# Quantitative Analysis on Several Nuclear Fuel Cycle Options

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## 1. Introduction

As a nation turns to nuclear for meeting its power demand, the first thing is to identify a fuel cycle option that suits it. Resource security, environmental friendliness, economic competitiveness, technology readiness, and social acceptance are generally deemed as key criteria to evaluate a fuel cycle option. Once evaluating criteria have been selected, the important thing is to calculate the material flows which are the basis to perform fuel cycle evaluation, because from material flow the resource consumption, waste generation and service requirement can be determined from which environment evaluation could be performed, and thereafter integrated with unit cost the cost data are available.

In order to get a complete picture, it is necessary to analysis the whole fuel cycle in an integrated way, but when a decision maker wants to decide how to carry out the deployment of the optimized fuel cycle, two key components needs to be focused, i.e., reactor and spent fuel treating technology. Three popular reactors have been considered here, e.g., PWR, CANDU, SFR. Two key reprocessing technologies, i.e., PUREX and Pyroprocessing were selected. Accordingly, in this work, seven types of options have been evaluated: once-through cycle named as OT Cycling for short, DUPIC (Direct Use of PWR spent fuel In CANDU) Recycling, thermal reactor recycling after aqueous reprocessing named as PWR-MOX Recycling, extended PWR-MOX recycling by recycling Pu in spent MOX from PWR in a SFR named as PWR(MOX)-SFR(MOX) Recycling, a similar process by utilizing TRU extracted from spent MOX from PWR by Pyroporcessing and cycling in a SFR named as PWR(MOX)-SFR(TRU) Recycling, a fast reactor recycling coupled to pyroprocess named as Pyro-SFR Recycling, and a pure breeder reactor recycling name as Breeder Recycling. For SFR involved cycles, i.e., PWR(MOX)-SFR(MOX), PWR(MOX)-SFR(TRU), Pyro-SFR, and Breeder Recycling, the wide range of a key parameter, conversion ratio, has been considered.

## 2. Method and NFC option

### 2.1 Method

An equilibrium model focus on the batch study with the assumptions that the whole system is in a steady state and mass flow as well as the electricity production all through the fuel cycle are in equilibrium state, which calculates the electricity production within a certain period and associated material flow to obtain several criteria for assessment of the sustainability of nuclear power, e.g., resource utilization, waste generation, environment affects.

### 2.2 Main components of nuclear fuel cycle

Fig. 1 schematically describes the seven types of fuel cycle options in simplified flows with identification of materials to be transferred, emphasizing on the reactor types and the back ends of the fuel cycles. With consideration of flexibility of conversion ratio, totally thirteen options were considered.

The adoption of the seven types of nuclear fuel cycles, particularly thirteen fuel cycle alternatives, covers open fuel cycle, closed fuel cycle and partial closed fuel cycle, with regard of main popular commercial reactors, i.e. PWR and CANDU, and Gen IV sodium fast reactor, employing both conventional PUREX and advanced pyroprocessing technologies. In general, the evaluation of thirteen fuel cycles enables several comparisons, e.g., the differences between closed and open fuel cycles, the role of employing a conventional or advanced reprocessing technology, the effects of SFRs with different CRs, the advantage or disadvantage of MOX or TRU metallic fuel application to SFRs, etc.

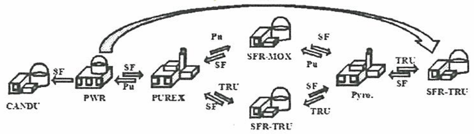


Fig. 1. Schematic description of fuel cycle options.

