Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25–26, 2012

Current Status and Future Directions of Development of PR/PP Evaluation Methodology

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1. Introduction

Proliferation resistance (PR)—a mandatory design requirement for the introduction of generation IV nuclear energy systems (NESs)—is defined as "the characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material, or misuse of technology, by State in order to acquire nuclear weapons or other nuclear explosive devices [1]." The same report also defines physical protection (PP) as "the use of technical, administrative, and operational measures to prevent the theft of nuclear/radioactive material for the purpose of producing nuclear weapons, producing nuclear devices for nuclear terrorism, or using the facility or transportation system for radiological sabotage [1]."

Since the early 1970s right after the Indian nuclear test, the international community has recognized the limits of political and diplomatic means to prevent overt proliferation by states and looked for ways to incorporate technical features that are inherent in NESs. As a first step, active research has been conducted to develop a methodology to evaluate PR&PP components of NESs and has now been reduced to two main R&D streams: the Generation IV International Forum (GIF) and International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO). (Currently, GIF and INPRO are leading the debate as major projects for PR&PP evaluation methods.) This paper presents an overview of the R&D accomplishments during the development of PR&PP evaluation methodology. It also suggests some directions for future research.

2. NASAP, INFCE, and TOPS

The Nonproliferation Alternative System Assessment Program (NASAP, 1976–1980), which was carried out under the leadership of the US Department of Energy (DOE), analyzed the concept of proliferation resistance by categorizing the component elements of proliferation resistance into resources, time, and detection; it concluded that once-through fuel cycles showed the highest proliferation resistance. Later, this program became the basis for the International Fuel Cycle Evaluation (INFCE, 1977–1980) project, led by the International Atomic Energy Agency (IAEA); INFCE added one more component safety measure to NASAP's sub-category and initiated an unprecedented international debate on the subject, inviting 66 states and five international organizations to participate. However, owing to differing views among participating states, no consensus was reached; the only shared view was that there is no simple technical solution to nuclear proliferation.

Research efforts in this field were put on hold over the next two decades, after the Chernobyl accident. As the expectations of nuclear expansion began to increase, the concept of spent fuel standards (SFS) was introduced in the 1990s; this enabled qualitative analysis of proliferation resistance of the remaining plutonium.

In 1999, the US DOE formed a task force under the Nuclear Energy Research Advisory Committee (NERAC): the Technical Opportunities for Increasing the Proliferation Resistance of Global Civilian Nuclear Power System (TOPS) [2]. TOPS developed an evaluation methodology for the proliferation resistance of global nuclear system and introduced the concept of three barriers: material and technological barriers derived by expanding the concept of innate characteristics of SFS and institutional barriers (global nuclear nonproliferation regime) that are related to external measures. One of the most important results of TOPS was the development of the multi-attribute utility assessment (MAUA), which arranged elements affecting resistance in order of importance. Furthermore, TOPS became the basis for other evaluation methods such as INPRO and the Simplified Approach for Proliferation Resistance Assessment (SAPRA).

3. GIF and INPRO PR&PP Evaluation Methodology

In 2002, the United States, along with nine other founding members, launched the Generation IV International Forum (GIF) and established the PR&PP Working Group (PRPPWG) to develop a methodology for PR&PP evaluation. In a succession of revisions beginning in 2004, consensus was achieved among all participating GIF countries and related organizations (i.e., IAEA and EU), and Revision 6 of the methodology report was approved by GIF for open distribution in 2011 [3].

GIF considers proliferation resistance from the perspective of a nuclear energy system designer based on a pathway analysis that provides case-by-case scenarios against threats imposed by proliferators.

Accordingly, the GIF PR&PP evaluation methodology has an advantage over others as it can lay out detailed analyses for each pathway. Based on this methodology, GIF PRPPWG conducted a demonstration study in 2010–2011 using the Example Sodium Fast Reactor (ESFR), which consists of four sodium-cooled fast reactors of medium size collocated with an onsite dry-fuel storage facility, and carried out pathway analyses for four scenarios: diversion, misuse, breakout, and theft and sabotage [4].

Another major evaluation methodology introduced in the 2000s together with that developed by the GIF PRPPWG was the INPRO PR&PP evaluation methodology. This IAEA-led project provided guidance on developing a system with high proliferation resistance for newly developed nuclear reactors and fuel cycles. Unlike the GIF methodology, which considers proliferation resistance from the perspective of a nuclear energy system designer, INPRO's approach is more user-oriented; it consists of 17 indicators with specific criteria, a basic principle of proliferation resistance, and five user requirements. INPRO assessors evaluate the proliferation resistance of each state's nuclear energy system by checking a state's compliance level among the five user requirements.

4. Other Studies on PR/PP Evaluation Methodology

Other than the US, France and Korea are the two leading countries in developing PR&PP evaluation methods. France formed a Working Group on Proliferation Resistance and Physical Protection (GT3) in 2003 composed of domestic professionals from CEA, EDF, AREVA, etc., and developed the SAPRA. It is based on the TOPS evaluation methodology, which uses MAUA, but differs as it further elaborates four groups under the headings of diversion, transportation, transformation, and weaponization of nuclear materials.

In Korea, research on the PR&PP evaluation methodology is mainly conducted by the Korea Atomic Energy Research Institute (KAERI); it first introduced the concept of "electric circuit" in the evaluation of the PR components of NESs and conducted quantitative evaluation of proliferation resistance of various fuel cycles. KAERI also took the lead in INPRO studies that ultimately resulted in the recent kickoff of the Proliferation Resistance and Safeguardability Assessment Tools (PROSA) project in 2012 to develop a "nuclear proliferation + safeguardability" evaluation tool for NESs.

5. Conclusions

As the world nears a renaissance of nuclear energy, the importance of PR&PP continues to grow. In particular, the concept of 3S-by-design (SBD), which reflects safety, security, and safeguards for the initial stage of nuclear facility design, is being emphasized for the construction of new nuclear energy facilities. Therefore, introducing measures to strengthen proliferation resistance from the initial stage of the system and further increase resistance by harmonizing internal characteristics and external measures is important. In addition, as institutional characteristics, infrastructure, and other external factors vary from state to state, conducting individual case studies will become more essential to develop a customized evaluation methodology for each state. Korea, which initiated the project "Pyroprocessing PR/PP Enhancement Technology Development" as part of its mid- and long-term nuclear R&D program in March 2012, is conducting relevant studies in order to apply the concept of SBD to pyroprocessing, which is currently under development by the Korea Atomic Energy Research Institute (KAERI).

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