ABSTRACT

The TRIstructural ISOtropic (TRISO) fuel, composed of uranium kernel covered with silicon carbide (SiC) and pyrolytic carbon (PyC) coating layers, serves as the smallest component of the nuclear fuel. Thousands of the TRISO-particles are immersed in the graphite matrix, taking the form of a sphere (pebble bed reactor type) or pellet (prismatic reactor type), which are used in High-Temperature Gas-cooled Reactors (HTGRs). Due to the fuel irradiation in the reactor core, partial or complete damage to the covering TRISO layers might occur. The examination of the defects occurring in the TRISO layers is a key aspect of a good understanding of the failure-free performance of TRISO-particle fuel and is key to the safe and efficient operation of the HTGRs.

The damage-rate measurements of the TRISO-particle layers are performed at the production stage and after extracting the irradiated fuel from the reactor core. Neutron irradiation is a long-term process. The experimental, ion-irradiation method, which is suggested in the dissertation, allows to verify the level of damage in the coating layers, without the necessity to deal with activated material. In addition, this method is an effective tool to reflect the neutron irradiation damage in the reactor core, by radically shortening the time for inducing damages.

The examination of the TRISO samples was carried out at the front-end stage. The purpose of this research was to verify the coating layers for damage occurrence, before the TRISO-particle fuel is placed in the reactor core, but under conditions corresponding to the irradiation of the fuel in the reactor core. The front-end stage is the initial analysis of the failure rates of freshly manufactured or stored but unirradiated samples. The experiments were performed on surrogate in-process coated particles, called p-TRISO. The unique feature of p-TRISO particles is the absence of uranium in the kernel, which was replaced by zirconia dioxide. The p-TRISO samples were produced in 2001, retained, and never used.

The ion-irradiation experiments were conducted on both polished and unpolished p-TRISO samples, implanted with Ne^+ and He^+ ions of specific fluences and energy. The purpose of this experiment was to capture the point at which damage starts to occur to the individual layers, as well as to understand the appearance of damage at the interface of the Buffer-IPyC layers. Several diagnostic methods such as Raman spectroscopy, Scanning Electron Microscopy (SEM), and Confocal Laser Scanning Microscopy (CLSM) were used.

The performed research determines whether and how the passage of time affects the occurrence of changes in the p-TRISO fuel layers structure, and at the same time, whether it contributes to increasing the probability of damage to the examined fuel material. The experiment confirmed that significant structural changes appear after one year of ion irradiation of the samples. Significantly, with further time (i.e., after 3 and 5 years) of irradiation, no noticeable changes were observed in the p-TRISO coating layers (in comparison to the changes observed after 1 year of irradiation). Moreover, it should be taken into account that the experiments were performed on 22-year-old TRISO-particle fuel samples. Therefore, the results of the experiment allow us to conclude that also the stored but unirradiated fuel can be effectively used as fuel in the reactor core. However, the results obtained in the mentioned scope should be compared with freshly manufactured TRISO samples within the occurrence of damage in the coating layers. Then the question of whether the damage in the TRISO sample layers is more progressive in “old” (stored, but unirradiated) fuel than in “new” (freshly manufactured) fuel could be answered. Such research, however, was not the subject of this dissertation, nevertheless, it should be undertaken in the future.

The result of this work confirmed that an ion irradiation technique is a quick and efficient tool for reflecting irradiation-induced damages in the p-TRISO sample layers. This method can be used at the front-end stage, to determine if the stored but unirradiated TRISO-particles pass the quality control and could be placed in the reactor core.