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A Study on Monte Carlo Depletion Options for a Hybrid Reactor Design

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1. Introduction

Reliable methods for an isotopic depletion simulation are one of the crucial steps in a conceptual design of a fusion-fission hybrid reactor. MCNPX [1] and MONTEBURNS [2] are most commonly used and available tools. BURN card [3] is a new module in MCNPX2.6 which integrates the CINDER90 code in MCNPX for depletion calculations. MONTEBURNS couple the ORIGIN with MCNP-4C for depletion calculations.

The choice of time step in BURN card is analyzed by choosing different lengths of burn time steps and their calculation results were compared with MONTEBURNS for Waste Transmutation Hybrid Reactor (WT-Hyb) design [4].

2. BURN card Analysis

Irradiation cycle of 600 days was considered and seven different time step size values 600, 300, 200, 150, 100, 50 and 25 days/step were chosen for inter-comparison. TRU and FP mass depletion and k_{eff} at the end of cycle were calculated for different time step sizes.

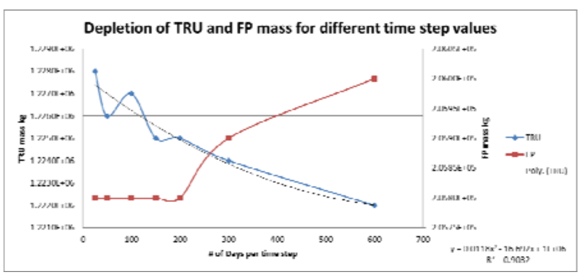

Figure 1: TRU and FP mass burned for different time step sizes of MCNPX burn card.

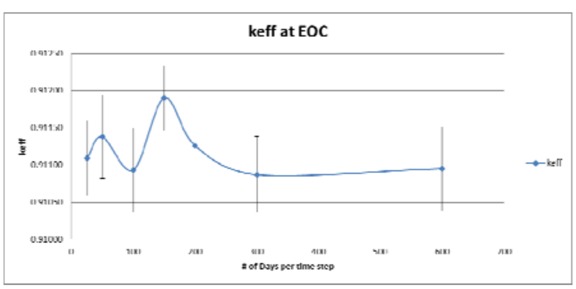

Figure 2: keff at end of cycle for different time step sizes of MCNPX burn card.

The behavior of TRU and FP mass depletion with time step size changes is shown in figure 1. TRU burned mass increase with the decrease of burn time step size and below the step size of 200, the increase in TRU burned mass are not monotonous. It may be because with smaller time step short lived TRUs formed and transmuted effectively. With the decrease of burn time step size the FP burned mass also decreased slightly. Because at smaller time step the FP number density is sampled frequently which decrease the FP mass transmutation over the irradiation cycle. But below the step size of 200 the burned FP mass depletion becomes constant. The percentage difference between burn mass of TRU at smallest (25 days/step) and largest (600 days/step) time step size is 0.5% which is very small. It is also evident from k_{eff} values, calculated at the end of cycle for different time step sizes, shown in figure 2. The variation in k_{eff} values is within the statistical error which means that the variation in TRU burned mass with length of burn time step is negligible.

3. Comparison of MCNPX2.6 and MONTEBURNS

MONTEBURNS use one group cross sections [2] whereas MCNPX use 63 group cross sections [3] for depletion calculations which is the major difference between two code systems. To evaluate its effect on hybrid reactor design study depletion and toxicity variations of TRU and FP, keff and tritium breeding were calculated for WT-Hyb using MONTEBURNS and compared with MCNPX 2.6 [1]. ENDF/B-VII library was used for both codes.

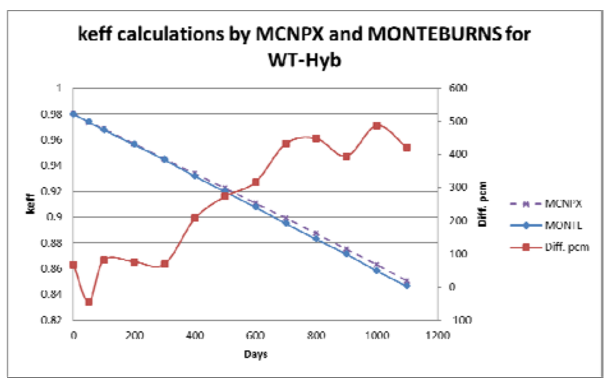

Figure 3: Comparison of keff calculated with MCNPX and MONTEBURNS for Hyb-WT.

The comparison of k_{eff} variation over the irradiation cycle for MONTEBURNS and MCNPX is shown in figure 3. The difference between two k values is almost zero at the beginning of cycle and increased with time. The maximum difference was observed to be 488 pcm at the end of cycle. It shows that MONTEBURNS slightly overestimate the TRU transmutation.

