# Evaluation of Proliferation Resistance Using The INPRO Methodology

YongDeok Lee, Joo-Hwan Park and Myung Seung Yang
*Korea Atomic Energy Research Institute, P.O. Box 105, Yusung, Daejon, Korea 305-600, ydlee@kaeri.re.kr*

## 1. Introduction

The INPRO (International Project on Innovative Nuclear Reactors and Fuel Cycles) program initiated by the IAEA in 2000 proposed proliferation resistance (PR) as a key component of a future innovative nuclear system (INS) for fulfilling the energy needs in the $21^{st}$ century along with a sustainability, economics, safety of nuclear installation and waste management[1]. In designing future nuclear system, it is important to consider the potential for misuse of such system for the purpose of producing nuclear weapons. Such considerations are among the key considerations behind the international non-proliferation regime, with its many national and multinational agreements and institutions, and the IAEA safeguards system is a fundamental element of this regime.

PR is defined as the characteristics of a nuclear energy system that impedes the diversion or undeclared production of nuclear material, or misuse of technology, by States intent on acquiring nuclear weapons or other nuclear explosive devices. The goal of a PR evaluation is to provide guidance for the nuclear energy system development groups that will develop the proliferation resistant technology, and to present results, showing how the non-proliferation goals will be met, to institutions responsible for deciding which nuclear concepts to pursue. The PR assessments need to be conducted for the life cycle of an INS from the beginning of a concept design to final process.

In this study, the updated INPRO methodology in the INPRO manual[2] is introduced. It is noted that the indicators and their subsequent variables are better classified and rearranged for applying the INPRO methodology to a realistic evaluation of an INS. Finally, the application of the INPRO methodology was carried out on the DUPIC (Direct use of PWR spent fuel in CANDU reactors) fuel cycle to assess the adequacy of the revised INPRO methodology with new indicators as a practice.

## 2. INPRO PR Evaluation Methodology

### *2.1 Structure of the INPRO User Manual*

INPRO has developed a set of Basic Principles (BP), User Requirements (UR) and Criteria (CR) including Indicators and Acceptance Limits (AL) to set out the desired goals of a PR[2]. Five URs were developed under one basic principle to provide guidance to a government, sponsors, designers, regulators, investors and other users of nuclear power and fuel cycle facilities, which incorporates the PR of a future nuclear energy system. The criteria were setup based on the objectives of a UR and each UR has different and independent indicators. Therefore, all the indicators under a UR involve all the essential elements to present a UR. Each indicator specifies the evaluation parameters with the acceptance limits to decide and provide guidance on the actual evaluation results of an INS. The degree of a proliferation resistance results from a combination of technical design features, operational modalities, institutional arrangements, safeguards measures and so on.

### *2.2 Evaluation Method*

To assess the PR of an INS in terms of evaluation parameters, evaluation scales are required. Some barriers can be quantified but other barriers, such as extrinsic measures or a safeguardability, may be expressed only in a logical value such as "Yes" or "No". The present study suggests a five stage scale such as VW(Very Weak), W(Weak), M(Moderate), S(Strong) and VS(Very Strong) regarding the quantifiable evaluation parameters. For a logical scale, U(Unacceptable) and A(Acceptable) for extrinsic measures and W(Weak) and S(Strong) for some intrinsic features related to a safeguardability are suggested.

The key to the bottom-up approach for an evaluation is to determine if a nuclear energy system can meet the acceptance limits suggested in the INPRO and then to judge the higher level requirements. The starting point for the analysis should be indicator 1 of UR1[2] because it will be a common indicator for all the identified nuclear system components.

