# Acquisition/Diversion Pathway Analysis of the DUPIC Fuel Cycle for the Assessment of Proliferation Resistance

Hong-Lae Chang*, Won Il Ko
*Korea Atomic Energy Research Institute, 150 Deokjin-dong, Yuseong, Daejeon, Korea 305-600*
**Corresponding author: hlchang@kaeri.re.kr*

## 1. Introduction

Within the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) of the IAEA, a methodology for evaluating proliferation resistance (INPRO PR methodology) has been developed [1] in order to provide guidance in using the INPRO methodology. However, it remains to develop the methodology to evaluate User Requirements (UR) 4 regarding multiplicity and robustness of barriers against proliferation (innovative nuclear energy systems should incorporate multiple proliferation resistance features and measures). To develop the assessment procedure and metrics for User Requirement 4 (UR4), the coarse acquisition/ diversion pathway analysis of the DUPIC Fuel Cycle has been performed. The most plausible pathways for the acquisition of weapons-usable nuclear material were identified and analyzed using a systematic approach herein, and future work to complete the assessment approach for the UR4 of the INPRO methodology regarding the multiplicity and robustness of barriers against proliferation are also proposed.

## 2. Concept of the DUPIC Fuel Cycle

The basic concept of the DUPIC fuel cycle (Fig.1) is to fabricate CANDU nuclear fuel from PWR spent fuel using dry thermal/mechanical processes without separating stable fission products. PWR spent fuel in the

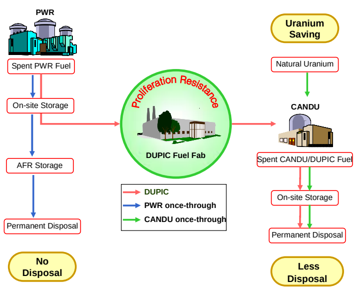

Fig.1 Concept of the DUPIC Fuel Cycle

DUPIC fuel cycle was assumed to be with a minimum 10 years of cooling time after 35,000 MWD/MTU of final burn-up, and Table 1 shows plutonium contents in fresh and spent DUPIC fuels.

The assumed proliferation threat is a covert diversion of nuclear material by the host-state which is an industrialized country that has indigenous uranium resources, physical control over the commercial nuclear energy system and materials being evaluated, declared facilities and materials that are subject to international safeguards, and signed Additional Protocol.

Table 1: Pu contents in PWR spent fuel and DUPIC fuels

| Isotopes | PWR SF | | Fresh DUPIC Fuel | | Spent DUPIC Fuel | |
|---|---|---|---|---|---|---|
| | g/MtHM | Pu (wt%) | g/MtHM | Pu (wt%) | g/MtHM | Pu (wt%) |
| $^{238}$Pu | 1.54E+02 | 1.7 | 1.54E+02 | 1.7 | 3.88E+02 | 4.9 |
| $^{239}$Pu | 5.33E+03 | 59.9 | 5.33E+03 | 59.9 | 3.16E+03 | 39.7 |
| $^{240}$Pu | 2.20E+03 | 24.8 | 2.20E+03 | 24.8 | 2.79E+03 | 35.1 |
| $^{241}$Pu | 7.52E+02 | 8.4 | 7.52E+02 | 8.4 | 5.24E+02 | 6.6 |
| $^{242}$Pu | 4.57E+02 | 5.1 | 4.57E+02 | 5.1 | 1.10E+03 | 13.8 |

## 3. Target Identification

Target identification begins by breaking the DUPIC fuel cycle into system elements for analysis, and the system element review looks for targets in each of the material balance areas. In the study, two Material Balance Areas are defined for possible diversion by the host State as defined in Figure 2: (1) the DUPIC fuel fabrication facility, and (2) a CANDU power plant.

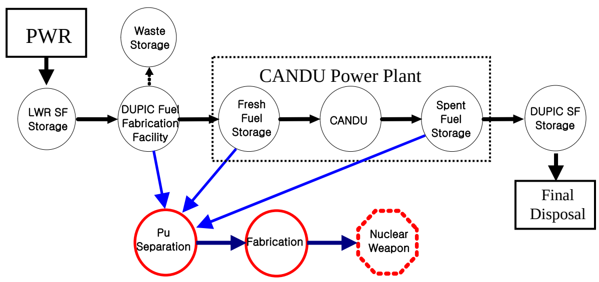

Fig.2 Material Flow in the DUPIC Fuel Cycle

Since the DUPIC fuel fabrication process is self-contained in a heavily shielded hot cell, intermediate process materials are not deemed viable for diversion. Therefore, potential diversion materials are (1) fresh DUPIC fuel bundles produced at the end of the DUPIC fuel fabrication process, (2) fresh DUPIC fuel from the fresh fuel bay in a CANDU power plant, and (3) spent DUPIC fuel from the DUPIC fuel discharge bay.

Considering the significant quantity of plutonium in the DUPIC fuel, the number of bundles of 17.64 kg HM/bundle for one significant quantity of 8 kg plutonium containing less than 80% $^{238}$Pu would be around 49 fresh and 54 spent DUPIC fuel bundles, respectively.

