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Feasibility Design Study of Long Life BWR with Natural Uranium/Thorium as Fuel Cycle Input

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Abstract

Feasibility design study of Long Life BWR with natural uranium/thorium as fuel cycle input has been performed. The reactor core is divided into 6 equal regions in radial direction. The fresh fuel is first loaded into the most outer region then shifted to the center of the core, and from there shifted to the nearby region in the outward direction. Nitride fuel is employed in the core to get better criticality and conversion/breeding ratio. The results show that uranium fuel combined with low moderating ratio environment is superior to make the system critical.

***Keywords**: Long life, BWR, Uranium cycle, Thorium cycle, Criticality*

1. Introduction

The utilization of natural uranium and thorium is important to keep the optimal nuclear energy resources. On the other hand nuclear fuel enrichment and nuclear fuel reprocessing which is needed to use nuclear energy using current technology are very sensitive issues related to the nuclear non-proliferation in the world especially when it is carried out in the developing countries. Long life reactor without on-site refuelling based on uranium or thorium fuels are an example of method to more efficently utilize these fuels[1-11)].

In the previous works, liquid metal cooled long life fast reactor which can be continuously operated by only supplying natural uranium without fuel enrichment plant or fuel reprocessing plant has been confirmed possible[12-15)]. Combined with high neutronic and safety performance such reactors have good prospects in the future. However the dominant current commercial Nuclear Power Plant (NPP) are based on water cooled system.

Therefore, in this paper feasibility design study of long life tight lattice BWR reactors which can be continuously operated by only supplying natural uranium without fuel enrichment plant or fuel reprocessing plant is investigated. Using such type of NPPs optimum nuclear energy utilization including in developing countries can be easily conducted without the problem of nuclear proliferation.

2. Design Concept and Calculation Method

In this study the following design concept are adopted. The active core is subdivided into 6 sub region in radial direction (see Figure 1) and reflector is put in the the most outer region. The fresh fuel is initially put in region 5, then shifted to region 6, and after that shifted to regions 1, 2, 3 and then 4. Region 7 is filled with reflector (mainly water). Nitride fuel is employed to provide high density fertile and fissile material in the core.

Reg. 1	Reg. 2	Reg. 3	Reg. 4	Reg. 5	Reg. 6	Reg. 7
Third shift	Fourth shift	Fifth shift	Sixth shift	First shift	Second shift	Reflector

Figure 1. Shuffling scheme

The calculation method can be described as follows. The calculation is started by guessing power density in each region, then cell burn-up calculation is performed using SRAC code system. Then multi-group diffusion calculation is performed using FIITB-CH1 code and the resulted power density distribution is taken as feedback for cell calculations. The iteration is performed till convergence condition is reached[12-14)].

3. Calculation Results and Discussion

The Tables 1 and 2 show the parameters of calculated cores. In this paper we present 4 type BWR core, first using thorium cycle while others using uranium cycle. In order to get high conversion/breeding high void fraction coolant is selected which in general give relatively fast spectrum. The calculation results are shown in Figures 2-13. Figure 2 shows Keff pattern change during burn-up for case A (Th cycle) and it shows that the system is subcritical. It means that for thorium cycle current core configuration is not possible to make long life reactor which fuel cycle input is thorium only (without additional U-233 or U-235). Figure 3 shows Kinf change during burn-up for case A. It shows that in some burn-up period the Kinf value becomes more than 1.0 but the value is too small to make the whole core critical. The average burn-up level of the fuel is nearly 350000MWd/tonHM.

Table 1. General Reactor Parameter

Parameter	Value/description
Power (MWth)	2200-3500
Number of equal volume region in core	6
Sub cycle length (years)	10
Fuel type	Nitride (UN-PuN)
Fuel volume fraction	60%
Cladding vol. fraction	12.5%
Coolant volume fraction	27.5%
Fuel diameter	1.2 cm
Coolant type	H_2O
Radial width of first (central) region	70 cm
Axial reflector width	70 cm
Radial reflector width	70 cm
Active Core Radius	171.5 cm

Table 2 Specific parameter for each core type

Core Type	Power MWt	Active Core Height (cm)	Void Fraction (%)	Note
A	2200	200	99	Thorium cycle
B	3000	250	98	Uranium cycle
C	3000	250	95	Uranium cycle
D	3200	250	97.5	Uranium cycle

Figures 4 and 5 show Keff and Kinf pattern change during burn-up for case B (U cycle with very high void fraction). It is shown that the system is critical with enough margin of Keff, and during burn-up the value of Keff continuously increases. The kinf value is more than 1.0 for more than half of the burn-up period. The average burn-up level of the fuel in this case is nearly 370000MWd/tonHM.

