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Thesis outline

"Design Study for Modular Pebble Bed High Temperature Gas-cooled Reactor with Rock-like Oxide Fuel Element"

Ho Hai Quan

Pebble bed reactor (PBR) is claimed to be have excellent passive safety features among various type the reactors. Rock-like oxide (ROX) fuel has been studied with high chemical stability under geological condition. It is of interest that using ROX as fuel in PBRs can improve safety features during normal operation and the final disposal of spent fuel. The purpose of this study was to show the design concept for a small modular PBR with ROX fuel that could achieve a high safety feature of spent fuel with high burnup performance.

In the first step, the burnup performance of once-though-then-out (OTTO) cycle PBRs with ROX fuel has been investigated. The MCPBR code, which was particularly designed for modeling the OTTO cycle movement of PBRs, was used to perform the burnup analysis with the JENDL-4.0 cross section library. Results at equilibrium condition showed that ROX fuel PBR presented some advantages as well as disadvantages compared to the UO_2 fuel. Even though the fissile density was too low, PBR with OTTO cycle utilizing single-phase YSZ fuel could achieve criticality at equilibrium condition. The ROX fuel reactor showed lower fission per initial fissile atoms (FIFA) than the UO_2 fuel reactor at the same amount of heavy-metal (HM)/pebble, about 5-15%. However, the power peaking factor and maximum power per fuel ball in the ROX fuel core were lower than that of UO_2 fuel core. In addition the ROX fuel reactor had a negative temperature coefficient, required for the passive safety feature of the PBR. From the results, it is expected that a small modular PBR with ROX fuel can achieve higher stability in geological disposal of spent fuel without significantly reducing the burnup performance.

In the second step, the design concept for a small PBR with ROX fuel has been proposed. Firstly, optimization of fuel composition was implemented by cell calculations. The highest 20% enrichment of uranium with 3-g HM loading in a pebble could give a discharge burnup of about 135 GWd/t-HM. This means that even if the low fissile density, the UO_2-ROX fuel PBR can be expected to achieve high burnup when fuel with high uranium enrichment is used. After finishing the infinite calculation, whole core optimizations were performed with and without fuel pebbles movement. With a heavy metal amount of 2 g per pebble and 20% uranium enrichment, the PBR with OTTO cycle could achieve maximum burnup of about 145 GWd/t-HM. In addition, the results show that the core height can be reduced due to the fact that the impact of bottom core on burnup performance is insignificant. From the viewpoint of economy issues, it was found that the reactor power as well as burnup performance do not change much, even if the core height decreases from 10 m to 6 m, even as the construction cost is considerably reduced. A

reactor with 6-m core height and 120-MWth reactor power was ultimately determined as the optimal design for a PBR with ROX fuel. This optimal design also has a negative temperature coefficient, and the peak power density was less than the limit of 10 W/cm^3.

As in the third step, burnup performance of the ROX fuel in molten salt LiF-BeF_2 (Flibe) has been carried out to investigate the burnup performance of the U-ROX fuel in flibe coolant and to show that the ROX fuel PBR with flibe coolant could achieve higher reactor power than that with helium gas coolant. The results in the infinite analysis show that flibe coolant has a benefit in term of moderator characteristic, it made the neutron spectrum shift to being softer compared to helium coolant at the same amount of HM/pebble. However, the softening neutron spectrum in case of flibe coolant could not make the burnup of the ROX fuel higher than that with helium gas coolant due to the fact that flibe was also an absorber material; the softer neutron spectrum the higher neutron absorption of flibe. In whole core calculation, changing from helium gas coolant to flibe coolant resulted in slightly enhance the burnup performance of the ROX fuel in PBR if the large amount of HM/pebble was used. The peak power density in case of flibe coolant was higher than that in helium gas coolant because of the reflection at the top of the core. However, the PBR with flibe coolant could increase the reactor power to 200 MW_{th} in comparison with 120 MW_{th} for the helium-cooled PBR, thanks to the high volumetric heat capacity of flibe coolant. The U-ROX fuel PBR with flibe coolant also had the negative values of temperature reactivity coefficient including fuel temperature coefficient, graphite temperature coefficient, and coolant temperature coefficient.

The study showed the possibility in the use of ROX fuel in PBR. A design concept of a small PBR with ROX fuel has been proposed with high burnup performance of U-ROX fuel. Also, the feasibility of using fluoride salt as coolant in ROX fuel PBR has been confirmed, in which the high reactor power could be achieved without reducing the safety features of the reactor.