Figure 4 shows the TRU and FP mass depletion calculated by MCNPX and MONTEBURNS. There is very small difference in TRU mass depletion as seen in figure 5, the maximum % difference for TRU mass is 0.12% at the end of cycle.

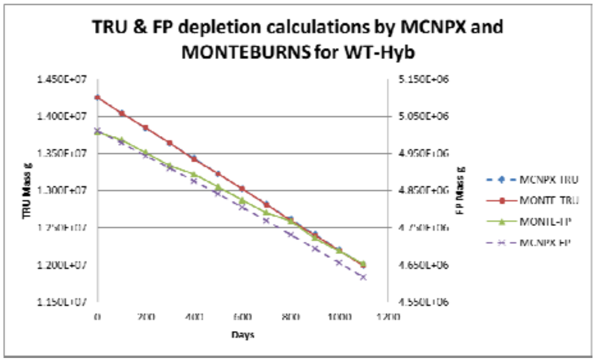

Figure 4: Comparison of TRU and FP mass depletion calculated with MCNPX and MONTEBURNS for WT-Hyb.

MONTEBURNS underestimate the FP transmutation because of 1 group cross sections. FP transmutation is higher at thermal energy range. The % difference in FP mass depletion is higher than TRU and maximum 0.76% difference is observed at the end of cycle as shown in figure 5.

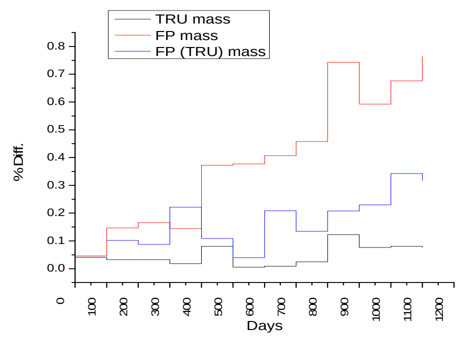

Figure 5: %Difference between MCNPX and MONTEBURNS calculated depletion of FP and TRU mass for WT-Hyb

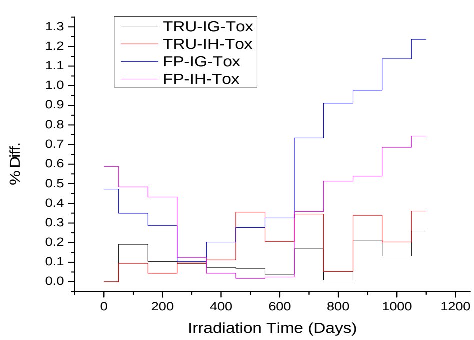

Figure 6: %Difference between MCNPX and MONTEBURNS calculated toxicity of FP and TRU mass for WT-Hyb.

Maximum % difference in TRU toxicity calculation was observed to be 0.36% at the end of cycle as shown in figure 6. For a FP toxicity calculation the maximum % difference was 1.24% at the end of cycle. IG-Tox is the ingestion toxicity and IH-tox is inhalation toxicity in figure 6.

A big difference between MCNPX and MONTEBURNS tritium breeding calculation is observed as shown in figure 7. MCNPX calculates 13.24 kg tritium breeding whereas MONTEBURNS predicts 5.89 kg over the irradiation cycle. This error may come from that the Li7 is not considered for tritium breeding in MONTEBURNS. Tritium production cross section for Li7 is not negligible above 2 MeV and promptly becomes higher than cross section of Li6 [5].

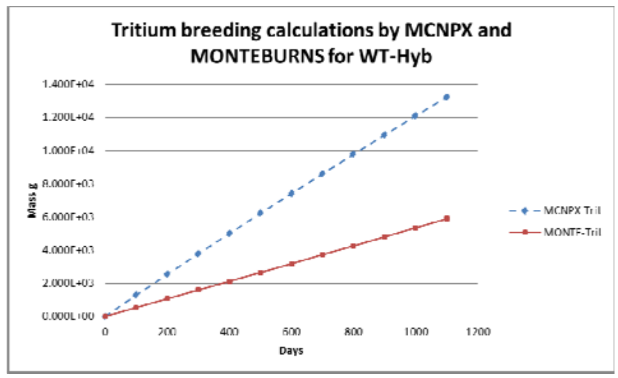

Figure 7: Tritium breeding calculated by MCNPX and MONTEBURNS over the irradiation cycle for WT-Hyb.

3. Conclusions

The effect of time step size in MCNPX BURN card is not significant. Step size of 200 days or below is optimum considering accuracy and computational time.

MONTEBURNS may not be a better option for hybrid reactor design study especially for tritium breeding calculation.

REFERENCES

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[5] KAERI, “Nuclear Data Evaluation Lab.,” *Korean Atomic Energy Research Institute (KAERI)*, 2012. http://atom.kaeri.re.kr/.