Figures 6 and 7 show Keff and Kinf pattern change during burn-up for case C (U cycle with 95% void fraction). It is shown that the system is critical with small margin of Keff, and during burn-up the value of Keff also continuously increases. The kinf value is more than 1.0 for more than half of the burn-up period but the maximum value is still lower than that of case B. The kinf value is more than 1.0 for more than half of the burn-up period. The average burn-up level of the fuel in this case is nearly 365000MWd/ton HM.

Figures 8 and 9 show Keff and Kinf pattern change during burn-up for case D (U cycle with 97.5% void fraction). It is shown that the system is critical with enough margin of Keff, and during burn-up the value of Keff also continuously increases. The kinf value is more than 1.0 for more than half of the burn-up period but the maximum value is still lower than that of case B. The kinf value is more than 1.0 for more than half of the burn-up period which is slightly larger than that of case B but higher than that of case C. The average burn-up level of the fuel in this case is nearly 400000MWd/ton HM as shown in Figure 10.

Figure 11 shows radial power distribution at the beginning of life of case D. It is shown that the core becomes very active just after entering region 2 (after half of overall burn-up process). Figure 12 shows conversion ratio change during burn-up. As burn-up proceed the conversion ratio continuously decreases due to decreasing number of fissile material and increasing number of fissile material especially at the first half of burn-up period. This is shown in Figures 13-14.

From the above results it can be seen that the neutron spectrum has important role in this system. Higher void ratio means harder spectrum that give higher conversion/breeding ratio so that natural uranium/thorium can be transformed into fissile material more effectively.

The burn-up level up to 400000MWd/ton or about 40%HM show that the natural uranium/thorium fuel can be utilized optimally without fuel cycle facilities but the material problem becomes important.

