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The effect of the different parameters on the infinite multiplication factor of Gas-Cooled Fast Reactors

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ABSTRACT

One of the Gen IV reactor concepts is the Gas-Cooled Fast Reactor, the design of which contains a lot of improvements compared to the nowadays operating nuclear reactors; not only regarding the coolant, but the fuel assembly is also different from that of conventional ones. Hence the ceramic fuel design and the helium coolant, it is important to understand the effects of the different parameters, e.g. what the rhenium layer, which is applied on the inner surface of the cladding, may cause. During different examinations of the test reactor ALLEGRO it was investigated how certain geometry and material parameters influence the infinite multiplication factor and thus the reactivity.

1. Introduction

Generation IV nuclear reactors have many advantages over the nowadays operating reactor types. The most researched concepts, which were selected by the Generation IV International Forum, contain numerous technical and technological innovations (Generation IV International Forum, 2009). The Gas-Cooled Fast Reactor (GFR) is one of these conceptual types. The coolant of this reactor is helium whose temperature at the outlet is 850 °C (Stainsby et al., 2011). For proper operation, it is necessary that the fuel and the cladding withstand these conditions. The choice fell on the carbide-type fuel (uranium-carbide and plutonium-carbide) and on some sort of silicon-carbide as cladding (Carre et al., 2010). These ceramic materials have very high melting point, density and thermal conductivity. Because of the lack of sufficient experience with the application of these types of materials in nuclear reactors and also with the Gas-Cooled Fast Reactors, an experimental facility, named ALLEGRO, is designed to perform the needed measurements and tests (Stainsby et al., 2011). The initial design of ALLEGRO investigated in this paper was developed by CEA (France) and provided to partners of the GoFastR project (Stainsby et al., 2011; GoFastR project website) for further investigations. The core of ALLEGRO contains 86 fuel assemblies, each of which consists of 90 fuel pins. The thermal power of this reactor is planned to be 75 MW (Čerba et al., 2013). In order to prevent the fuel-cladding chemical interaction, the inner surface of the cladding is covered by a layer of rhenium and a layer of tungsten-rhenium alloy (Bertrand et al., 2012; Meyer, 2004). In this paper, the effects of the rhenium layer, the pin pitch, the cladding, the coolant, the fuel pellet diameter, the fuel density and the temperature on the multiplication factor are investigated. A small difference in the multiplication factor can result in a significant change in reactivity because of the low effective delayed neutron fraction. The calculations were carried out with the aid of the code MCNPX for a fuel assembly model with the ENDF/B-VII cross section library. The boundary condition on the vertical surfaces of the investigated unit cell were reflective; nevertheless, in axial direction all the parts was modeled (bottom reflector, active length, upper reflector).

2. Description of the models

For the analysis, an MCNPX (Pelowitz, April 2008) model of the ALLEGRO fuel assembly was built according to the accurate geometry data of the initial design. The model contains the (uranium, plutonium)-carbide fuel, the gap, which is filled by helium gas, the two different layers of rhenium, the silicon-carbide cladding and the silicon-carbide wrapper. The initial design of the ceramic fuel pin can be seen in Fig. 1.

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The ceramic fuel composition provided in the initial design was used. The active length of the fuel pin is 86 cm. Under this region, a 40 cm long gap is located, which is filled with helium. The role of this gap is that it ensures sufficient room for the fission products. Under and above the fuel pin a reflector section was modeled, the material of which is ZrC. The reflector parts also have covers in axial directions, which were B_4 C shielding.

The MCNPX model of the fuel assembly can be seen in Fig. 2. It contains 90 fuel pins with a pitch of 1.157 cm in cold state, which decreases to 1.1 cm under operational conditions. The number of active cycles was 500 in each calculation and the number of neutrons started was 10,000 per cycle.

3. The effect of material properties

In this section, the effect of the Pu content and the pellet density is investigated. These properties are determined during the fuel fabrication process.

3.1. Plutonium content

The designed fuel assembly contains 28.44% plutonium-carbide and 71.56% uranium-carbide. The latter is natural uranium so it contains 0.72% U235. In this part of the investigation, the plutonium content of the fuel assembly was varied uniformly in every fuel assembly. Since the percentage of plutonium is changing, the uranium content is also different in the calculations. The results are shown in Fig. 3. It is obvious that the increasing amount of plutonium increases the infinite multiplication factor and in this way the reactivity of the system. As a first order approximation, a linear was fitted on the data. It can be seen that in this interval it gives a good description for the change of the multiplication factor. According to the fitted linear, 0.1% Pu content difference causes about 240 pcm $\Delta k_{inf}/k_{inf}$ change.

