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# A Compact Sodium-cooled Traveling Wave Reactor

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## 1. Introduction

As an alternative to the conventional fast reactor concepts, the traveling wave reactor (TWR) are under development based on the breed-burn concept.[1,2] Usually, the initial criticality is achieved by using an LEU (Low-Enriched Uranium) fuel in TWRs and either natural or depleted uranium is used as the blanket fuel. Later on in the core, the reactor gradually converts the non-fissile material into the fissile in a process like a traveling wave. The PWR spent fuel can also be used as the blanket fuel in TWR.[3]

For realization of the TWR concept, the neutron economy should very good. Thus, TWR is usually rather medium or big size. In this work, we studied feasibility of an extremely compact sodium-cooled TWR concept. Important reactivity coefficients, kinetic parameters, and power profiles were analyzed. The neutronic analyses were all performed by the Monte Carlo code McCARD [4].

## 2. Compact TWR Concepts

The basic objective of this study is to find the acceptable compact sodium-cooled TWR which traveling in the axial direction. Through wide range of numerical optimization study, we came with a fuel assembly configuration (FA) consisting of 127 fuel pins. For a very high fuel volume fraction (over 60%), the fuel pin diameter was increased to 1.9 cm. The pitch and diameter ratio is chosen to be 1.064 in order to get a tight lattice. The flat-to-flat distance of FA is 23.72 cm. The same FA configuration is used for the initial active and blanket fuel assembly.

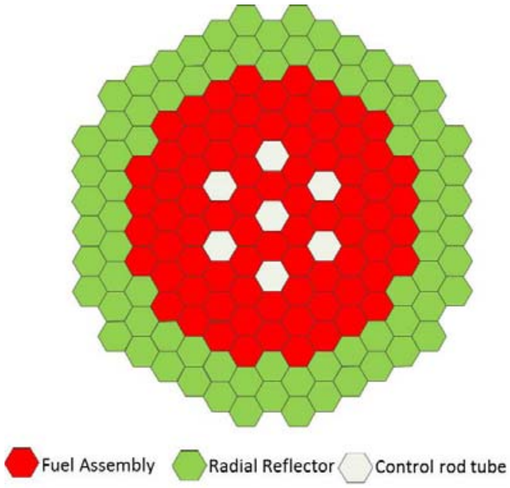

Figure 1. Radial layout of the TWR

The radial reflector assembly configuration in this study is a 6-ring configuration with 91 reflector pins. The pin diameter is 2.32 cm. In order to minimize the neutron leakage, a lead reflector is utilized as in Ref 3.

As shown in Fig.1, the fuel assemblies and the reflector assemblies are arranged in the 8-ring hexagonal core. The U-Zr metallic fuel with a 75% smear density is used in this study in both the initial LEU and blanket regions. The core consists of 78 fuel assemblies, 78 reflector assemblies, and 7 control rods assemblies. Seven control rod assemblies can be grouped into primary and secondary control rod since the burnup reactivity swing in TWR can be very small. In the axial region, a 40 cm axial reflector is located at bottom of the core, while 40 cm-thick bonding sodium is placed at the top of the core. The equivalent core radius is only 83.37 cm.

Height of the LEU core is fixed to be 60 cm after a trade-off analysis to minimize the excess reactivity during operation. A 90 cm thick natural uranium blanket is placed above the LEU core. Based on the fuel temperature and coolant speed analysis, the core power was determined to be 250 MWth. The coolant speed is ~2.12 m/sec.

## 3. Analysis Results and Discussion

Figure 2 below shows the change of the k-eff for 3 types of U-Zr fuel during the ultra-long core life. The Zr weight fraction was varied from 8% to 10%. While using the U-10Zr, the enriched uranium in the active core should be 12.30%, and reduce to 12.08% for U-9Zr, and 11.85% for U-8Zr.

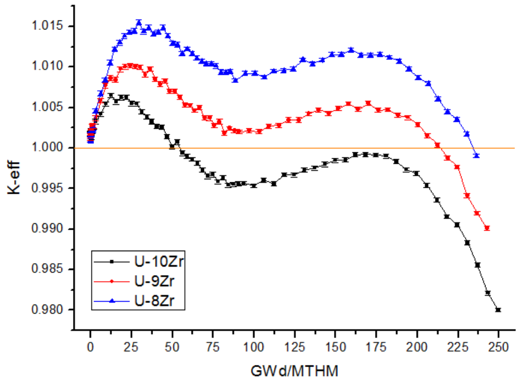

Figure 2. Evolution of k-eff during burnup

It is clear that a higher uranium loading is necessary in order to make the travelling wave reactor possible.

Using U-9Zr, the burnup can be increased up to 212 GWd/MTHM, corresponding to a 96-year lifetime. It is worthwhile to note that a U-8Zr is not favorable due to the large excess reactivity.