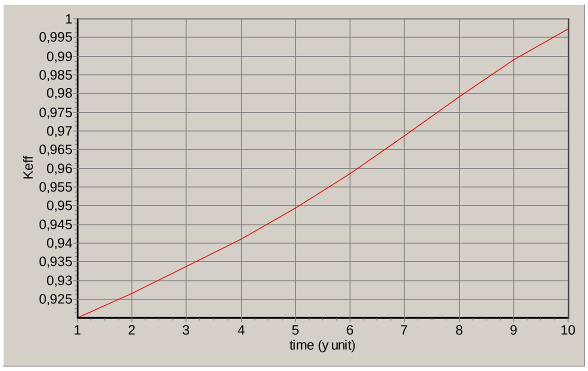

Figure 2. Keff change during burn-up for case A

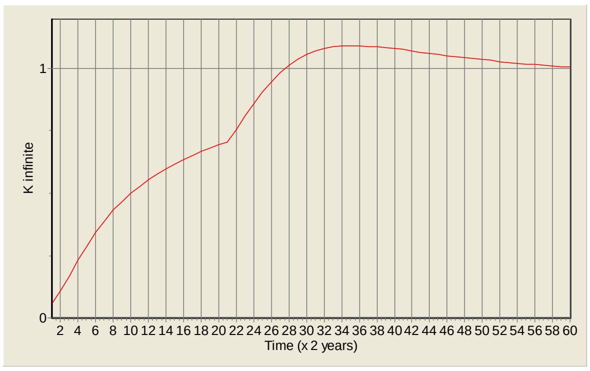

Figure 3. Kinf change during burn-up for case A

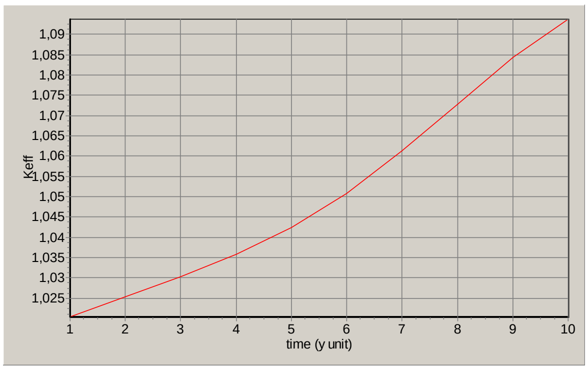

Figure 4. Keff change during burn-up for case B

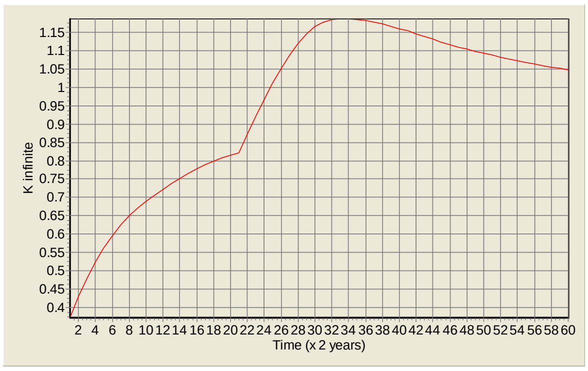

Figure 5. Kinf change during burn-up for case B

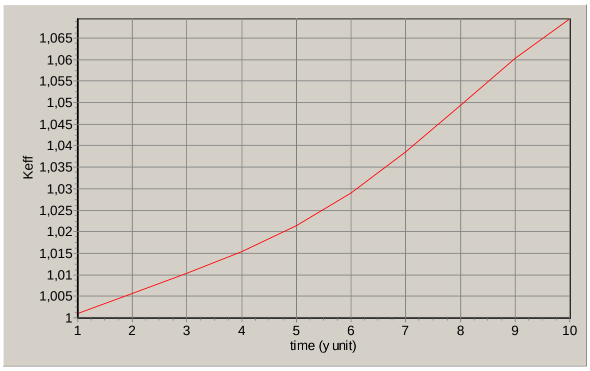

Figure 6. Keff change during burn-up for case C

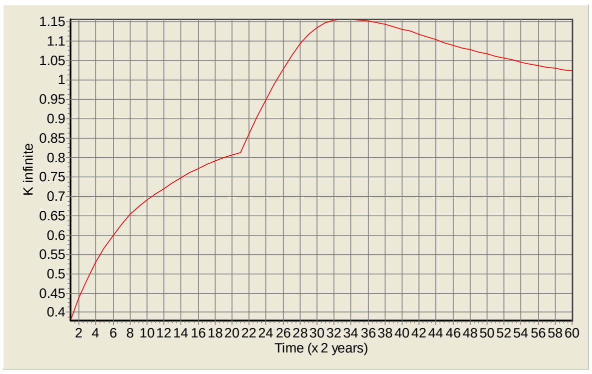

Figure 7. Kinf change during burn-up for case C

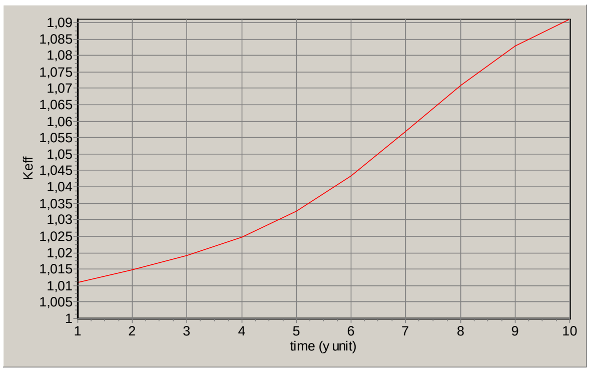

Figure 8. Keff change during burn-up for case D

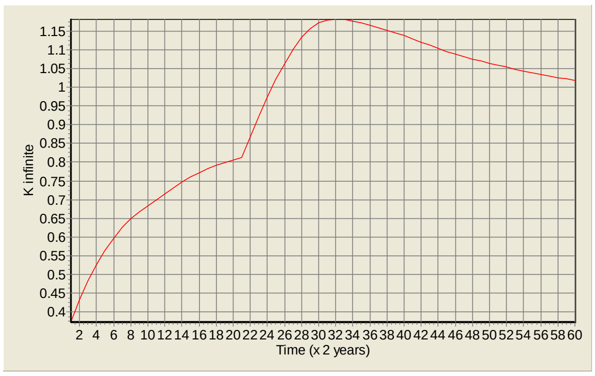

Figure 9. Kinf change during burn-up for case D

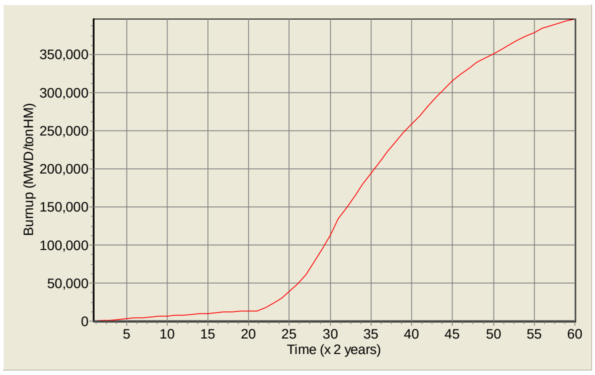

Figure 10. Burn-up history for case D

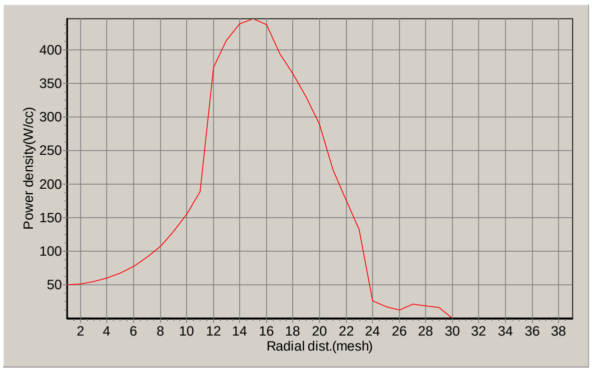

