A New Conceptual Core Design of REX-10 with Thorium Fuel

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1. Introduction

In previous studies, a new conceptual core design of REX-10 (Regional Energy Reactor, 10 MWth) has been carried out. [1, 2] This reactor core was used once-through thorium fuel cycle to accomplish especially ultra long fuel cycle length with non-proliferation. Moreover Thorium has high natural abundance and it can cause high conversion ratio as well as low production of long-life minor actinides in thermal reactor. However, thorium-based core is not easy to satisfy both safety and economic goals because of its high fuel cycle cost even for the optimized core design. [3] In this study, design optimization was done for high proliferation resistance, maintaining the design goal of 20-year cycle length and comparable reactor safety within a boundary limit of economics goal.

2. REX-10 Design Goals and Design Guidelines

2.1 Reactor Design Goals

The reactor design goals of REX-10 are as follows:

1) Small integral power reactor
2) Automatic control without operator (possible to remote control)
3) Natural circulation RCS without RCP
4) Ultra-long cycle length (~20-year)

2.2 Nuclear Core Design Guidelines

The nuclear core design guidelines would be

1) Small size safe reactor: rated thermal power – 10 MWt
2) Soluble boron free operation
3) Proliferation resistance fuel and core management

3. Fuel, Fuel Assembly Design and Core Design

3.1 Fuel Candidate

In the previous study, UO_2+(U+Th)O_2 fuel option was adopted due to its least production of plutonium isotopes and most ultra-long cycle length among four kinds of fuel options.

3.2 Fuel Assembly Design

Among five kinds of fuel assembly options, the optimized fuel assembly option can be seen in figure 1. In this fuel assembly option, UO_2: (Th+U) O_2 is 1:1. The optimum volume percent ratio of Thorium and Uranium in homogeneous mixture, (Th+U)O_2, is 75:25. Enrichment for that mixture is 19.5 % U-235 whereas 4.5 % U-235 for pure UO_2.

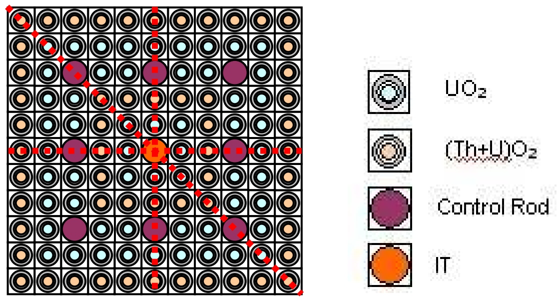

Figure1. Heterogeneous Fuel Assembly Configurations

3.3 REX-10 Core Design

The REX-10 core design and its some design parameters are shown in figure 2 and Table 1. In REX-10 core, only control rods control reactor power.

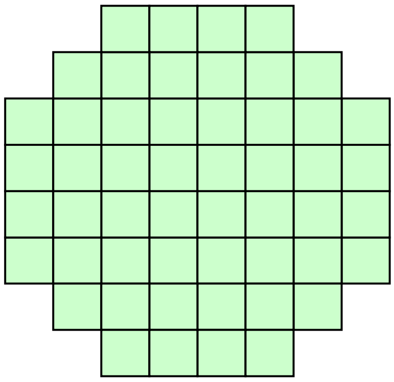

Figure 2. Conceptual Core Design

Table 1. Some core design parameters

Parameter	Value
Thermal power	10 MWth
Specific power	2.969244 W/g
Avg. linear power density	1.717 kW/m
Active core height	100 cm
Fuel pellet radius	0.4096 cm
Array size/FA	121 (11X11)
# of CRs /FA	8
# of ITs/FA	1
# of fuel rods/FA	112
# of FA	52
Initial Inventory of UO_2	3.36786 tons

4. Results and Discussion

According to core calculation results using HELIOS-MASTER package, excess reactivity and cycle length are shown in figure 3. It can be seen that REX-10 core design can give the desire design goal of 20-year cycle length.