The core with the U-9Zr fuel was characterized at BOC (0 GWd/MTHM), MOC (103.2 GWd/MTHM), and EOC (212.5 GWd/MTHM), and the results are summarized in Table I. Figure 3 show the gradual change of the delayed neutron fraction and prompt neutron generation lifetime as a function of burnup. The sodium void worth is quite small at EOC due to the tight fuel lattice. Figures 4 and 5 show the axial and radial power distributions, respectively. It is worthwhile to note that the temperature increase of the Pb reflector leads to a negative reactivity, enhancing the safety.

Table I. Reactivity coefficients

| Parameters | BOC | MOC | EOC |
|---|---|---|---|
| Delayed neutron fraction | 7.19e-03 ± 5.31e-05 | 4.05e03 ± 3.70e-05 | 3.72e-03 ± 3.90e-05 |
| Prompt neutron lifetime, sec | 3.89e-07 ± 2.06e-09 | 3.18e-07 ± 1.10e-09 | 3.11e-07 ± 1.06e-09 |
| Doppler coefficient, cent/K | -0.062 ± 0.014 | -0.079 ± 0.018 | -0.049 ± 0.019 |
| Sodium void worth, cent | -38.249 ± 5.914 | 526.932 ± 10.146 | 644.568 ± 10.272 |
| Pb reflector coeff., cent/K | -0.121 ± 0.033 | -0.176 ± 0.052 | -0.079 ± 0.019 |

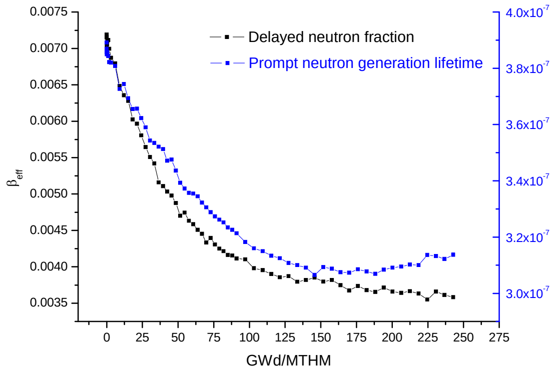

Figure 3. Delayed neutron fraction and prompt neutron generation lifetime as a function of burnup

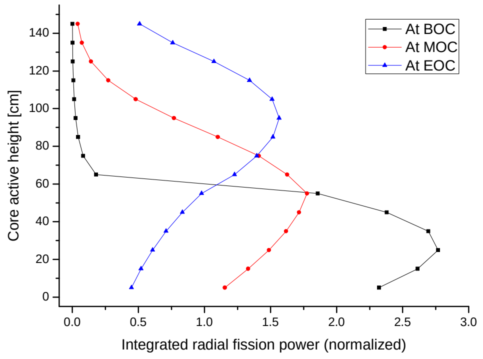

Figure 4. Axial power profile at BOC, MOC, and EOC

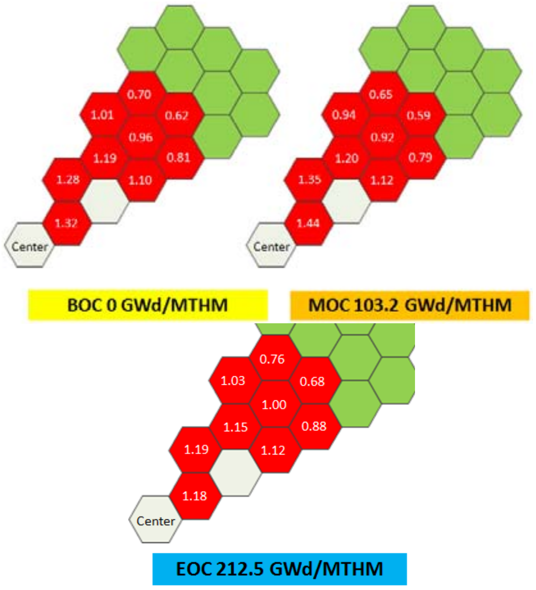

Figure 5. Normalized assembly-wise power distribution at BOC, MOC, and EOC

## 4. Conclusions

We have shown that a very compact LEU-loaded sodium-cooled TWR can be designed by adopting a Pb radial reflector and a compact fuel assembly. For the small long-life TWR, the fuel volume fraction should be extremely high, e.g., over 60%. The high fuel fraction can be achieved by using a large fuel pin diameter. Due to the low power density of the small TWR, the fuel assembly can be very compact and the sodium void worth is very small, less than 2 dollars. In spite of the small and pancake core configuration, the fuel burnup is over 20% and can be much higher by increasing the core height. The burnup reactivity swing of the core can be very small by adjusting the height of the initial LEU core. However, the power density in the initial core should be much higher than in the equilibrium core. The high fuel burnup results in a very high fast neutron fluence, which exceeds the current limit of the structural materials. The Pb reflector can improve the negative temperature feedback of the core.

## REFERENCES

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