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Abstract

This paper presents an evaluation methodology for proliferation resistance and physical protection (PR&PP) of Generation IV nuclear energy systems (NESs). For a proposed NES design, the methodology defines a set of challenges, analyzes system response to these challenges, and assesses outcomes. The challenges to the NES are the threats posed by potential actors (proliferant States or sub-national adversaries). The characteristics of Generation IV systems, both technical and institutional, are used to evaluate the response of the system and determine its resistance against proliferation threats and robustness against sabotage and terrorism threats. The outcomes of the system response are expressed in terms of six measures for PR and three measures for PP, which are the high-level PR&PP characteristics of the NES. The methodology is organized to allow evaluations to be performed at the earliest stages of system design and to become more detailed and more representative as design progresses. Uncertainty of results are recognized and incorporated into the evaluation at all stages. The results are intended for three types of users: system designers, program policy makers, and external stakeholders. Particular current relevant activities will be discussed in this regard. The methodology has been illustrated in a series of demonstration and case studies and these will be summarized in the paper.

Keywords: *proliferation resistance, physical protection, Generation IV nuclear energy systems, methodology*

1. Introduction

The Technology Goals for Generation IV nuclear energy systems (NESs) highlight Proliferation Resistance and Physical Protection (PR&PP) as one of the four goal areas along with Sustainability, Safety and Reliability, and Economics:

> *Generation IV nuclear energy systems will increase the assurance that they are a very unattractive and the least desirable route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism.*

Proliferation resistance and physical protection are defined here as follows.

Proliferation resistance is that characteristic of an NES that impedes the diversion or undeclared production of nuclear material or misuse of technology by the Host State seeking to acquire nuclear weapons or other nuclear explosive devices.

Physical protection (robustness) is that characteristic of an NES that impedes the theft of materials suitable for nuclear explosives or radiation dispersal devices (RDDs) and the sabotage of facilities and transportation by sub-national entities and other non-Host State adversaries.

2. The evaluation methodology

The Generation IV Roadmap [1] recommended the development of an evaluation methodology to assess NESs with respect to PR&PP. Accordingly; the Generation IV International Forum formed an Expert Group in December 2002 to develop a methodology. This paper presents the PR&PP methodology [2] and some of its applications.

Figure 1 illustrates the methodological approach at its most basic. For a given system, analysts define a set of ***challenges***, analyze ***system response*** to these challenges, and assess ***outcomes***.

CHALLENGES → **SYSTEM RESPONSE** → **OUTCOMES**

Threats ***PR & PP*** ***Assessment***

Fig. 1 Basic Framework for the PR&PP Evaluation Methodology

The challenges to the NES are the threats posed by potential proliferant States and by sub-national adversaries. The technical and institutional characteristics of the Generation IV systems are used to evaluate the response of the system and determine its ***resistance*** to proliferation threats and ***robustness*** against sabotage and terrorism threats. The outcomes of the system response are expressed in terms of PR&PP ***measures*** and assessed.

The evaluation methodology assumes that an NES has been at least conceptualized or designed, including both the intrinsic and extrinsic protective features of the system. Intrinsic features include the physical and engineering aspects of the system; extrinsic features include institutional aspects such as safeguards and external barriers. A major thrust of the PR&PP evaluation is to elucidate the interactions between the intrinsic and the extrinsic features, study their interplay, and then guide the path toward an optimized design.

The structure for the PR&PP evaluation can be applied to the entire fuel cycle or to portions of an NES. The methodology is organized as a *progressive* approach to allow evaluations to become more detailed and more representative as system design progresses. PR&PP evaluations should be performed at the earliest stages of design when flow diagrams are first developed in order to systematically integrate proliferation resistance and physical protection robustness into the designs of Generation IV NESs along with the other high-level technology goals of sustainability, safety and reliability, and economics. This approach provides early, useful feedback to designers, program policy makers, and external stakeholders from basic process selection (e.g., recycling process and type of fuel), to detailed layout of equipment and structures, to facility demonstration testing.

3. The evaluation process

The first step in the evaluation process is *threat definition*. For both PR and PP, the threat definition describes the challenges that the system may face and includes characteristics of both the actor and the actor's strategy. For PR, the actor is the Host State for the NES, and the threat definition includes both the proliferation objectives and the capabilities and strategy of the Host State. For PP threats, the actor is a sub-national group or other non-Host State adversary. The PP actors' characteristics are defined by their objective, which may be either theft or sabotage, and their capabilities and strategies.

To facilitate the comparison of different evaluations, a standard Reference Threat Set (RTS) can be defined, covering the anticipated range of actors, capabilities, and strategies for the time period being considered. Reference Threat Sets should evolve through the design and development process of nuclear fuel cycle facilities, ultimately becoming Design Basis Threats (DBTs) upon which regulatory action is based.

