Pb-208 Coolant for Small Long-life CANDLE Reactors

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INTRODUCTION

CANDLE (Constant Axial shape of Neutron flux, nuclide densities and power shape During Life of Energy production) burning concept was proposed by the author more than 10 years ago [1, 2]. Since then detailed discussions on this burning characteristics [3, 4] and feasible design studies [5, 6] have been strongly and steadily promoted.

Previous studies have clarified that CANDLE reactors easily satisfy all the key requirements for nuclear energy attributed to the inherent problems: using the same technology for nuclear weapons making and producing lots of strong radioactive materials during reactor operation [5, 6]. Large CANDLE reactors cooled by sodium can satisfy both technological and economical requirements for nuclear reactors by introducing both MOTTO (Multi-pass Once-Through Then Out) cycle and power flattening with addition of thorium in the inner core [6].

CANDLE reactor can be designed also as a long-life reactor, since the burning region velocity is very low. However, CANDLE reactor requires more neutrons than conventional fast reactors since it does not employ reprocessing. Therefore, it is important to use a neutronically superior coolant. In the present paper Pb-208 coolant is employed and compared with a LBE (lead bismuth eutectic) (Lead is natural one.) coolant. The feasibility of natural coolant circulation is also discussed.

PB-208 COOLANT

Coolants whose neutron slowing-down and absorbing powers are small are desirable for fast reactors. Larger scattering cross section is also desirable for small reactors since its neutron confinement performance becomes improved. Lead or LBE show the better performance on these issues than sodium, and were used as the coolant of small long-life fast reactors [7].

In the previous lead or LBE cooled small long-life reactors employ natural lead from economical reason, but the natural lead contains several isotopes. Pb-208 is a double magic nucleus, and shows much smaller capture cross section and higher threshold energy of inelastic scattering than the other isotopes. The price of this isotope, \$200 kg^{-1} [8], is very expensive, but such an expensive small long-life reactor may be acceptable in special usages.

DESIGN PARAMETERS

An integral type reactor design where steam generators are installed within a reactor vessel is employed, since severe reaction between lead reactor coolant and steam generators water coolant is not anticipated. Mechanical centrifuge pumps are also inserted in the reactor vessel to make forced circulation. Its design parameters are shown in Table I. The calculation is performed by using the computing system developed by the author's group. Several techniques are implemented to calculate moving flux and nuclide density distribution [5, 6]. The group cross section set is generated with SRAC code system [9] using JENDLE-3.2 library [10].

Table I. Design Parameters and Some Results

Thermal power rate	440 MWt
Electric power rate	179 MWe
Fuel type	U–10wt% Zr
Smear density	85 %TD
Cladding	HT-9
Cladding outer diameter/thickness	1.50 cm/0.5 mm
Bonding material	Sodium
Pin array	Triangular
Pitch to Diameter (P/D)	1.2
Coolant	Pb-208 (95% enriched)
Maximum coolant velocity	2.0 m/sec
Coolant inlet/outlet temperature	$400^oC/550^oC$
Core diameter/height	2 m/1.5 m
k_{eff}	1.001
Average power density	93 W/cm^3
Burning region velocity	2.6 cm/year

RESULTS

The calculation results are also shown in Table I. If the coolant is changed from Pb-208 to natural lead-bismuth eutectic, P/D should be decreased to 1.14 to make the reactor critical (k_{eff}=1.001). It reduces the average power density and thermal and electric power rates to 363 MWt, 148 MWe and 77 W/cm^3, respectively.

If the natural circulation is employed instead of forced one, the maximum coolant velocity becomes 0.63 m/sec, and the average power density becomes 29 W/cm^3. The thermal power rate, electric power rate and burning region velocity become 139 MWt, 56 MWe and 0.82 cm/year, respectively.

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