Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 29-30, 2014

The Analysis of Evaluation Methodologies for Proliferation Resistance

Jaejin Lee, Sunyoung Chang, Hosik Yoo*
Korea Institute of Nuclear Nonproliferation and Control, 1534 Yuseong-daero, Yuseung-go, Daejeon, 305-348, Republic of Korea
**Corresponding author: hsyoo@kinac.re.kr*

1. Introduction

Proliferation resistance (PR) is one of main goals in terms of improvements in the Gen-IV project. It is also considered importantly in the components of nuclear energy systems and design elements. However, there are needs to consider not only components of a nuclear system but also several factors such as political factors, international commitments, safeguards and so on in order to evaluate proliferation resistance. In addition, some measurement cannot be quantified easily. Despite of toughness of PR evaluation, developing objective and quantitative methodology will be helpful to construct regulation guidelines and design criteria for nuclear energy systems.

Therefore, analyzing various evaluation methodologies for proliferation resistance is needed to establish a pathway of further researches and use it as a reference. In this paper, common PR measuring factors among methodologies are found through the analysis of various PR evaluation methodologies.

2. Scope of study

International Nuclear Fuel Cycle Evaluation (INFCE) conducted by IAEA and Nonproliferation Alternative Systems Assessment Program (NASAP) carried out by U.S. Department of Energy in 1980 are studied as initial state of PR evaluation. Technical Opportunities to Increase the Proliferation Resistance of Global Civilian Nuclear Power System (TOPS) by U.S. Department of Energy in 1999 and Simplified Approach for Proliferation Resistance Assessment of nuclear systems (SAPRA) by Groupe de Travail sur la Resistance à la Prolifération et la Protection Physique (GTR3P), France in 2003 are covered as well.

For the recent international researches, International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) from 2000 by IAEA and The Proliferation Resistance and Physical Protection Evaluation Methodology Working Group of the Generation IV International Forum (GIF PR&PP Working Group) from 2002 are selected in this study.

3. Comparison of each methodology

3.1. INFCE and NASAP

Both NASAP and INFCE have the importance in terms of the fact that they were the first trial about evaluating PR. They applied Multi-Attribute Utility (MAU) method to assess PR, which can help decision makers to choose the best selection by quantifying attributes about trade-off problems.

However, they have a limitation because they conclude that it is not possible to prevent a host state from the diversion of nuclear weapons when the host state decides to obtain nuclear weapon strongly [1,2].

3.2. TOPS

Table I. Barriers to proliferation used in TOPS

Barrier type	Barrier	Attributes
Material barriers	Isotope	- Critical mass - Degree of isotopic enrichment - Spontaneous neutron generation - Heat generation rate - Difficulty presented by radiation to weapons design
	Chemical	- Degree of difficulty in refining weapons material
	Radiological (dose to humans)	- Degree of remote handling normally required
	Mass and bulk	- Concentration of material, ease of concealment
	Detectability	- Degree of passive detection capability - Active detection capability - Hardness of radiation signature - Uniqueness of material's signatures - Uncertainties in detection equipment
Technical barriers	Facility unattractiveness (degree of difficulty of production of weapons material inherent in a facility)	- Complexity of required modifications - Cost of modifications - Safety implications of modifications - Time required to modify - Facility throughput - Effectiveness of observable environmental signatures
	Facility accessibility	- Difficulty and time to perform operations - Need for specialized equipment - Manual versus automatic, remote operation - Frequency of operational opportunity to divert
	Available mass	- Amount of potentially weapons useable material at a given point in a fuel cycle

	Diversion detectability	- Type of material and processes wrt accountability - Uncertainties in detection equipment - Form of material as amenable to counting
	Skills, expertise and knowledge	- Dual-use skills and knowledge - Applicability of dual-use skills - Availability of dual-use information
	Time	- Time materials in a facility or process are available to proliferant access
Extrinsic barriers (institutional barriers)	Safeguards	- Availability and access to information - Minimum detectability limits for material - Ability to detect illicit activities - Response time of detectors and monitors - Precision and frequency of monitoring - Degree of incorporation into process design and operation
	Access control and security	- Administrative steps for access - Physical protection and security arrangements - Existence of effective back-up support - Effectiveness of access control and security
	Location	- Remoteness and/or co-location of facility

TOPS introduced material, technical, institutional barriers and tried to analyze PR systematically. It is a well-developed methodology, so a lot of other methodologies are based on TOPS. However, it does not take proliferation scenarios and pathways into account and has a limit on the concrete assessment process and the application of results [3].

3.3 SAPRA

SAPRA is the improved version of TOPS which added PR evaluation with regard to pathways, and has strength on calculating PR of overall commercial reactors simply and fast. Figure 1 shows one of examples obtained from SAPRA. It is about overall non- proliferation index of closed fuel cycle according to the diversion phase.

