Reactivity Control Devices for a Pb-Bi Cooled Transmuter, PEACER-300

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1. Introduction

Design concept of a Pb-Bi cooled transmutation fast reactor, PEACER has been studied to satisfy the Gen-IV design goals; proliferation resistance, transmutation capability, accident-tolerance, energy & environment sustainability and economics. For several years, the most of design features were decided in field of neutonics, thermal hydraulics, pyro-processing, materials and waste disposal. [1]

A lead-bismuth coolant is circulating in a loop at the moderate temperature from 300°C to 400°C in order to reduce corrosion and erosion speed of core structure materials. A square lattice fuel assembly design is adopted to ensure a sufficient mass flow rate not only in normal operation but also in natural cooling under accidents. The core has fairly flat shape with 0.1 of the ratio of height to diameter. A metal fuel of (U,TRU)10%Zr is chosen because of high thermal conductivity. Cheap and small scale collocated pyro-processing is another feature of PEACER reactor complex. Recovery factors in reprocessing plant were controlled to dump low-level waste only to the repository within a level of US NRC class-C. [2]

However, to meet the design goals and safety limits, a core design has been modified based on the following three guidelines:

1) Excess reactivity at the beginning of equilibrium cycle should not be exceeded 3% $\Delta k/k$ for obtaining a sufficient shutdown margin during the whole reactor operation period.

2) The maximum relative pin power peaking should not exceed 1.5 which is a limit value against the fuel centerline melting.

3) Two diverse concepts of shutdown system with different driving mechanism should be installed achieving shutdown capability of sub-criticality under 0.98 of k-effective at HZP.

2. Design Features of Reactivity Devices

2.1 Reduction of Excess Reactivity

In order to increase the transmutation capability of long-lived minor actinides (LLMA), PEACER core was designed as a flat core enhancing the neutron leakage rate which could decrease TRU production rate. However, this design concept is not favorable in neutron economy. Therefore, a larger amount of fissile material has to be loaded in fresh fuel. It leads large excess reactivity at the beginning of equilibrium cycle (BOEC) and high pin power peaking.

In this study, two kinds of treatments were adopted to solve those problems. Enrichment zoning which has 14/16/18 w/o in the inner/middle/outer core respectively was applied to reduce maximum power peaking. The maximum pin power peaking could be reduced up to 1.347 from 1.421. A new material for burnable absorber was tested to attenuate the initial excess reactivity at BOEC. A few kinds of BP material were compared with under a neutron energy spectrum of PEACER. Because dysprosium has a larger neutron absorption cross-section than boron and gadolinium in keV neutron energy range, metallic Dy BP was chosen. For fuel assemblies loaded in inner core part, 12 Dy BP rods are designed to reduce pin peaking in the central part of core. As a result, excess reactivity could be reduced from 1.042 to 1.029 and maximum pin peaking could be also reduced from 1.347 to 1.321.

2.2 Primary Shutdown System

The one of important design feature is shutdown system in safety concern. Generally, two kinds of shutdown system - primary and secondary shutdown system - have to install in reactor core at once. In PEACER reactor, primary shutdown system should meet the following design conditions.

1) Shutdown system should be reduced the k-effective to under 0.98 during whole cycle.

2) The control rod worth of the strongest control assembly should not exceed 1 $ at BOEC.

3) Shutdown should be guaranteed even though one strongest control assembly was not inserted.

Because PEACER core is large in radial but short in axial, shutdown capability is dependent on number and layout of control rod assemblies. As absorber for control assembly, B_4C was used as the common design of fast reactors in present. 20 control assemblies are loaded in inner and middle core region where pin peaking values are large. The driving mechanism is mounted on top of reactor vessel and axial motion is produced by gear motor-driven. The configuration of control assembly is same with that of fuel assembly which has 17 by 17 lattice and 208 B_4C rods and 81 skeletal bars were constituted as shown in figure 1 in order to adjust the control rod worth to under 1$.