## 4. Plausible Pathways

Pathway analysis begins with a consideration of every target in light of the specific threats under consideration. Exit locations as well as the physical and design barriers to removal of targets are identified in the maintenance cell of the DUPIC fuel fabrication facility and a CANDU reactor building, including the safeguards barriers in place to protect the physical mechanism of diversion which include surveillance cameras, seals, neutron and gamma detectors, inventory key measuring points (KMPs), transfer KMPs, etc. Figure 3 shows DUPIC fuel paths and some of safeguards equipments in the CANDU reactor.

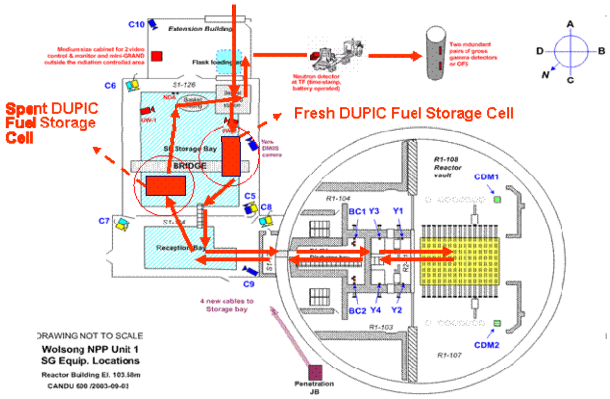


Fig. 3 DUPIC Fuel Cycle in a CANDU Reactor

The fresh DUPIC fuel bundles are subject to the item counting for inventory verification, the visual inspection and dimension measurement in the maintenance cell of the DUPIC fuel fabrication plant. In the CANDU power plant, the fresh fuel is remotely loaded into the channels of the reactor core by an operator. During the operation, the integrity of the fuel is monitored by the radiation level of the coolant during normal operation. The burnt DUPIC fuel bundles are then discharged from the core to the discharge bay, and intact fuels are moved from the discharge bay to the storage bay. During the operation, it is difficult to distinguish the fresh DUPIC fuel from the spent DUPIC fuel by the core discharge machine through neutron and gamma radiation measure, and the bundle counter in the discharge bay can not distinguish the moving directions of fresh and spent fuels. Therefore, imitated dummy fuels may be used to replace fresh and/or spent DUPIC fuel bundles for diversion - the fresh DUPIC fuel bundles can be removed by replacing with slightly enriched CANDU fuel imbedded with radiation source like $^{252}$Cf and spent DUPIC fuel by imitated spent fuel bundles

## 5. Qualitative and Quantitative Pathway Analysis

Pathways are potential sequences of events or actions followed by a proliferant State or adversary to achieve objectives [2], and Table 2 shows an example pathway analysis worksheet for the fresh DUPIC fuel in the maintenance cell of the DUPIC fuel fabrication facility.

Table 2: Pathway Analysis Worksheet

| Target ID | Target description | Diversion point | Potential strategies | Pathway ID | Proliferator actions | Pathway description |
|---|---|---|---|---|---|---|
| T1 | Fresh DUPIC fuel bundles | MBA-1 Exit-1 | Abrupt diversion | MBA-1-1A | 1. Use heavy truck and trailer to move basket containers<br>2. Fool or disable the IAEA cameras<br>3. Compromise the inventory measurement records | |
| | | | | | | |

Once the pathway is identified and analyzed, the next step is to assess each pathway and determine values for the PR measures. The GEN-IV PR&PP Expert Group [2] proposes six measures for the evaluation of the proliferation resistance (PR) of the nuclear energy systems: proliferation technical difficulty (TD), proliferation cost (PC), proliferation time (PT), fissile material type (MT), detection probability (DP), and detection resource efficiency (DE). The quantitative pathway analysis can be performed as an elicitation process or using the logic trees of which the goal is to identify potential proliferation pathways based on possible strategies, related targets, and sufficient design and process information of the DUPIC fuel cycle and processing of material to obtain weapons usable material.

In the expert elicitation, experts will be asked for each pathway to estimate measures for both acquisition and processing steps based on knowledge of material and process required to prepare weapons-usable material. After each pathway has been evaluated and the relevant PR measures determined, the results must be rolled up and consolidated in order to evaluate safeguards, identify potential weaknesses or alternative approaches. The analysis result can also provide a basis for more detailed analysis that could improve and enhance existing facility safeguards.

## 6. Conclusions

A scheme to develop coarse pathway analysis was demonstrated with the DUPIC fuel cycle. The overall PR characteristics of the DUPIC fuel cycle will be evaluated using the logic trees to assess the multiplicity and robustness of barriers against proliferation.

## REFERENCES

[1] International Atomic Energy Agency, Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems, INPRO Manual – Proliferation Resistance, Volume 5 of the Final Report of Phase 1 of the International Project on Innovative Nuclear Reactors and Fuel Cycles(INPRO), IAEA-TECDOC-1575, IAEA Vienna (2007).
[2] Generation IV International Forum Proliferation Resistance and Physical Protection Expert Group, “Evaluation Methodology for Proliferation Resistance and Physical Protection of Generation IV Nuclear Energy Systems, revision 5,” November 30, 2006, GIF/PRPPWG/2006/005.