For PR, the threats include:

- Concealed diversion of declared materials
- Concealed misuse of declared facilities
- Overt misuse of facilities or diversion of declared materials
- Clandestine dedicated facilities.

For PP, the threats include:

- Radiological sabotage
- Material theft
- Information theft.

When threats have been sufficiently detailed for the particular evaluation, analysts perform the system response step, which has four components:

1. **System Element Identification**. The NES is decomposed into smaller elements or subsystems at a level amenable to further analysis.
2. **Target Identification and Categorization.** Target identification is conducted by systematically examining the NES for the role that materials, equipment, and processes in each element could play in each of the strategies identified in the threat definition.
3. **Pathway Identification and Refinement.** Pathways are potential sequences of events and actions followed by the actor to achieve objectives. An example approach to pathway development is given in [3].
4. **Estimation of Measures.** The results of the system response are expressed in terms of PR&PP measures.

The result of the system response step is to express the outcomes in terms of measures. This is the third step in this process.

For PR, the measures are:

- *Proliferation Technical Difficulty* – The inherent difficulty, arising from the need for technical sophistication and materials handling capabilities, required to overcome the multiple barriers to proliferation.
- *Proliferation Cost* – The economic and staffing investment required to overcome the multiple technical barriers to proliferation including the use of existing or new facilities.
- *Proliferation Time* – The minimum time required to overcome the multiple barriers to proliferation (i.e., the total time planned by the Host State for the project)
- *Fissile Material Type* – A categorization of material based on the degree to which its characteristics affect its utility for use in nuclear explosives.
- *Detection Probability* – The cumulative probability of detecting a proliferation segment or pathway.
- *Detection Resource Efficiency* – The efficiency in the use of staffing, equipment, and funding to apply international safeguards to the NES.

For PP, the measures are:

- *Probability of Adversary Success* – The probability that an adversary will successfully complete the actions described by a pathway and generate a consequence.
- *Consequences* – The effects resulting from the successful completion of the adversary's action described by a pathway.
- *Physical Protection Resources* – the staffing, capabilities, and costs required to provide PP, such as background screening, detection, interruption, and neutralization, and the sensitivity of these resources to changes in the threat sophistication and capability.

The final steps in PR&PP evaluations are to integrate the findings of the analysis and to interpret the results. Evaluation results should include best estimates for numerical and linguistic descriptors that characterize the results, distributions reflecting the uncertainty associated with those estimates, and appropriate displays to communicate uncertainties.

The information is intended for three types of users: system designers, program policy makers, and external stakeholders. Thus, the analysis of the system response must furnish results easily displayed with different levels of detail. Program policy makers and external stakeholders are more likely to be interested in the high-level measures, while system designers will be interested in measures and metrics that more directly relate to the optimization of the system design.

4. Current activities and future work

The PR&PP working group is currently performing a case study on an example sodium fast reactor and its associated fuel to exercise the methodology and to obtain preliminary insights on the PR&PP aspects of this system [4]. In addition, the is an ongoing effort [5] to seek harmonization between the PR&PP methodology and an initiative by the International Atomic Energy Agency on a related approach to proliferation resistance that has been developed under the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO). The purpose of this harmonization activity is to more fully understand and articulate the range of applicability and the potential for appropriate synergy and cooperation among the two efforts. Finally, the PR&PP working group and the System Steering Committees for each of the six design concepts within GIF have undertaken a focused effort integrate PR&PP notion into the design activities for each of the six concepts.

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References

[1] U.S. Department of Energy, Nuclear Energy Research Advisory Committee and the Generation IV International Forum. December 2002. *A Technology Roadmap for Generation IV Nuclear Energy Systems.* GIF002-00, DOE Nuclear Energy Research Advisory Committee and the Generation IV International Forum, Washington, D.C.

[2] *"Evaluation Methodology for Proliferation Resistance and Physical Protection of Generation IV Nuclear Energy Systems,"* Revision 5, Generation IV International Forum, GIF/PRPPWG/2006/005,November30,2006;www.gen4.org/Technology/horizontal/PRPPEM.pdf

[3] M. Yue, L-Y. Cheng, and R.A. Bari, "A Markov Model Approach to Proliferation Resistance Assessment of Nuclear Energy Systems," *Nucl. Technol.*, **162**, 26 (2008).

[4] Panel Sessions Presentations on *Proliferation Resistance and Physical Protection of Generation IV Nuclear Energy Systems* at Global 2007 Conference, Sponsored by the American Nuclear Society, Boise, Idaho, September 9-13, 2007.

[5] G. Pomeroy, E. Wonder, R. Bari, and M. Zentner, *"Approaches to Evaluation of Proliferation Resistance of Nuclear Systems,"* Proceedings of the Institute of Nuclear Materials Management, Annual Meeting, Nashville, TN, July 13-17, 2008.