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Technical Feasibility of Ultra Long Life Fast Reactor Concepts with Fuel Shuffling and Its Potential

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1. Introduction

The TWR, the design development of which is led by Terra Power, is a core concept that was first suggested by Edward Teller. The TWR adopted the CANDLE burnup strategy in the early phase of the development and is now working toward the development of a standing wave reactor (SWR) based on fuel shuffling for earlier commercialization. This paper, describes the enhanced performance with respect to the operating life and lower fast neutron irradiation of the structural material as cladding using a two region core, and optimized fuel shuffling scheme, and controlling the primary control rods.

2. Model and Result

The SWR by Terra Power is fueled by 10-12 wt.% uranium and depleted uranium in the active core zone and blanket zone, respectively[1]. In this paper, the fuel shuffling scheme follows the analysis of burnup, fissile material mass, and fast neutron fluence for each assembly. One cycle length of the operation depends on the k_{eff} value with the above 3 conditions. The drive fuel should be replaced with blanket fuel or another region fuel to minimize the fast neutron fluence of the cladding or attain criticality.

2.1 Description of ULFR Core

Table I shows a description of the TPRP (Terra Power Reactor Plant) core. The diameter of the TPRP core is approximately 6.4m due to the use of 1,315 assemblies.

Table I: The TPRP Core Description

Assembly	No.
FAs in Active Zone	475
Primary Control Assemblies	18
Secondary Control Assemblies	6
FAs in Blanket Zone	666
Absorber Assemblies	60
Spare Control/Absorber Assemblies	90

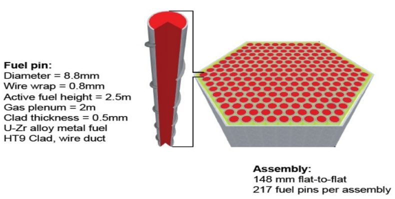


Fig. 1. Fuel Pin and Assembly Design of the TPRP[2].

The fuel assemblies are composed of gas plenum, which is shorter than the active fuel, which may cause an increase in the coolant pressure drop.

The TPRP is evaluated numerically based on opened information by Terra Power using REBUS 3 code. However, a description of the TPRP has not been sufficiently opened, except for the fuel assemblies. Therefore, non-fuel assemblies were equipped in proportion to the present development SFR in KAERI. Description of the TPRP core and refined core are shown in table Ⅱ.

Table Ⅱ: Design Description of Reactors

	TPRP (Reference)	Refined Design
Reactor Power (MWt/MWe)	3,000/1,150	
Reactor Inlet/Outlet Temperature (℃)	360/510	
Fuel in Active Zone	U (10~12 wt.% U-235)-Zr igniter at BOL	U (9.3 / 11.275 wt.% U-235)-Zr igniter at BOL
Fuel in Blanket Zone	U(depleted)-Zr	
Cladding Material	HT9	
Cladding Outer Diameter (mm)	8.8	10.8
Fuel Slug Diameter (mm)	6.75	7.79
Volume Fraction of Fuel slug (%)	40.76	43.26

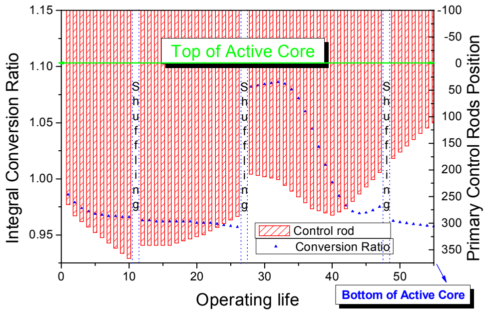
In this paper, power is controlled using primary control rods (50 wt.% 10-B of B_4C) to attain k_{eff} ≒ 1.002 and a flat radial power distribution. Moreover, for a performance improvement, the TPRP core separates 2 regions core as average 10 wt.% enrichment of fuel rods for radial power distribution. Also, the refined design core increases the volume fraction of fuel for breeding into the blanket zone.

