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DESIGN STUDY ON

SMALL SODIUM COOLED CANDLE BURNING REACTOR

Nguyen Hoang Hai

CANDLE burning concept was proposed to solve the disadvantages of current nuclear reactor designs. In CANDLE reactor, the core was divided axially into three regions: spent fuel, burning, and fresh fuel regions. The burning region propagated axially without changing the shape of core characteristics. In most studies of CANDLE burning reactor, LBE was used as coolant because of its hard neutron spectrum and low neutron leakage. Besides LBE, sodium was another option for coolant because sodium provided good heat-removal performance and sodium coolant technology was established widely in the field of fast reactor designs. However, when using sodium as coolant, the neutron economy of CANDLE burning reactor decreased due to the softer neutron spectrum and higher neutron leakage. Although there were several studies of CANDLE burning reactors using LBE and sodium as coolant, there was no detailed quantitative investigation on the differences between these coolants on the burnup performance of CANDLE reactor. Therefore, the purpose of this study was to show the possibility of small sodium cooled CANDLE design with the reactor size that was comparable to other sodium fast reactor concepts based on the quantitative difference in burnup performance between CANDLE cores with sodium coolant and LBE coolant.

Studies of CANDLE burning were investigated mostly by deterministic methods. Although these methods had advantages in computational time, it was difficult to increase the results accuracy with these methods due to the uncertainties of group constants. To solve this issue, a Monte Carlo based procedure was developed for CANDLE burning analysis with high accuracy. In this procedure, neutron transport equations were solved by MVP code with JENDL-4.0 nuclear data library and burnup equations were solved by MVP-BURN code with

detailed burnup chain. To achieve the equilibrium condition, a shuffling process, in which spent fuels were discharged at the core top and fresh fuels were added at the core bottom, was applied. To simulate this process, an auxiliary code was developed by Python language. The equilibrium condition could be achieved by repeating the shuffling process. Based on this Monte Carlo based procedure, the burnup performance of CANDLE burning reactor was investigated at the equilibrium condition.

The results showed that with the same fuel pin design and core volume, changing coolant from LBE to sodium decreased the effective multiplication factor 2.3% and the average discharge burnup 15.6%. The reasons of this decrease could be explained by the softer neutron spectrum and higher neutron leakage of sodium coolant. When changing coolant from LBE to sodium, the neutron leakage increased from 4.6% to 6.5%. One way to maintain the criticality of the sodium cooled CANDLE reactor was to increase the fuel volume. This study showed that the with the same fuel pin design, the sodium cooled core could be critical by increasing the number of fuel pins 38%. As a consequence, the sodium cooled core radius increased 17%.

This study also presented the ideas to minimize the size of the sodium cooled CANDLE reactor. Firstly, because of the better heat-removal features of sodium coolant, the fuel pin pitch in sodium cooled core could be reduced. It was concluded that the fuel pin pitch could be reduced from 1.08 cm to 1.02 cm in the point view of thermal hydraulics analysis. It was found that when the fuel pin pitch was reduced from 1.08 cm to 1.02 cm, the increase of fuel pins for the core criticality was not necessary because of the lower neutron leakage. With the minimized fuel pin pitch, the critical sodium cooled CANDLE core radius could be saved 19.4% from 170.4 cm to 137.4 cm. Secondly, the size of sodium cooled core could be minimized by changing the material for radial reflector. In original design, sodium was used as coolant and reflectors. Changing radial reflector from sodium to lead based materials could decrease the neutron leakage and therefore, reduce the radial reflector thickness. In this study, there types of lead based materials for radial reflector were investigated: pure lead, lead oxide with theoretical density, and lead oxide with 70% of theoretical density. It was concluded that changing radial reflector from sodium to lead based materials could save the critical reactor vessel, including the reactor core and the radial reflector, 15.7% from 187.4 cm to 158.0 cm. The final sodium cooled CANDLE burning design was as small as other sodium fast reactor designs.

One of the important issues for safety of a sodium cooled reactor was sodium void phenomenon. In this study, the sodium void reactivity was estimated in four scenarios. In scenario 1, sodium was removed in both reactor core and reflectors. In scenario 2, sodium was removed only in the reactor core. In scenario 3, sodium was removed in the upper part of the reactor core; and in scenario 4, sodium was removed in the middle part of the reactor core. It was found that changing radial reflector from sodium to lead based materials did not increase the void reactivity sufficiently.

In conclusion, this study showed the feasibility of CANDLE burning design using sodium coolant. In addition, based on the features of sodium, there was a possibility to reduce the reactor size of the sodium cooled CANDLE burning reactor so that it was nearly as small as other sodium fast reactor concepts. The combination between the small CANDLE burning reactor and sodium coolant provided the advantages for CANDLE burning design in particular and for fast reactor designs in general.