# Sustainomics of the AMBIDEXTER-NEC Fuel Cycle and Management

Se Kee Oh *, Young Joon Lee, Tae Kyu Ham, Myung Hwan Seo, Sung Taek Hong, Tae An Kwon
*Energy System Division, Ajou University, Korea 442-749*
*skoh@ajou.ac.kr*

## 1. Introduction

Energy issues these days become planetary concerns, recognized as the major driver for the resiliency of the earth in the sustainomics framework of the society, economy and environment axes. In the circumstances, in order for the nuclear to take advantage of its GHG-free nature, criticisms associated with the fuel cycle should be defied.

As long as the uranium fuel cycle persists, problems bearing on the HLW management and the proliferation prevention could be neither completely decoupled nor independently resolved. Geopolitics around the Korean peninsula makes them be more complicated.

Reference of the AMBIDEXTER[1] fuel cycle relies on the DUPIC technology[2]. Combined with fluoride volatility process, desired quantity of uranium contents in the PWR spent fuel powder could be removed. Then, the reactor system runs with the fluorides salt of this uranium-reduced DUPIC fuel material.

Surplus uranium from the AMBIDEXTER-DUPIC[1] processes should satisfy the LLW classification criteria. So far, the sustainomics goal of the AMBIDEXTER fuel cycle focuses on generating energy from the HLW, meanwhile, converting into LLW without jeopardizing proliferation transparency.

## 2. AMBIDEXTER Fuel Cycle

In Figure 1, the simplified process diagram of the AMBIDEXTER fuel cycle is shown, whose main stream consists of the DUPIC REDOX and the low temperature fluorination processes.

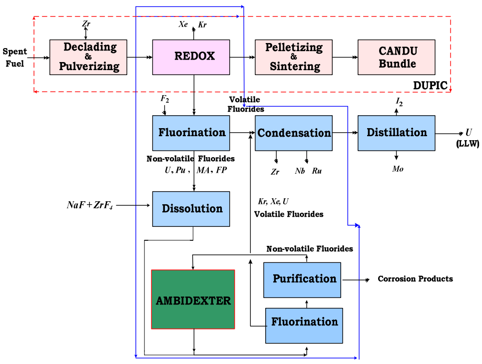


**Fig. 1 AMBIDEXTER-DUPIC Fuel Cycle Flow Diagram**

### *2.1 Uranium-reduced DUPIC Fuel Material*

[1] Advanced Molten-salt Break-even Inherently-safe Dual-missioning and EXcellenTly-Econogical Reactor

The REDOX throughput powder normally contains non-volatile chemical species remained in PWR spent fuel. In order to be dissolved in the solvent fluoride salt, it should be converted by a fluoride volatility process at 500℃, meanwhile approximately 95% of the uranium contents could be volatilized. Together with the uranium hexafluoride, certain quantity of fluoride compounds of the non-volatile elements, for instance, Mo, Nb, Zr, I, and Tc could be entrained.[3]

To keep the reactor in critical, the online fluorination process unit further reduces the uranium concentration level down to ~1%. Table 1 summarizes the isotopic concentrations of the AMBIDEXTER fuel salt made of 99% uranium-reduced DUPIC compositions.

Table 1: Isotopic Compositions of the AMBIDEXTER fuel

| Isotopic Composition | | Isotopic Composition | |
|---|---|---|---|
| nuclide | mol % | nuclide | mol % |
| Na-23 | 50.0 | Pu-236 | 1.3933E-7 |
| Zr-90 | 46.0 | Pu-238 | 2.3118E-2 |
| F.P's | 2.9615 | Pu-239 | 2.4481E-1 |
| U-234 | 4.2554E-6 | Pu-240 | 1.3863E-1 |
| U-235 | 1.0002E-3 | Pu-241 | 8.1625E-2 |
| U-236 | 2.1393E-3 | Pu-242 | 6.1414E-2 |
| U-238 | 4.4403E-1 | Am's | 2.7955E-2 |
| Np's | 4.0373E-2 | Cm's | 1.3665E-2 |

### *2.2 NaF-ZrF$_4$ Solvent Salt*

Determining the type and constitution of the solvent salt is one of key success factors for the MSR design. Its electro- and thermo-chemical performance over lifetime is equally important with the neutronics and thermal-hydraulic behaviors.

Because the prime objective of the AMBIDEXTER with the uranium-reduced DUPIC material is effectively burning actinides without proliferation burden, hardened neutron spectrum in the reactor core has to be preferred.

Also the TRU solubility should be as high as possibly achievable, in order to minimize the fuel salt loading in the reactor system. Vietez[4] set the solubility limit for a mixture of TRUs, in NaF-ZrF$_4$ to 1.56 mol %, compared to 0.169 mol % in LiF-BeF$_2$, at 550°C.

### *2.3 AMDEC Method for the Double-bank Core*

To decelerate accumulation rates of non-fissile TRU, the AMBIDEXTER core is configured to a double-bank shape that is a hybrid of fast and thermal reactors so as the fuel salt passes through the thermal-spectral outer core and the fast-spectral inner core consecutively.

Unlike non-volatile fluorides, most of the noble gases and noble metals, and also parts of the rare earths and corrosion products are continuously removed from the fuel salt. And on-power feeding of fuel materials is provided to compensate the reactivity decay due to fuel burn-up.

To be able to accommodate the above unique features in the design analysis, AMDEC[5] was developed and used to assess the nuclides concentration changes during steady power operation with active online fluorination and purification processing.