3.2. Fuel density

The designed value of density was varied between ±2% to investigate the effect of how it influences the infinite multiplication factor. As can be seen in Fig. 4, the linear approximation of the calculated values is appropriate for this interval.

The equation of the fitted linear is $(0.03449\pm0.0361902)\cdot x+0.97698\pm0.00395$, where x is the density in units of g/cm^3. Based on the results, the $\Delta k_{inf}/k_{inf}$ change is about 34 pcm if the density difference is 1%. Therefore, the infinite multiplication factor is not very sensitive to fuel density changes.

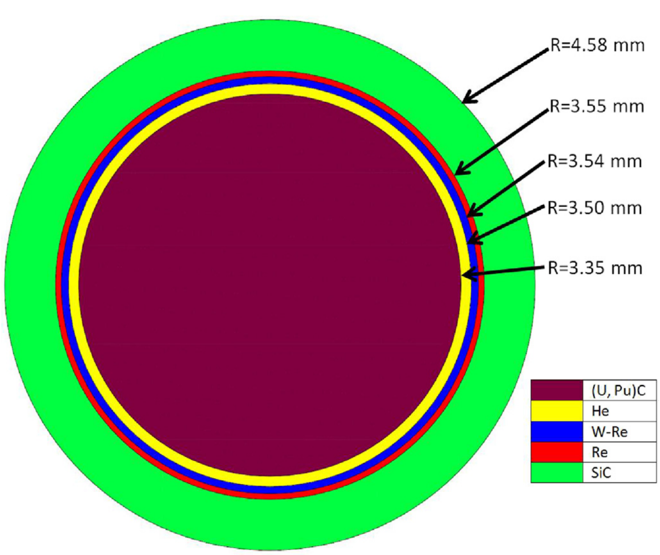

Fig. 1. The geometry of the initial design of the ceramic fuel pin.

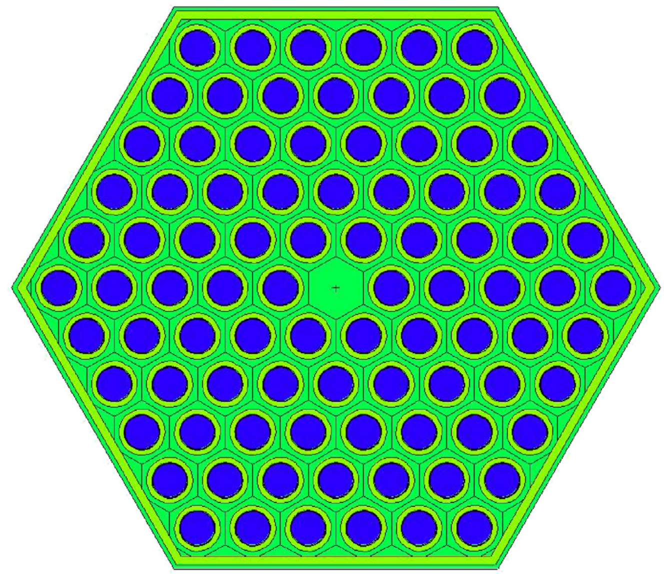

Fig. 2. The MCNPX model of the fuel assembly.

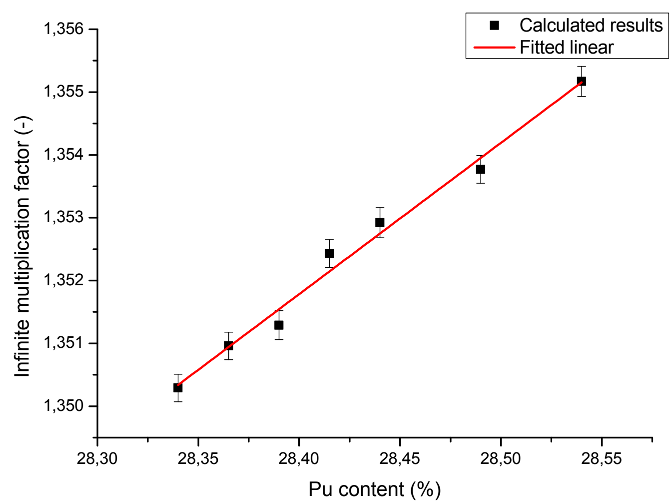

Fig. 3. The effect of the Pu content on the multiplication factor.

4. Geometrical parameters

In this section, the fuel pellet diameter, pin pitch, cladding, and the width of the rhenium layers were varied.

4.1. Pin pitch

The designed distance between the centers of the fuel pins is 1.10 cm. This value was changed between 1.06 cm and 1.14 cm. The results show that in the investigated interval, the first order approximation is a good approximation of the variance of the multiplication factor (Fig. 5).

The increased pin pitch (and size of the coolant channel