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THESIS OUTLINE

The CANDLE (Constant Axial shape of Neutron flux, nuclide densities and power shape During Life of Energy producing reactor) burnup strategy has been successfully applied to both fast and thermal reactors. In particular, fast CANDLE reactor has been found to offer many advantages. However, maintaining the material integrity of the fuel rods up to high burnup is a problem that requires particular attention. For presently available structural materials compatible with liquid metal coolants, the acceptable limit for radiation damage is 200 dpa. In order to overcome the material integrity issue while obtaining larger fuel burnup it is necessary to recondition the fuel by recycling and re-cladding. For the sake of keeping the fuel cycle as proliferation resistant as possible, which excludes actinide separation, the melt-refining process has been developed for metallic fuel in the Experimental Breeder Reactor II project.

The objective of the present study is to show design concepts of small CANDLE reactor with the melt-refining process. A 300 MWt LBE cooled reactor is designed. The reactor uses metallic (90 wt. % U - 10 wt. % Zr) natural uranium as fresh fuel and 12Cr ferritic ODS steel as cladding material.

Neutronic analyses are performed to compare the burnup performance of reactors with and without the melt-refining process. Three bounding scenarios are considered: all actinides are recovered during the melt-refining process (scenario 1), 5 % (scenario 2) and respectively 10 % (scenario 3) of all actinides are unrecovered during the melt-refining process. The radioactive decay of the fission products during cooling time intervals is taken in consideration during the melt-refining process. Thermal-hydraulic analyses are conducted in steady state regime to make sure that the core design obeys a number of constraints: fixed core inlet and outlet temperatures, core pressure drop, maximal core coolant velocity, peak cladding temperature and peak fuel temperature. However, these analyses have no ambition at assessing the global performance of the cooling systems. In particular, once equilibrium has been reached, the hottest sub-channel, located in the core center, is selected for the thermal-hydraulic analysis.

The results of the simulations show that the burnup performance of the small CANDLE reactor is remarkably increased in the scenario where all actinides are recovered during the melt-refining process. Its increase can be maximized by optimizing the melt refining regions in the core and by adjusting core design parameters, such as the radius of the active core, the thickness of the reflector and the fuel pin pitch. The analysis results show that the application of the melt-refining process makes it possible to reduce the radius of the active core zone from 130 cm to 100 cm, the fuel pin pitch being increased from 1.08 cm to 1.175 cm. The average discharged burnup is increased by 20.8 % in comparison with that of the reference small CANDLE reactor. Uranium consumption in each fuel cycle is reduced by 50.0 % in comparison with that of the reference reactor.

In the scenarios where some fractions of all actinides are unrecovered during the melt-refining process, compensation for the fuel losses have been considered following two different methods: (1) By adding fuel into each melt refining region separately, assuming 10 % of all actinides to be unrecovered during the melt-refining process. In this method, compensating for the fuel losses is assumed to take place at the melt refining stage. As a results, the CANDLE burnup strategy was achieved in the core. The value of k-eff is increased over the equilibrium cycle. (2) In the second method, compensating for the fuel losses during the melt-refining process by feeding fresh fuel into breeding region, two scenarios were considered, with respectively 5 % and 10 % of all actinides being unrecovered during the melt-refining process. In the present method, compensating for the fuel losses in the stage of refabricating fuel pins is considered. The scenario with 10 % of all actinides being unrecovered, the reactor is critical, but the radiation damage is higher than the radiation damage constraint at 200 dpa. It is expected that the core would meet the design constraints by improving the core design. The scenario with 5 % of all actinides being unrecovered, the reactor is subcritical. By increasing smear fuel density, 79 %, instead of 75 % in the fuel pins, the core is critical and the value of k-eff is increased over the equilibrium cycle.

Compensation for the fuel losses distorts the power density distribution but does not significantly affect the results of the thermal-hydraulic analysis, leaving all relevant parameters within acceptable limits. Compensation for the fuel losses requires feeding additional uranium to make up for missing fuel. Therefore, the average fuel burnup is lower than without the fuel reprocessing but this disadvantage is compensated by a longer safety operating time.

In this study, the design concepts of the small CANDLE reactor with the melt-refining process has been shown. The CANDLE reactor is designed to operate with fuel reconditioning and replacing the cladding when the fuel pin reaches its radiation damage constraint. By applying the melt-refining process, the material integrity issue of the CANDLE reactor can be solved. In this study, a new concept of an innovative nuclear reactor system has been successfully shown.