## 3. Results and Discussion

### 3.1 Uranium utilization

As shown in Fig. 2, in general, higher uranium utilization can be attained by the recycling options. In the DUPIC Recycling, U-235 in the PWR SF would be further burned in the CANDU reactor which contributes 29.0% of electricity generation, consequently, 8% less uranium would be required along with the DUPIC recycling option compared with the OT Cycle. As for the PWR-MOX

Recycling option, the MOX fuels were manufactured with Pu from the PWR SFs and then burning them in the PWR could save approximately equivalent amount of uranium resource. The MOX fuels would produce 13.4% of the 1 TWh electricity which would be reflected in the uranium requirement reduction of 13% compared with the OT option. In the Pyro-SFR Recycling option, TRUs recovered both from the PWR SFs and SFR SFs are utilized to extract electricity resulting to the corresponding reduction of a certain required uranium amount. The utilization of fissile materials, Pu or TRU, contained in PWR UO2 spent fuel explains the less uranium resources requirement of PWR(MOX)-SFR(TRU) and PWR(MOX)-SFR(MOX) as well.

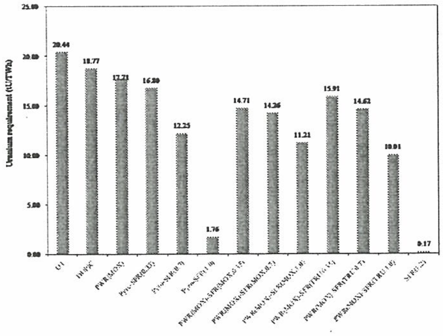


Fig. 2. Comparison of uranium requirements with nuclear fuel cycle options.

**3.2 Waste categorization**

Decay heat generated from wastes of a given nuclear fuel cycle could be a measuring criterion to quantify the ease or difficulty of waste management. The decay heat of wastes is mainly from fission products and actinides. Similar with changing trends of activity, actinides dominate the decay heat and decay heat of fission products decrease faster than actinides, particularly, after 100 years of cooling. MA's contribution to the decay heat of HLW play a considerable role if PUREX is employed to separate Pu for MOX fabrication.

The decay heats from HLW generated in the fuel cycle options decrease with time and their behaviors are compared in Fig. 3. It is clearly shown by Fig. 6 that the decay heat generated from HLW in Pyro-SFR(CR=0.35) Recycling is smallest after cooling for 100 years due to TRU recovery. The changing trend of decay heat of PWR (MOX)- SFR (TRU) and PWR(MOX)-SFR(MOX) are quite similar. The minor advantage of PWR (MOX)-SFR (TRU) over PWR (MOX)-SFR (MOX) comes from the utilization of MA from MOX spent fuel. No SFR cycles, i.e. OT, PWR-MOX and DUPIC, are similar in the changing trend of decay heat. Given a certain electricity generation, CR affects the $UO_2$, MOX and TRU fuel shares, and therefrom, the decay heat of fuel cycle options with different CRs can be different caused by the changes of MA steams.

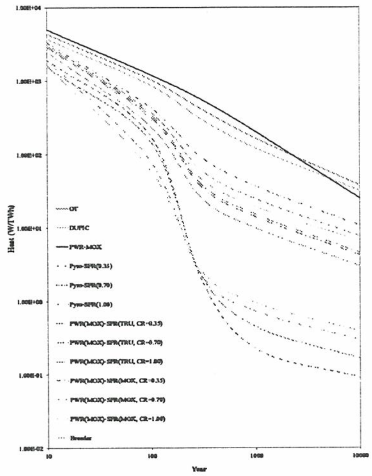


Fig. 3. Decay heat generated from HLW through different nuclear fuel.

**4. Conclusion**

Setting the OT Cycle as a basis, for the DUPIC Recycling, it burns 92% of the uranium needed by OT to produce 1 TWh of the electricity, by introducing 146% of LILW-SL, 177% of LILW-LL, and 129% of HLW. In the PWR-MOX case, it produces 116% of LILW-SL, 180% of LILW-LL, and 20% of HLW, by using 88% of uranium. The Pyro-SFR Recycling option appears to be the most attractive one among the reference cycles according to the higher uranium resource utilization efficiency (60% of uranium) and the smaller amount of radioactive wastes generation (80% of LILW-SL, 73% of LILW-LL, and 2% of HLW). On the whole, SFR involved recycling shows explicit advantages in controlling HLW generation with regard to waste amount, decay heat, and activity.

**5. REFERENCES**

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