2.2 Performance of ULFC design.

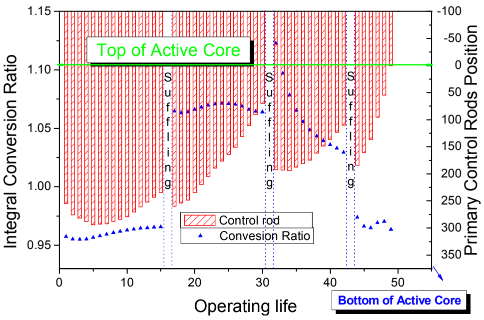
First, the performances of the TPRP core and refined core were estimated and compared based on their operating life, radial power distribution, and fast neutron irradiation of HT9, with the evaluation conducted under control of the primary control rods. As a result, the operating life is shorter than the condition of controlling primary control rods and the burnup swing is approximately 10,000 pcm. Table Ⅲ and figure 2 show the results of operational control primary control rods.

Table Ⅲ: Core performance of operational control of the primary control rods

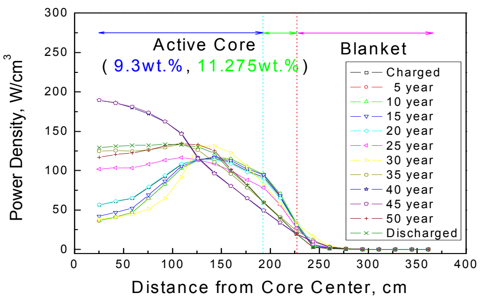
	TPRP Core	Refined Core
Operating Life (years)	49	55
Peak Discharged Burnup (MWD/kg)	704.528	612.299
Whole Core Average Burnup (MWD/kg)	257.08	233.67
Active Core Average Burnup (MWD/kg)	628.53	577.77
Peak Discharged Fast Fluence (10^{23} n/cm^2)	31.5633	24.4503



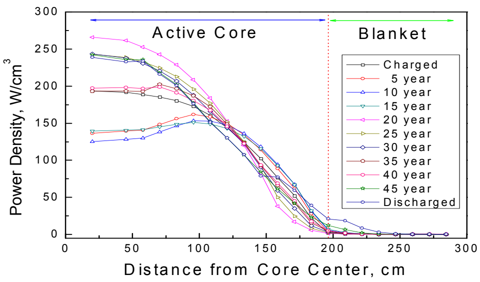
(a) Refined 2 Regions Core (9.3, 11.275 wt.%)



(b) TPRP Core



(c) Radial Power Distribution of Refined 2 Regions Core (9.3, 11.275 wt.%)



(d) Radial Power Distribution of TPRP Core

Fig. 2. Evaluation of core performance during operating life.

A refined core can operate 6 years longer than the TPRP core through shuffling. Even though the peak fast neutron fluence can decrease 22.6% more than the TPRP core, the peak fast neutron fluence of HT9 is limited to 4×10^{23}n/cm^2. Thus, alternative cladding material should be developed for a resistance of at least 4-5 times more than HT9 against fast neutron fluence. Also, the radial power distribution of a refined core could be flatter than the TPRP core, as it decreases by more than approximately 33%. A method of effective heat removal and flow distribution should be developed. Finally, the TPRP core and refined core were determined to have high potential for enhancing the uranium utilization efficiency and proliferation resistance in respect to the design features. However, both of the proposed cores have a possibility of proliferation risks relate to Nuclear Material if the blanket fuel zone is not physically protected from access.

3. Conclusions

The TPRP core and refined core can operate for 49, 55 years, respectively, by controlling the primary control rods and fuel shuffling without refueling. Even though the active core of the refined core is divided into 2 regions with U-7.5 Zr alloy of 10 wt.% on average, a high integrity fuel cladding material should be developed for covering the high fast neutron fluence of more than 4-5 times HT9, which results from a long life cycle and high burnup. Also, the performance of the 2 regions of the refined core can be enhanced by more than the TPRP core, which results in 1) control of the burnup swing, 2) distribution of radial power, 3) long-life operation, and 4) a decrease in fast neutron fluence. Finally, the fuel shuffling scheme will be improved, the performance of the core will operate longer, the fast neutron fluence will be minimized, and a flat radial power will be distributed.

REFERENCES

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[2] Charles Ahlfeld, Pavel Hejzlar, Kevan Weaver, Robert Petroski, Jon McWhirter, Ash Odedra, Thomas Burke and Thomas Weaver, Cost and Safety Features of 500 MWe to 1150MWe Traveling Wave Reactor Plants, American Nuclear Society, Winter Meeting, 2002.