*2.4 Fuel Cycle Scenarios*

Using the HELIOS-AMBIKIN2D-AMDEC system, the implications of AMBIDEXTER-DUPIC fuel cycle options were investigated. Table 2 lists up values of the $250MW_{th}$ AMBIDEXTER design parameters relevant to this study, but not described in Reference [1].

Table 2: the 250MW AMBIDEXTER Design Data Used for Fuel Cycle Studies

| Parameters | Values |
|---|---|
| Initial Loading of nuclides, kg | |
| $U(U^{235}/U^{238})$ | 0.265/119.480 |
| $Pu(Pu^{239}/Pu^{240}/Pu^{241}/Pu^{242})$ | 66.150/37.620/ 22.243/16.806 |
| M.A. | 11.437 |
| Fission products | 412.300 |
| Removal rates of nuclides groups, /core/d | |
| Noble gases | 8640 |
| Noble metal | 1728 |
| Lanthanides | 0.020 |
| Uranium | 0.005 |

The first case is that the reactor runs solely with the R-DUPIC cycle, so as to burn actinides in spent fuel. Another scenario is that the reactor runs with a hybrid cycle of R-DUPIC combined with thorium cycle, where burns TRUs but breeds U-233. Limiting criteria for both scenarios have to be the excess reactivity or the actinide solubility.

In Figure 2, the estimated material balances at each of processing steps for the sole R-DUPIC option. In order to produce 1MWD of energy in the AMBIDEXTER, 7.353g of R-DUPIC, which is equivalent to 743.09g of PWR spent fuel, is required.

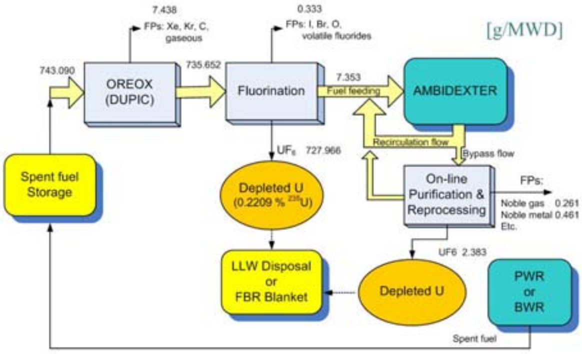


Table 3 compares the simulation results of both fuel cycle options. Roles of thorium in the AMBIDEXTER-DUPIC fuel cycle are dual so as to be burnable poison, at early days, to compensate burnout of excess fission products and, for entire cycle, to be breeding of U-233.

Table 3: Comparison of Material Balances for AMBIDEXTER fuel cycle options

| | R-DUPIC | +Thorium |
|---|---|---|
| Initial H.E. loading, kg | 291.609 | +1,086.394 |
| Daily feeding rate, g/d | | |
| R-DUPIC | 1,838 | 2,592 |
| Thorium | 0.0 | 8.27 |
| Online U removal rate, g/d | 63.0 | 946.75 |
| Atom density ineq., g/cm$^3$ | | |
| Th; | $6.744x10^{-12}$ | $2.870x10^{-1}$ |
| U; | $3.198x10^{-2}$ | $3.349x10^{-2}$ |
| $\%(U^{232}:U^{233}:U^{234}: U^{235}:U^{238})$ | 0.0:0.0:0.07: 0.17:99.77 | .003:3.59:0.19 :0.19:96.04 |
| Pu; | $5.885x10^{-2}$ | $8.454x10^{-2}$ |
| $\%(Pu^{238}:Pu^{239}:Pu^{240} Pu^{241}:Pu^{242})$ | 8.134:16.58: 33.98:17.74:23.57 | 6.95:22.23:34.24 17.21:19.38 |
| M.A.; | $7.581x10^{-3}$ | $9.481x10^{-3}$ |

## 3. Conclusions

In perspectives oo sustainomics, the AMBIDEXTER-DUPIC promises abundant technical, economical and social incentives to the nuclear energy sector, because it helps lightening the HLW burden while generating extra energy without concerning on proliferation critiques.

Another incentive is born of flexibility in fuel cycle options, for instance, breeding slightly enriched uranium via denatured with thorium.

Should AFCI improve pyro-processing technology for lanthanide removal, value system design of the AMBID-EXTER fuel cycle would get more flexible.

## REFERENCES

[1] S.K. Oh, et. al., *Concept Synopsis of the AMBIDEXTER Nuclear Energy Complex*, presented in this conference, (2009).

[2] M.S. Yang, H.B. Choi, et. al., *The Status and Prospect of DUPIC Fuel Technology*, Journ. Of Korea Nuclear Society, vol.38, no.4, pp.359-374, June (2006).

[3] J. Uhlir, et. Al., *Current Status of Czech R&D Program in Partitioning and Transmutation*, Proc. of OECD/NEA 7th Information Exchange Meeting on Actinide and Fission Product Partitioning and Transmutation, Jeju, Korea, Oct 14-16 (2002).

[4] E. R. Vieitez, M. D. Lowenthal, E. Greenspan, J. H. Ahn, *Optimization of a Molten-salt Transmuting Reactor*, Physor 2002, (2002).

[5] T.K. Ham, *AMDEC: A Computer Code for Analysis of Radioactive Nuclide Generation and Depletion in the Double-Banked AMBIDEXTER Core*, M.S. Thesis, Ajou University, (2008).