Using this shutdown system, the possibility of shutdown was confirmed by k-effective value change from 1.029 to 0.968 at BOEC and from 1.001 to 0.939 at EOEC.

Even though the strongest control assembly located in inner core was not inserted, we confirmed that k-effective value was not exceeded 0.98.

2.3 Secondary Shutdown System

For a secondary shutdown system with different diving mechanism, a new design concept was developed. Under lead-bismuth liquid metal coolant, very strong buoyancy force exists because of a large density difference between coolant and the others. Because a control assembly is consisted of B_4C absorber with HT-9 structure material, both are lighter elements than coolant. We may add a vacant volume area in control rod tube where helium gas can be charged by (n,alpha) reaction of boron. Based on conservative analysis, it was found that control assembly has enough buoyancy force to be inserted within 1 second from ARO position.

Generally, because secondary shutdown system is activated for emergency state, the secondary shutdown system of fast reactor concepts such as IFR, MONJU,[3] KALIMER[4] consists of small number of control assemblies. However, many number of secondary control assemblies are required in PEACER because of flat core shape. 12 control assemblies were dispersed in inner/middle core as shown in figure 2. In order to increase the control rod worth, the configuration of control assembly was changed with 280 B_4C absorber rods and 9 skeletal bars and the enrichment of B-10 was increased upto 40 w/o.

By above design changes, the capability of secondary shutdown system was shown, in k-effective value 1.029 at BOEC can be changed to 0.972 only by secondary system.

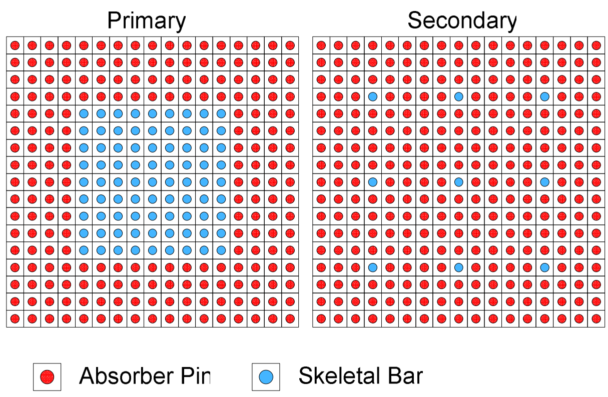

Fig. 1 Control assembly configuration of primary and secondary shutdown system

3. Conclusion

In order to secure the safety of PEACER reactor, 3 kinds of reactivity control devices were adopted and searched in this paper. A new burnable absorber material – dysprosium was used in inner core region to reduce excess reactivity and maximum power peaking. To guarantee sufficient shutdown possibility, two kinds of shutdown system were applied. Primary and secondary shutdown system had different driving mechanism such as motor-driven and floating mechanism and could be restraint the large amount of excess reactivity at BOEC.

Acknowledgement

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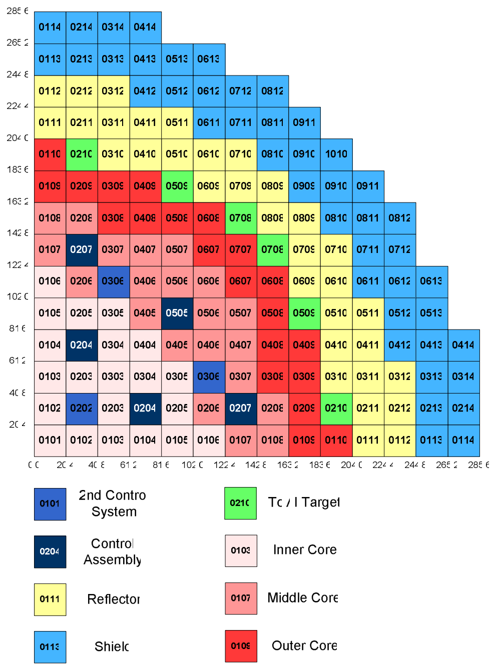

Fig. 2 Core configuration of PEACER-300