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Framework of Comprehensive Proliferation Resistance Evaluation Methodology

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1. Introduction

Civilian nuclear programs can be used as a pretext to acquire technologies, materials, equipment for military weapon programs. Consequently, international society has a strong incentive to develop a nuclear system more proliferation resistant to assure that the civilian nuclear energy system is an unattractive and least desirable route for diversion of weapon usable material.

The First step developing a more proliferation resistant nuclear energy system is to develop a systematic and standardized evaluation methodology to ensure that any future nuclear energy system satisfies the proliferation resistance goals. Many attempts to develop systematic evaluation methodology have been proposed and many systems for assessing proliferation resistance have been previously studied.

However, a comprehensive proliferation resistance evaluation can not be achieved by simply applying one method since complicated proliferation resistance characteristics, including inherent features and extrinsic features, should be completely evaluated. Therefore, it is necessary to develop one incorporated evaluation methodology to make up for weak points of each evaluation method.

The objective of this study is to provide a framework of comprehensive proliferation resistance evaluation methodology by incorporating two generally used evaluation methods, attribute and scenario analysis

2. Framework of Evaluation Methodology

Figure 1 shows framework of proliferation resistance evaluation methodology proposed in this study. The framework consists of three primary elements: actor identification, diversion scenario modeling and evaluation of diversion scenario.

As actors, there are nuclear systems, which are subject to proliferation resistance evaluation, and threat which makes an attempt to proliferate, and safeguarder that competes with proliferant to prevent proliferation.

Once the actors are identified, specific target of nuclear system that proliferant will choose is determined. All possible diversion scenarios are constructed based on the specific target of the nuclear system. Then diversion scenario is modeled using success tree logic diagram reflecting intrinsic and extrinsic features of target nuclear system.

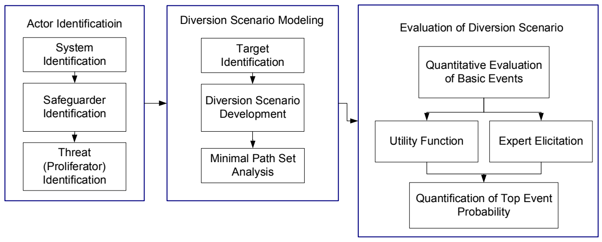

Figure 1. Framework of proliferation resistance evaluation methodology

Once the model is developed, minimal path sets that are any set of events for system success not containing another path set as a subset, are identified. In calculating the value of top event success probability, success probabilities of basic events in the minimal path set affect the values of high level events and finally the value of the top event success probability is derived from the values of basic events.

These basic events are divided into two categories. One category is for values of basic events affected by intrinsic features of the nuclear system and the other category is for values of basic events affected by extrinsic features. The values of basic events affected by intrinsic features of nuclear system are quantified by utilizing utility functions and the values of basic events affected by extrinsic features are quantified by direct expert elicitation.

The probability of top event success, namely proliferation resistance of that nuclear system, has various values according to each minimal path sets which are different according to the proliferant's diversion strategies.

Through these values, the most plausible pathway of proliferant can be identified and this pathway can be interpreted as the most vulnerable part to the proliferation of that nuclear system.

2.1. Actor Identification

Actors refer to the target nuclear energy system subject to the evaluation. Threat refers to someone who attempts a nuclear proliferation and safeguarder refers to someone who competes with proliferation to prevent proliferation. Diversion scenario and elements to be considered in proliferation resistance evaluation become different according to the ways for defining the target nuclear energy system and to categorize the threat to the system. Therefore, actor identification is the first step in the evaluation.

2.2. Diversion Scenario Modeling

This step models all plausible diversion scenarios of proliferant on the basis of information previously identified. Modeling of diversion scenario is facilitated by the use of logic diagrams to describe the flow of events and their interdependencies.

2.3. Evaluation of Success Tree Model

Proliferation resistance is viewed within the context of a success tree model. So, from the proliferant's point of view, diversion risk for nuclear energy system is indicated by the value of top event probability through the most probable minimal path set and proliferation resistance for that nuclear energy system is indicated by the failure probability of top event.

The ultimate goal of this step is to quantify the success probability of the top event of a success tree model by quantification of likelihoods of basic events that constitutes the top event. There are two different ways to quantify the basic events shown in figure 2. Likelihood of basic event that relates to intrinsic features of that system is evaluated by using multi attribute utility theory (MAUT). Likelihood of basic event relates related to extrinsic features are evaluated directly by expert elicitation.

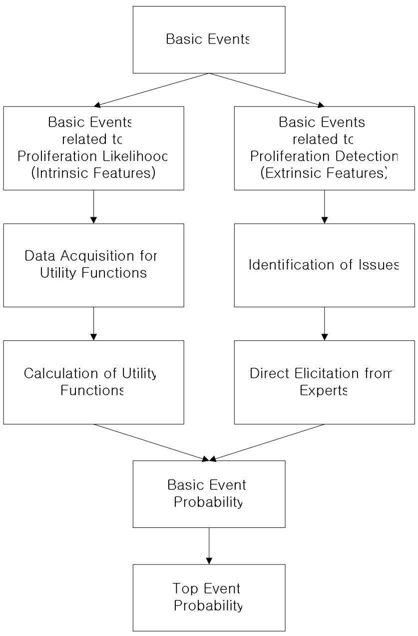

Figure 2. Order of calculation of top event probability and basic event probability

2.4. Quantification of Top Event Probability

The probabilities top events of each minimal path sets can be calculated by assuming that the basic events constituting the minimal path sets are mutually independent.

Once the basic events' probabilities are quantified, then the top event probability can be calculated based on the intersection of probabilities of basic events.

$$\Pr(MPS_i) = \Pr(\prod_{k=1}^{n} BE_k) = \Pr(BE_1) \cdot \Pr(BE_2) \cdots \Pr(BE_n)$$

Where BE_k is the k-th basic event constituting the i-th minimal path set

As previously mentioned, diversion risk for that nuclear energy system is indicated by the value of top event probability through most probable minimal path set and proliferation resistance for that nuclear energy system is indicated by failure probability of the top event. Therefore proliferation resistance for nuclear energy system is provided by

$$PR = 1 - \Pr(MPS)$$

3. Conclusion

The framework of methodology, based on the attribute analysis and the scenario analysis, for evaluation of proliferation resistance of nuclear energy system was introduced. This methodology reflected attributes of nuclear energy system in evaluating diversion pathway by introducing the attributes as affecting factors to basic event. This is conducted in an attempt to incorporate attribute analysis and scenario analysis into one evaluation method. Incorporation of two different methods may be misleading by hiding weak links between two methods. Hence, incorporated methodology requires a more acceptable means by making clear and strong links between two different methods.

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