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Summary

A 100-MWt HTGR has been designed under the concept of small, long-life prismatic HTGR coupling with the improvement of safety features to reduce the possibility of severe accident. The essential solutions have been proposed to improve the safety features of the prismatic HTGR to avoid from the graphite oxidation in depressurization accident and the reactivity insertion accident when all control rods were withdrawn.

To reduce the possibility of severe accident from the graphite oxidation, the concept of SiC coating layer on the graphite structure has been proposed and investigate the impact of SiC coating layer on the core performance and the thermal-hydraulic behavior of the core. The result showed that the appropriate technique of SiC coating layer can be confirmed the effect from the neutronic and the thermal-hydraulic point of view; adding a small amount of SiC instead of graphite as a coating layer can have a small impact on the neutronic characteristic by slightly decreasing the reactivity and shortening the fuel burnup life cycle.The coating of SiC layer with the thickness of 500 μm led the discharge burnup decreased from 104 GWd/t for the HTGR without SiC coating layer to 98 GWd/t which in turn reduced the reactor core lifetime from 1,670 EFPDs to 1,572 EFPDs. Regarding the heat transfer behavior, the fuel temperature was slightly impacted by the coating of a SiC layer. By the coating of SiC layer with the thickness of 500 or 700 μm, the maximum fuel temperature was increased from 1,320^{o}C to about 1,325 - 1,327^{o}C which was less than that given in the HTGR design at 1,600^{o}C. So it can be concluded that SiC coating layer is practical and achievable in the improvement of passive safety features in the HTGR because it can effectively improve the oxidation resistant of the graphite and can be acceptable the effects on the neutronic and the thermal-hydraulic characteristics.

By the experience from the Chernobyl accident, the importance of reactor design free from the prompt criticality state during the operation when all control rods were withdrawn has been concerned by using the particle-type burnable poison to control the excess reactivity lower than the prompt critical state at one dollar along the burnup operation. The result showed that the appropriate matching of B_4C particles with Gd_2O_3 particles and that of B_4C particles with CdO particles were recognized on the excellent performance to suppress the reactivity from 30 %Δk/k to be within 1.3 %Δk/k and control the long-term reactivity. However, only the use of BP particles cannot achieve to control the reactivity below the prompt critical state for the whole burnup operation. Therefore, it required the reactor design with a subcritical state for some operation periods. The lack of the reactivity during subcritical operation can be compensated by decreasing the core temperature. The core temperature was required to decrease by 180 K for the reactivity compensation which caused the drop of thermal efficiency from 48% to 42%. To design the reactor free from any supercritical accident, the reactor was designed with subcritical operation along the burnup period.

By this design, the core temperature required to decrease by 350 K which can cause the decrease of thermal efficiency to be 36%.

Even the improvement of safety features can achieve to avoid the reactor from the sever accidents, but the viewpoint of energy sustainability should be concerned. Therefore, thorium has been proposed to use as an alternative nuclear fuel instead of uranium fuel which has the limited resource. By loading of thorium fuel, it can recognize the improvement of neutron economic that the discharge burnup was increased from 101 GWd/t in uranium fuel based HTGR to be 143 GWd/t in thorium fuel. Otherwise, it also recognized on the reduction of the safety aspect by positive core temperature coefficient. Therefore, the particle-type burnable poison which can show the capability on the reactivity control in the HTGR using uranium fuel has been introduced. The result showed that the loading with appropriate composition of BP particles can effectively suppress high excess reactivity in the HTGR using thorium fuel and flatten the reactivity swing, but it cannot achieve to control the reactivity lower than the prompt criticality state because of a very small β_{eff} of ^{233}U and very high excess reactivity for a long-term operation. Even the use of BP particles cannot make the reactor using thorium fuel free from the prompt critical accident, but it can show the usefulness on the reactivity control as low as possible and lead the core temperature become negative for a while operation. For unloading of BP particles, the core temperature coefficient of ^{233}U-^{232}Th fuel was $(0.23\sim3.72)\times10^{-5}\Delta k/k/K$, but when the BP particles were loaded, it can effectively reduce the core temperature coefficient to be $(-2.65\sim3.87)\times10^{-5}\Delta k/k/K$.

This study was shown that the concept of SiC coating layer on the graphite structures and the loading of BP particles in uranium fuel based HTGR were the essential solutions in the improvement of inherent safety features of the HTGR. The loading of BP particles in thorium-based fuel can show the usefulness on the large excess reactivity compensation and make the reactor become more inherent safety reactor by providing negative core temperature coefficient.