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Performance Analysis of Hyb-WT with Homogenous and Heterogeneous Core Design

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1. Introduction

Most of hybrid reactors are studied using homogenous fission core models which are easy to design geometrically. The heterogeneous fission core model is the real geometrical depiction. In this study the neutronic and transmutation performance of hybrid reactor for waste transmutation (Hyb-WT)[1][2] is assessed with homogenous and heterogeneous core models. It is the part of parametric study of Hyb-WT [3]. The material compositions and geometrical dimensions are adapted from the reference design of Hyb-WT [2][4].

2. Core Design

Hyb-WT is a sub-critical fusion fission hybrid reactor. Fission core is operated by fusion neutron source, as the fusion neutron source is stopped the fission core will shut down instantly so it is inherently safe. Power level of fission core is controlled by the power level of fusion plasma.

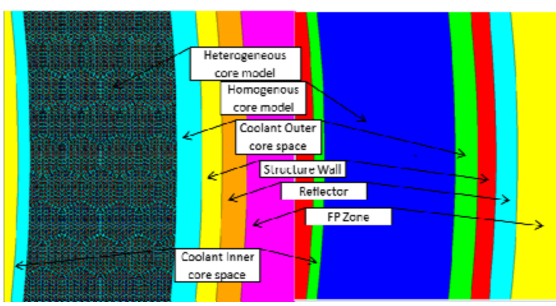

Figure 1: Heterogeneous and homogenous core models of Hyb-WT.

Table 1: Geometrical dimensions and fuel composition of heterogeneous and homogenous core designs.

Fission Core Model	Heterogeneous	Homogenous
Core Inner radius (cm)	370	370
Core Outer radius (cm)	415	415
Active Core Volume (m^3)	18.2545	18.2545
Fuel Assemblies in core #	1120	1120
Fuel Material	TRU-Zr	Volume average of TRU-Zr, Na, Clad, SiC and Coolant
Fuel Density (g/cm^3)	10.8	7.56
Fuel Volume (m^3)	2.27049	18.2545
TRU vol% in Fuel	33.548%	4.249%

Geometrical sketch of heterogeneous and homogenous core models, designed in MCNPX [5], are shown in figure 1. Small space at inner (3 cm) and outer (4.9 cm) boundary of core is introduced because of imperfect coupling of hexagonal assembly design and annular core shape. In homogenous core model all the materials in fission core (Fuel sludge, Na bond, clad, SiC and LiPb coolant) are averaged based on their densities and volume fraction in core. The middle part of core, excluding the inner and outer space can be called as the active core volume. The active core volume and total TRU mass loading is same for both homogenous and heterogeneous models as shown in table 1.

3. Performance Analysis

Sub-criticality level and transmutation performance of TRU and FP is calculated for both core models using MCNPX and ENDF/B-VII library. The difference between the k_{eff} values at the BOC is -456 pcm and it reduces over the burn cycle and becomes -117 pcm at the EOC as shown in figure 2. The homogenous core model is considered as reference so heterogeneous core model overestimate the k_{eff} value.

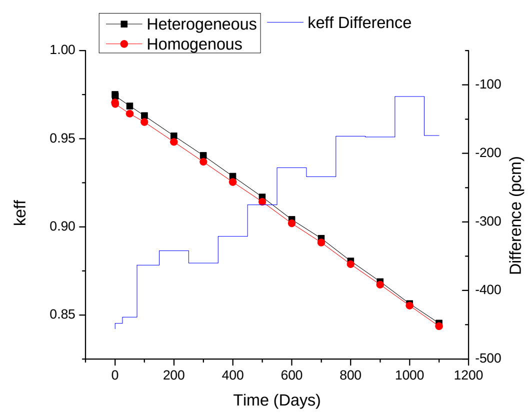

Figure 2: Difference between keff of homogenous and heterogeneous core models over the burn cycle.

The tritium mass production for both core models is almost similar the difference in TBR is mainly because of difference in k_{eff} and consequently the difference in required fusion power as shown in table 2. Reactivity safety margin is 10 times higher than the delayed neutron reactivity (β).

The calculated TRU inventory by MCNPX for two core models is slightly different as shown in table 3. Heterogeneous core model shows slightly larger TRU inventory, 3.8 kg higher than the homogenous model. In heterogeneous model the volumes of different materials in core design are calculated by MCNPX and rounded off to fifth decimal place whereas in homogenous model the core is just one big volume and the volumes of different materials in core are calculated separately using excel sheet for volume averaging. The difference in TRU inventory calculations could be because of rounding off in volume calculations and that difference could also be the major source of difference in k_{eff} values of two core models.

In homogenous core model all the core materials (TRU-Zr, Na bond, clad, SiC and LiPb-coolant) are considered in depletion calculations which change their isotopic composition by neutron capture and decay process.

