Th/U-233 Multi-recycle in Pressurized Water Reactors: Feasibility Study of Multiple Homogeneous and Heterogeneous Assembly Designs

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INTRODUCTION

The use of thorium in current or advanced light water reactors (LWRs) has been of interest in recent years. These interests have been associated with the need to increase nuclear fuel resources and the perceived non-proliferation advantages of the utilization of thorium in the fuel cycle. Various options have been considered for the use of thorium in the LWR fuel cycle. The possibility for thorium utilization in a multi-recycle system has also been considered in past literature [1, 2, 3, 4], primarily because of the potential for near breeders with Th/U-233 in the thermal energy range.

The objective of this study is to evaluate the potential of Th/U-233 fuel multi-recycle in current LWRs, focusing on pressurized water reactors (PWRs). Approaches for sustainable multi-recycle without the need for external fissile material makeup have been investigated. The intent is to obtain a design that allows existing PWRs to be used with minimal modifications.

ANALYSIS APPROACH

Initial sensitivity studies have been done using PWR fuel assembly dimensions for the multi-recycling Th/U-233 fuel cycle. The current design requirements imposed are:

- Fuel cycle length of 1.5 years ideally, but 1 year is acceptable.
- A sustainable fuel cycle (breeding must be achieved so that no external fissile material is needed within the fuel cycle). Clearly, for the transition or startup cycle using thorium fuels, an external source of fissile material would be required.

The focus in the current paper is on exploring a number of assembly designs and discussing the feasibilities of each design towards Th/U-233 multi-recycle (i.e. advantages and difficulties of each design in terms of meeting the requirements of Th/U multi-recycle in PWRs).

A reactivity integration model has been used for estimating cycle length, assuming a 3-batch fuel management scheme. The k-inf curve is integrated with respect to the assumed leakage to determine the discharge burnup. Unit assembly calculations with the WIMS9 code [5] were used with 172 energy groups based on JEF 2.2 library to estimate the performance of the PWR core. The core leakage was assumed to be ~3.0%.

RESULTS

Studies of multiple designs have been conducted, with results obtained for homogeneous and heterogeneous assembly designs. The reactor and fuel cycle design characteristics have been determined, including assembly design, fuel cycle length, material flow, decay heat, radiotoxicity and thermal-hydraulics considerations.

The investigation has led to the conclusion that a viable sustainable cycle in multi-recycling Th/U-233 oxide fuel cannot be achieved with a *homogeneous* PWR assembly within the parameter space of U-233 content in the fuel (2 - 4 %) and the moderator-to-fuel volume ratio (MR) (2.0 - 0.7) obtained by varying the fuel pin size. Increasing the initial U-233 content helps to improve k-inf but leads to a decrease in the Fissile Inventory Ratio (FIR). Decreasing the MR helps improve the FIR because of the high conversion rate of Th-232 to U-233 in the epithermal neutron energy range, but k-inf deceases significantly.

It is necessary, therefore, that a heterogeneous assembly model be considered to obtain a feasible point design to realize a self-sustainable Th/U-233 fuel multi-recycle scheme.

Various *heterogeneous* designs have been investigated using designs with seed and blanket configurations having different seed unit (SU) to blanket unit (BU) ratios. Compared to the homogeneous designs, heterogeneous designs have been shown superior in meeting the Th/U-233 multi-recycle requirements, but the maximum discharge burnup was less than ~20 GWd/t due to the reactivity penalties from the parasitic absorption of structural materials and the accumulated fission products. Thus, it was found that derating the power in the reactor assembly (with lower specific power densities) tends to better meet the design requirements for Th/U-233 multi-recycle. Derating the core power also serves to maintain a similar linear power density to that of the current PWRs.

A near optimal heterogeneous assembly design has been developed. The design parameters are listed in Table I. Fig. 1 is a schematic drawing of an assembly with fuel pitch of 1.26 cm. The following Fig. 2 illustrates the relationship of infinite multiplication factor (k-inf) and the Fissile Inventory Ratio (FIR) versus the burnup (GWd/t). FIR was used as an indicator of the conversion ratio.

The result shows that, assuming, 3.0% neutron leakage and a 3-batch core management scheme, the discharge burnup of the fuel is around ~18 GWd/t, or equivalently 2.7 years cycle length with a specific power density of 6.73 W/g (with 90% capacity factor assumed). The requirements of a self-sustainable cycle are met by this design. It is important to note that the low MR in this design (0.35) requires a detailed thermal-hydraulic evaluation and safety analysis. Additionally, only first recycle analysis has been completed and those of subsequent recycles are necessary. These are planned in future activities.

ACKNOWLEDGMENTS

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TABLE I

Design Parameters for Heterogeneous Th/U-233 Fuel Cycle (17 by 17 assembly design)

Parameter	Value
Assembly geometry	17 x 17
Core power, MWt	1000
Number of assemblies	193
Capacity factor, %	90
Number of batches	3
Active core height, cm	366
Number of fuel rods per assembly (seed/blanket)	88/176
Number of guide tubes	25
Assembly pitch, cm	21.5
Fuel pitch, cm	1.26
Fuel pin radius, cm	0.5095
Fuel pellet density, g/cm^3	9.5
Cladding thickness, cm	0.057
Cladding material	Zr-4
Guide tube inner radius, cm	0.5715
Guide tube outer radius, cm	0.6120
Coolant average density, g/cm^3	0.7116
Heavy metal per assembly, kg	770
Moderator-to-fuel volume ratio (assembly level)	0.35
Initial U-233 content in the seed units / blanket units (wt% U-233/(U-233+Th-232))	7.8 / 0.0
Specific power density, W/g	6.73

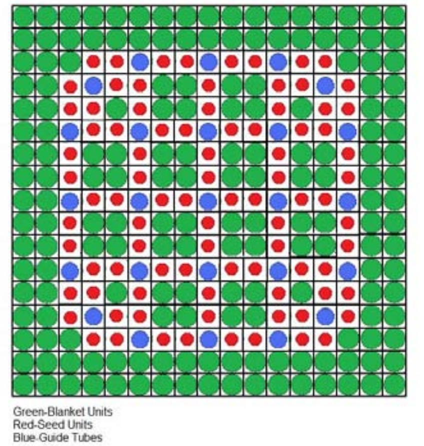

Fig. 1. Schematic drawing of the 17 by 17 heterogeneous assembly design.

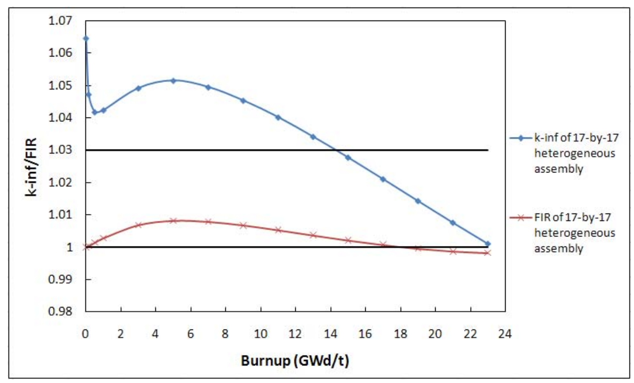

Fig. 2. k-inf and FIR (Fissile Inventory Ratio) versus burnup (solid lines are the indicators of 1.00 and 1.03 assuming 3.0% leakage).

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