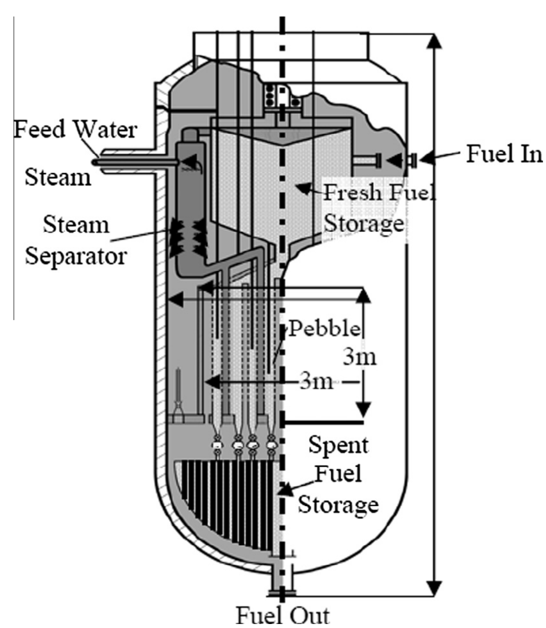


**Fig. 3.** AFPR-100 core reactor design.

- Uses the confined micro-fuel elements.
- Incorporates fresh and used fuel storage tanks inside the reactor vessel.