ABSTRACT

Good safety characteristics are an outstanding feature of High Temperature Reactors (HTR):

- The high graphite inventory in the core provides significant thermal inertia. Graphite also has a high thermal conductivity, which facilitates the transfer of heat to the reflector, and it can withstand high temperatures.
- The strongly negative Doppler coefficient gives a negative feedback, such that the reactor shuts down by itself in overpower accidental conditions.
- The high quality of fuel elements – tri-isotropic (TRISO) coated particles – minimizes operational and accidental fission gas release. The materials selected have resistance to high temperatures.
- The low power density enables stabilization of core temperature significantly below the maximum allowable, even in case of severe accidents (such as loss-of-coolant accident).

Together, these aspects significantly reduce the risk of massive fission product release, which is one of the attractive features of HTRs.

The fuel that is currently used in pebble bed reactors such as AVR, HTR-10 and soon PBMR is based on a homogeneous distribution of coated particles within a fuel pebble. This homogenizes power density in the pebble, but creates a radial temperature gradient across the fuel sphere. Fuel particles placed at its centre has the highest temperature. Reducing the average temperature of particles would help preserve their integrity and maintain the resistance of the first barrier against fission product release.

As early as the 1970s, attempts were made to reduce the peak fuel temperature by means of so-called “wallpaper fuel”, in which the fuel is arranged in a spherical shell within a pebble. At that time, the production process was not sufficiently mature and had caused unacceptable damage to the (less performing) BISO particles, which is why this fundamentally promising concept was abandoned. In this paper, proposals will be put forward to improve the production process.

This paper further exploits the wallpaper concept, not only from the point of view of temperature reduction, but also for enhanced neutronic performance through improved neutron economy, resulting in reduced fissile material and/or enrichment needs or providing the potential to achieve higher burn-up. Parameters modified were the density of the central fuel-free graphite zone and the packing fraction of the fuel zone.

It is demonstrated that this fuel type impacts positively on the fuel cycle, reduces production of minor actinides (MA) and improves the safety-relevant parameters of the reactor. A comparison of these characteristics with PBMR-type fuel is presented. The calculations were performed using Monte Carlo neutron transport and depletion codes MCNP/MCB and the deterministic code WIMS.

By comparison with PBMR fuel, the “wallpaper design” of the fuel pebble results in an effective neutron multiplication coefficient increase (by about 2%), which is combined with a decrease of between 3 and 15% in MA production. An improved neutron economy of the heterogeneous design enables enrichment of the “wallpaper type” of fuel to be reduced by more than 6%.

INTRODUCTION

Invented by Professor Dr. Rudolf Schulten [1] in the 1950s and developed in Germany in the 1970s, High Temperature Reactors feature several important inherent and passive safety characteristics, namely:

- high thermal inertia,
- negative Doppler coefficient,
- high quality fuel,
- low power density.

Together, the aforementioned aspects prevent massive release of fission products in the case of an accident and core melt down.