In heterogeneous core model only TRU-Zr fuel and coolant are considered for depletion calculations which speed up the calculations and do not calculate the variation in isotopic composition of other core materials (Na-bond, clad and SiC) over the burn cycle.

The TRU transmutation performance is similar for two core models as shown in table 3 so it seems that the variation in isotopic composition of Na-bond, clad and SiC over the burn cycle do not affect the neutron transport and flux.

Table 2: Neutronic parameters of Hyb-WT with homogenous and heterogeneous core model.

Fission Core Design	Homogenous	Heterogeneous
k_{eff} BOC EOC	0.97047- 0.84361	0.97503- 0.84535
Fusion Power (MW)	15.2 - 92.7	12.8 - 91.6
Tot. Tritium Mass (kg)	12.9	13.2
TBR	1.48	1.55
β (pcm)	300	300
Reactivity safety margin (pcm)	3343	2861

Table 3: TRU transmutation performance of Hyb-WT with homogenous and heterogeneous core model.

Hyb-WT – Core Design	Homogenous	Heterogeneous
TRU inventory kg	14843.1	14846.9
Total TRU burned kg	2250.7	2250.2
TRU Burn/fpy kg	746.8	746.7
% TRU burned	5.0%	5.0%
TRU produced/fpy in 1000 MWe PWR (kg) [6]	250	250
Support Ratio 100% availability	3.0	3.0
Support Ratio 75% availability	2.2	2.2
Ingestion Toxicity Reduction	6%	6%
Inhalation Toxicity Reduction	9%	9%

The FP transmutation performance of Hyb-WT for homogenous and heterogeneous core models is almost similar as shown in table 4. A minor difference is observed in total FP mass transmutation and it did not affect the support ratio calculations for two core models.

3. Conclusions

The two core models shows similar TRU and FP transmutation performance. The difference in TRU inventory is the source of difference in k_{eff} values and consequently for required fusion power and TBR values.

10 times higher reactivity safety margin ensure the sub-criticality and safe operation of fission core.

Table 4: FP transmutation performance of Hyb-WT with homogenous and heterogeneous core model.

Hyb-WT - FP Transmutation	Homogenous	Heterogeneous
Total FP loaded (kg)	2479.5	2479.5
Total FP burned (kg)	450.8	449.4
FP burned/fpy (kg/fpy)	149.6	149.1
% of FP burned/fpy	6.0%	6.0%
FP produced in TRU (kg)	163.0	162.6
Net FP burned (kg)	287.8	286.8
Net FP burned/fpy kg	95.5	95.2
FP produced/fpy in 1000MWe PWR (kg) [7]	39.9	39.9
FP support Ratio 100% availability	2.4	2.4
FP support Ratio 75% availability	1.8	1.8
Net Ingestion Toxicity Reduction	11%	11%
Net Inhalation Toxicity Reduction	14%	14%

REFERENCES

[1] M. T. Siddique and M. Kim, “Analysis on Radioactive Waste Transmutation at a Clean Fusion-Fission Hybrid Reactor,” *Transactions of the Korean Nuclear Society Spring Meeting Jeju, Korea, May 17-18*, 2012, no. 1, pp. 173–174.

[2] M. T. Siddique and M. H. Kim, “A Feasibility Study on a Clean Power Fusion Fission Hybrid Reactor,” *Fusion Energy Conference 2012, San Diego, CA-USA, Oct. 8-13*, 2012, pp. 1–8.

[3] M. T. Siddique and M. Kim, “A Study on Monte Carlo Depletion Options for a Hybrid Reactor Design,” *Transactions of the Korean Nuclear Society Spring Meeting Gyeongju, Korea, October 25-26*, 2012, pp. 25–26.

[4] M. T. Siddique and M.-H. KIM, “Preliminary Neutronic Performance Evaluation on a Conceptual Design for a Transmutation Fusion Blanket,” *Trans. Am. Nucl. Soc., Vol.105, 2011 ANS Winter Meeting, Washington D.C., USA, Oct.30-Nov.3*, 2011.

[5] J. S. Hendricks, G. W. Mckinney, M. L. Fensin, M. R. James, R. C. Johns, J. W. Durkee, J. P. Finch, D. B. Pelowitz, L. S. Waters, M. W. Johnson, and F. X. Gallmeier, “MCNPX 2.6.0 Extensions LA-UR-08-2216,” 2008.

[6] W. M. Stacey, W. V. Rooijen, T. Bates, E. Colvin, J. Dion, J. Feener, E. Gayton, D. Gibbs, C. Grennor, J. Head, C. Myers, A. Schmitz, C. Sommer, and T. Sumner, “A TRU-Zr Metal-Fuel Sodium-Cooled Fast Subcritical Advanced Burner Reactor,” *Nuclear Technology*, vol. 162, 2008.

[7] H. Condé, “Introduction to ADS For Waste Incineration and Energy Production,” *The Impact of Nuclear Science on Life Science*, 2001.