However, it takes too much broad approach, so it cannot give the detail assessment for each enrichment process or reprocessing system. In addition, the results from SAPRA are not absolute values, so it is not possible to compare a result with other results obtained from different nuclear systems [4].

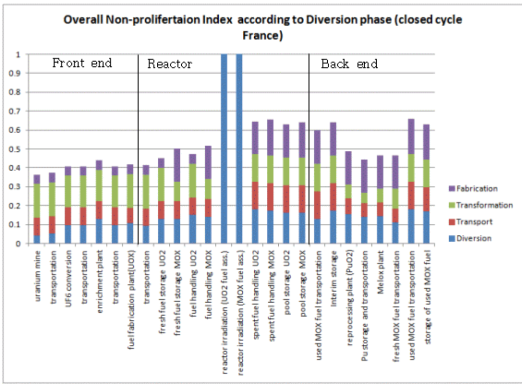

Fig. 1. Overall non-proliferation index according to diversion phase (closed cycle, France)

3.4 INPRO

INPRO where one of the most nations participated started from 2000 by IAEA. Its purpose is to contribute to fulfill energy demands and give efforts to cooperate both technology holders and users to develop Gen IV, advanced fuel cycle, as nuclear power is sustainable energy in the 21th century.

It has a hierarch structure which consists of one basic principle (BP) at the top, five user requirements (UR) in the middle, and more than one criterion (CR) at the bottom to help give the value of the UR. When the assessment is carried out, it starts from bottom to top, while when assessors start the discussion of results, it starts from top to bottom.

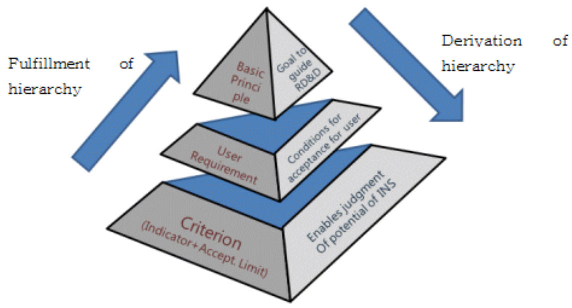

Fig. 2. Process of INPRO assessment

INPRO includes firstly the measurement of whether the state complies with international standards and regimes in the PR assessment. It has an importance on the fact that the PR evaluation can contain not only technical parts but also political aspects by adopting that measure. Table II describes INPRO's assessment tool related with political aspects.

Table II. INPRO assessment tool related with political aspects (UR1)

UR1: States' commitments, obligations and policies regarding non-proliferation and its implementation should be adequate to fulfill international standards in the non-proliferation regime				
Indicators IN	Evaluation Parameter EP	Evaluation scale		
		W	S	N/A

IN 1.1 States' commitments, obligation and policies regarding non-proliferation to fulfill international standards.	EP 1.1.1: Party to NPT	No	Yes	
	EP 1.1.2: Party to Nuclear-weapons-free zone (NWFZ) treaty	No	Yes	
	EP 1.1.3: Comprehensive safeguards agreements in force	No	Yes	
	EP 1.1.4: Additional protocol in force	No	Yes	
	EP 1.1.5: INFCIRC/66-type safeguards agreement in force	No	Yes	
AL 1.1 Yes, in accordance with international standards.	EP 1.1.6: Export control policies of NM and nuclear technology	No	Yes	
	EP 1.1.7: SSAC or RSAC in force	No	Yes	
	EP 1.1.8: Relevant international conventions/treaties in force	No	Yes	
	EP 1.1.9: Recorded violation of non-proliferation commitments	Yes	No	
IN 1.2 Institutional structural arrangements	EP 1.2.1: Multi-lateral ownership, management or control of a NES (Multi lateral, multi-national)	No	Yes	
AL 1.2 Yes, based on expert judgment.	EP 1.2.2: International dependency with regard to fissile materials and nuclear technology.	No	Yes	
	EP 1.2.3: Commercial, legal or institutional arrangements that control access to NM and INS.	No	Yes	

However, it has some problems that some questions are too much simple and some are qualitative measurements. It results in weakness on being distinct from other methods [5].

3.5 GIF PR&PP

The method developed by the Generation IV International Forum (GIF) is regarded as state-of-the-art one in these days. It gives quantitative results for the first time in the PR evaluation. Table III gives one of examples of metrics and estimated measure values for PR measures. There are six metrics in the GIF PR&PP methodology; technical difficulty (TD), proliferation cost (PC), proliferation time (PT), fissile material type (MT), detection probability (DP), detection resource efficiency (DE). They give PR values from very low (VL) to very high (VH) according to metrics scales bin. The result can be given as in figure 3. Furthermore, this methodology increases feasibility, because this methodology can elicit possible proliferation scenarios and carries out evaluation of PR with respect to each scenario.