## 3. Application to DUPIC Fuel Cycle

The basic concept of the DUPIC fuel cycle[3] is to fabricate CANDU nuclear fuel from a PWR spent fuel by the use of dry thermal/mechanical processes. Since no separation of the fission products and transuranic materials occurs in the process, the process materials are very radioactive throughout the whole manufacturing process. Therefore, access to the nuclear materials is extremely difficult and it is a strong incentive in terms of a proliferation resistance. The material type is characterized

Table 1. Evaluation of nuclear material attractiveness.

| **Indicators, IN** | **Evaluation Parameter, EP** | | **Evaluation scale** | | | | |
|---|---|---|---|---|---|---|---|
| | | | **VW** | **W** | **M** | **S** | **VS** |
| Material quality | Material type | | UDU | ***IDU*** | LEU | NU | DU |
| | Isotopic composition | $^{239}$Pu/Pu(wt%) | | W | | S | |
| | | | | >50 | | ***<50*** | |
| | | $^{232}$Ucontam.for $^{233}$U(ppm) | <400 | 400~ 1000 | 1000~ 2500 | 2500~ 25000 | >25000 |
| | Radiation field | Dose (mGy/hr) at 1 meter | <150 | 150- 350 | ***350- 1000*** | 1000- 10000 | >10,000 |
| | Heat generation | $^{238}$Pu/Pu(wt%) | | ***<20*** | | >20 | |
| | Spontaneous neutron generation rate | ($^{240}$Pu+$^{242}$Pu) /Pu(wt%) | | >50 | | ***<50*** | |
| | | | **VW** | **W** | **M** | **S** | **VS** |
| Material quantity | Mass of an item (kg) | | 10 | ***10~ 100*** | 100~500 | 500~ 1000 | >1000 |
| | Mass of bulk material for SQ (dilution) (kg) | | 10 | 10~100 | 100~500 | ***500~ 1000*** | >1000 |
| | No. of items for SQ | | 1 | 1~10 | ***10~50*** | 50~ 100 | >100 |
| | No. of SQ (material stock or flow) | | >100 | 50~ 100 | 10~50 | 10~1 | ***<1*** |
| Material form | Chemical/ physical form | U | Metal | Oxide/ Solution | U compound | ***Spent fuel*** | Waste |
| | | Pu | Metal | Oxide/ Solution | Pu compound | ***Spent fuel*** | Waste |
| | | Thorium | Metal | Oxide/ Solution | Th compound | Spent fuel | Waste |

as an irradiated direct use material (IDU). The isotopic composition, $^{239}$Pu/Pu, is ~60 wt%. The dose rate of a bundle is ~0.15 Sv/hr and the heat generation rate is related mostly to $^{238}$Pu/Pu which is 1.7 wt%. A spontaneous neutron generation comes from ($^{240}$Pu+$^{242}$Pu)/Pu and it is ~30 wt%. Table 1 shows the result on the evaluation of nuclear material attractiveness, which corresponds to UR2 in the manual.

## 4. Conclusion

The newly set-up INPRO methodology provides a strategic and realistic structure for the evaluation of a PR. The updated evaluation methodology is very informative and a big step forward to assess the degree of a proliferation resistance of a nuclear energy system. Also, it was very clear to draw conclusions on a nuclear system by trying to apply the methodology to the DUPIC case. From the evaluation result in the table, it is impossible to extract fissile materials and to modify the DUPIC facility for a misuse.

However, more development in the manual is necessary to finalize the PR evaluation methodology and to apply the methodology for actual and different types of nuclear systems.

## Acknowledgement

This work is performed under the auspices of Korea Ministry of Science and Technology as a long-term R&D project.

## REFERENCES

[1] International Atomic Energy Agency, Methodology for the assessment of innovative nuclear reactors and fuel cycles, Report of Phase 1B (first part) of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), IAEA TECDOC-1434, IAEA, Vienna, 2004.
[2] International Atomic Energy Agency, INPRO Manual for the area of Proliferation Resistance, IAEA-TECDOC-to be updated, Volume 5, IAEA, Vienna, 2007.
[3] Korea Atomic Energy Research Institute, A collaboration on Extended INPRO Case Study of the DUPIC Fuel Cycle, KAERI/RR-2752, 2005.