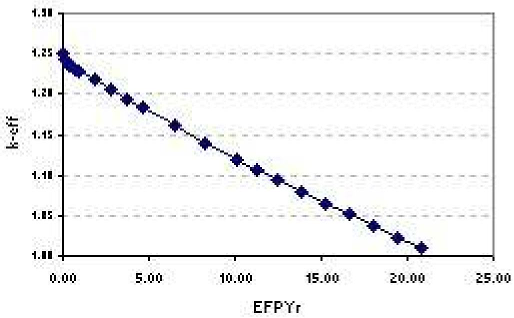

Figure 3. Excess reactivity and cycle length

Figures 4 and 5 show the characteristics of MTC and FTC. Both of them have negative value through the operation. The moderator temperature coefficient (MTC) is more negative at BOC than that at EOC. This is due to soluble boron free operation and this negative MTC enhances the reactor safety. In case of large positive reactivity insertion, MTC cannot turn the power raise for several seconds. For that kind of event, FTC starts adding negative reactivity immediately and hence negative FTC is more important than negative MTC.

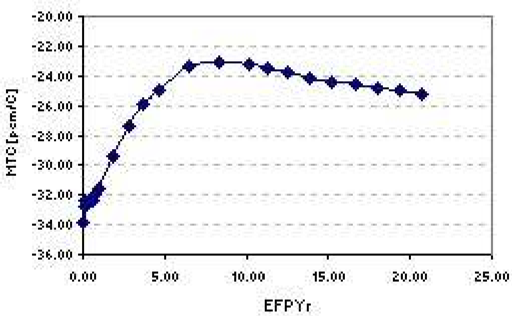

Figure 4. MTC versus cycle length

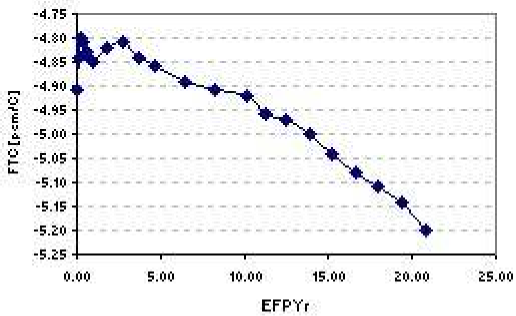

Figure 5. FTC versus cycle length

The power peaking factor is a key design limit for nuclear safety. Assembly power peaking occurs at the initial burnup step of the cycle. The assembly power peaking factor (Fq) is 2.4019 as seen in figure 6. REX_10 core is one batched core and hence it is look like homogeneous core.

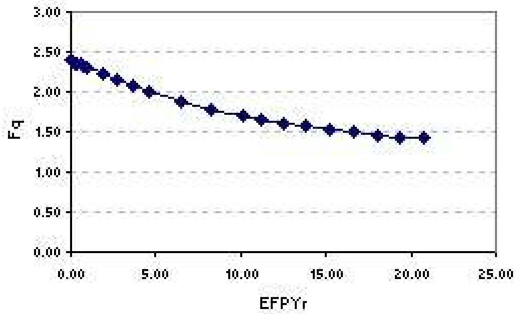

Figure 6. Fq versus cycle length

The maximum radial power peaking (Fr) is 1.5900 and it is occurred at core center as shown in figure 7. Since Fr is 1.55 for nominal PWR, Fr for REX-10 using Westinghouse fuel pin standard is reasonable.

1.5900 1.3560 1.1935	1.4390 1.2919 1.1838	1.1232 1.1266 1.1165	0.6844 0.7826 0.8596	BOC MOC EOC
1.4390 1.2919 1.1838	1.2741 1.2106 1.1544	0.9594 1.0100 1.0391	0.5419 0.6412 0.7267	
1.1232 1.1266 1.1165	0.9594 1.0100 1.0391	0.6402 0.7289 0.8004		
0.6844 0.7826 0.8596	0.5419 0.6412 0.7267			

Figure 7. Radial assembly-wise relative power distribution

5. Conclusion

REX-10 core has good characteristics from a reactor safety and a fuel economy point of view because of its MTC, FTC and Fq variations, and ultra-long cycle length. The Burnable Poisson Absorbers (BPAs) would also be used in REX-10 core as further study since excess reactivity is still high.

REFERENCES

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[3] Kang-Mok Bae and Myung-Hyun Kim, "Core Design for Heterogeneous Thorium Fuel Assemblies for PWR(I)-Nuclear Design and Fuel Cycle Economy," Nuclear Engineering and Technology, Vol.37, No.1, pp.91-100, February, 2005.