Table III. Example metrics and estimated measure values for PR measures

Measures and metrics	**Metrics scales bin (median)**	**Proliferation resistance**
Proliferation resistance measures determined by intrinsic features		
proliferation technical difficulty (TD)	0-5% (2%)	very low
	5-25% (10%)	low
	25-75% (50%)	medium
	75-95% (90%)	high
	95-100% (98%)	very high
proliferation cost (PC)	0-5% (2%)	very low
	5-25% (10%)	low
	25-75% (50%)	medium
	75-100% (90%)	high
	>100% (>100%)	very high
proliferation time (PT)	0-3mon (2mon)	very low
	3mon-1yr (8mon)	low
	1-10yr (5yr)	medium
	10-30yr (20yr)	high
	>30yr (>30yr)	very high
fissile material type (MT)	HEU	very low
	WG-Pu	low
	RG-Pu	medium
	DB-Pu	high
	LEU	very high
Proliferation resistance measure determined by extrinsic measures and intrinsic features		
detection probability (DP)	0-5% (2%)	very low
	5-25% (10%)	low
	25-75% (50%)	medium
	75-95% (90%)	high
	95-100% (98%)	very high
detection resource efficiency (DE)	<0.01 (0.005GWyr/PDI)	very low
	0.01-0.04 (0.02GWyr/PDI)	low
	0.04-0.1 (0.07GWyr/PDI)	medium
	0.1-0.3 (0.2GWyr/PDI)	high
	>0.3 (1.0GWyr/PDI)	very high

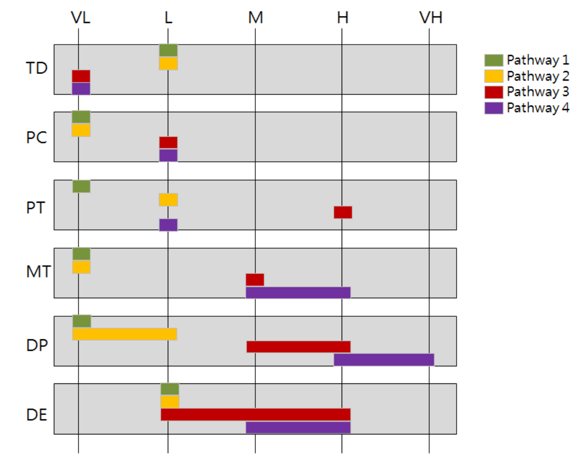

Fig. 3. Bar chart of PR pathway measures using binned qualitative descriptor

However, the results depend on specific threat research. Therefore, it is not possible to aggregate results from different threat definitions. In addition, it does not consider threat probability and weighting factor of each measurement [2,6].

4. Discussion

The most common and meaningful PR measuring factors of various PR evaluation approaches are 'legislative and institutional State's regime,' 'material attribute,' 'safeguardability,' 'technical difficulty,' and 'effectiveness of resource.'

Table III. Categorized common PR evaluating measures and elements

Category of PR measures	Detailed evaluating elements.
Material attribute	Level of fuel enrichment and radiation, fuel type, etc.
Technical difficulty	Technical level of handling nuclear material and enrichment, and so on.
Effectiveness of resources	Manpower, capital, time, etc.
Legislative and institutional State's regime	Party to NPT, CSA, etc.
Safeguardability	Any verification method used in IAEA and national inspection system

'Material attribute' is chosen as the PR measure in most of methodologies. It takes into account the level of fuel enrichment, fuel type, and likelihood of diversion of nuclear weapon.

And the measure that can evaluate required technical level to carry out proliferation activities is important. This measure can be called 'technical difficulty.' 'Technical difficulty' includes the level of radiation, detectability of diversion, accessibility of design information, required expertise and so on.

'Effectiveness of resource' is related with any resource that can be spent for the proliferation activity. For example, weapon fabrication time, time for overcoming proliferation barriers, money to support the activity, and available manpower are involved in this measure.

Because the actor of nonproliferation is a state, whether a state satisfies international regimes and standards in terms of PR should be determined first. This can be 'legislative and institutional State's regime' which gives questions such as whether party to Nonproliferation Treaty (NPT) or Comprehensive Safeguards Agreement (CSA) in force.

'Safeguardability' represents verification methods used by IAEA and national inspection systems. If more accurate and effective methods are developed and applied to safeguard systems, proliferation resistance will be increased.

5. Future work

As a result from analyzing PR measuring factors, the five PR measurements are categorized; legislative and institutional State's regime, material attribute, safeguardability, technical difficulty, and effectiveness of resource. They will be used to develop more effective and accurate schemes for the PR evaluation.

However, still there is a question about whether these measures have enough adequacies. Thus, each measurement will be verified through subsequent research and some measurements will be added or subtracted according to their validity. Measurements will be presented with quantitative and qualitative terms.

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