Figure 11. Radial power density distribution at the center for case D (BOL)

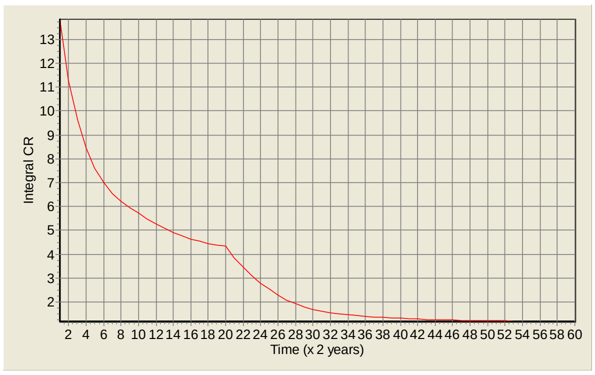

Figure 12. Conversion ratio change during burn-up for case D

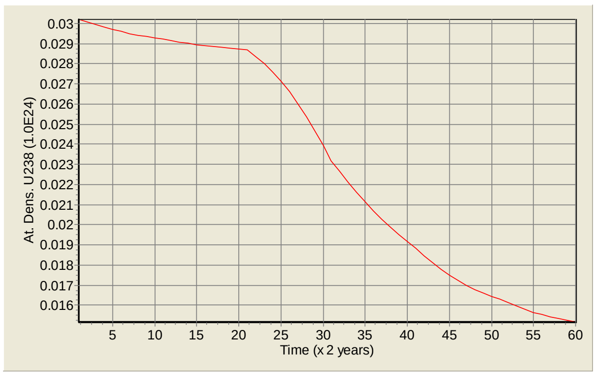

Figure 13 U-238 atomic density change during burn-up for case D

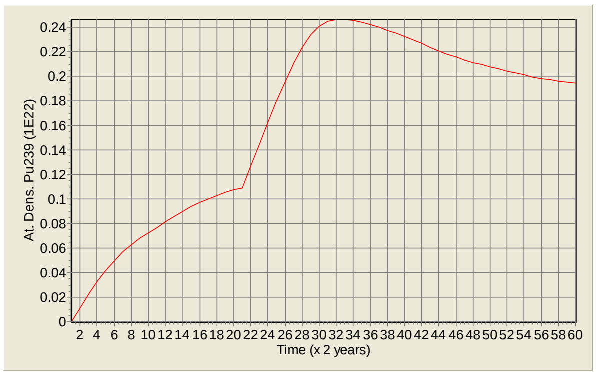

Figure 14 Pu-239 atomic density change during burn-up for case D

Conclusion

Feasibility design study of Long Life BWR with natural uranium/thorium as fuel cycle input has been performed and the results show that uranium fuel combined with high void fraction environment is superior to make the system critical. Thorium cycle can not make the system critical under current condition. The resulted burnup level is about 350000-400000MWd/tonHM, and special material is needed.

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