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Methodology Development and Applications of Proliferation Resistance & Physical Protection Evaluation

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METHODOLOGY DEVELOPMENT AND APPLICATIONS OF PROLIFERATION RESISTANCE AND PHYSICAL PROTECTION EVALUATION

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ABSTRACT

We present an overview of the program on the evaluation methodology for proliferation resistance and physical protection (PR&PP) of advanced nuclear energy systems (NESs) sponsored by the Generation IV International Forum (GIF). 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 to determine its resistance against proliferation threats and robustness against sabotage and terrorism threats. The outcomes of the system response are expressed in terms of a set of measures, 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 the design progresses. It can thus be used to enable a program in safeguards by design or to enhance the conceptual design process of an NES with regard to intrinsic features for PR&PP.

I. Introduction

This paper presents an overview of the objectives, accomplishments, and potential future activities of the program on the evaluation methodology for proliferation resistance and physical protection (PR&PP) of advanced nuclear energy systems (NESs). The Generation IV Roadmap [1] recommended the development of an evaluation methodology to define measures for PR&PP and to develop a methodology for evaluating them for the six NESs proposed within the Gen IV program. Accordingly, the Generation IV International Forum (GIF) formed a Working Group in December 2002 to develop a methodology. The current version of the methodology (Revision 5) has been approved by GIF for open distribution and is available at the GIF website [2]. An update of the methodology, Revision 6, is in preparation during 2010.

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 the design progresses. It can be used to enable a program in safeguards by design or to enhance the conceptual design process of an NES with regard to intrinsic features for PR&PP. The results are intended for three types of users: system designers, program policy makers, and external stakeholders.

II. Synopsis of Methodology

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.

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***.

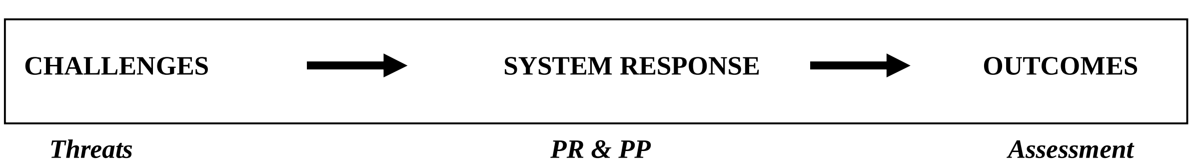

Figure 1: Basic Framework for the PR&PP Evaluation Methodology

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 a set of ***measures***, which are the high-level PR&PP characteristics of the NES.

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.

III. Recent Accomplishments and Current Activities

The PR&PP working group has performed a case study on an example sodium fast reactor and its associated fuel cycle facilities to exercise the methodology and to obtain preliminary insights on the PR&PP aspects of this system [3]. In addition, the PR&PP working group and the System Steering Committees for each of the six design concepts within GIF have an ongoing effort integrate PR&PP notions into the design activities for each of the six concepts. Finally, there is a cooperative effort [4] between the PR&PP working group 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 activity is to more fully understand and articulate the range of applicability and the potential for appropriate synergy and cooperation among the two efforts.

Example Sodium Fast Reactor (ESFR) Case Study

The PR&PP Working Group has developed its methodology with the aid of a series of studies using an example sodium fast reactor. The ESFR consists of four sodium-cooled fast reactors of medium size co-located with an on-site dry fuel storage facility and a pyrochemical spent fuel reprocessing facility.

The objectives of the Case Study were to exercise the GIF PR&PP methodology for a complete Gen-IV reactor/fuel cycle system; to demonstrate, via the comparison of different design options, that the methodology can generate meaningful results for designers and decision makers; to provide examples of PR&PP evaluations for future users; to facilitate transition to other studies; and to facilitate other ongoing collaborative efforts (e.g., INPRO) and other national efforts.

Lessons learned were that each PR&PP evaluation should start with a qualitative analysis allowing scoping of the study, of the assumed threats and identification of targets, system elements, etc.; that there is a need to include detailed guidance for qualitative analyses in the methodology; that the role of experts is essential; that there is a need for PR and PP experts and expert elicitation techniques; and that qualitative analysis offers valuable results, even at the preliminary design level. Qualitative analysis can directly address Technical Difficulty (TD), Proliferation Time (PT), Proliferation Cost (PC), and Material Type (MT). However, Detection Resource Efficiency (DE) and especially Detection Probability (DP) are harder to quantify using qualitative analysis.

Systematic identification of potential diversion pathways was a key goal. We found that it is possible to systematically identify targets and potential pathways for each specific threat, and to systematically search for plausible scenarios that could implement the potential proliferant Host State's strategies to divert the target material. A set of diversion pathways can be developed and the proliferation resistance measures for each pathway can be determined. The methodology can compare and distinguish how different design choices affect proliferation resistance.

The diversion pathways analysis can provide a variety of useful information to stakeholders, including regulatory authorities, government officials, and system designers. This information includes how attractive the material is to potential proliferators for use in a weapons program; how difficult it would be to physically access and remove the material; and whether the facility can be designed and operated in such a manner that all plausible acquisition paths are impeded by a combination of intrinsic features and extrinsic measures.

The misuse pathways analysis requires consideration of potentially complex combinations of processes to produce weapons-usable material, i.e., it is not a single action on a single piece of equipment, but rather an integrated exploitation of various assets and system elements. We found that, given a proliferation strategy, some measures are likely to dominate over the others, and within a measure some segments will dominate the overall pathway estimate.

The breakout pathways analysis found that breakout is a *modifying strategy* within the diversion and misuse threats and can take various forms that depend upon intent and aggressiveness, and ultimately the proliferation time assumed by a proliferant state. Furthermore, measures can be assessed differently within the breakout threat, depending upon the breakout strategy chosen. Some additional factors related to global response and foreign policy were identified as being relevant to the breakout threat, but those factors are not included in the PR&PP methodology.

The theft and sabotage pathways analysis found that multiple target and pathways exist. The most attractive theft target materials appeared to be located in a few target areas. Specifically, for the ESFR, the most attractive theft target areas with the most attractive target materials were found to be the LWR spent fuel cask parking area, the LWR spent fuel storage and fuel cycle facility staging/washing area, the fuel cycle facility air cell (hot cell), and the inert hot cell.

As noted in the PR&PP methodology report [2], a substantial base of analytic tools already exists for theft and sabotage pathway analysis. The case study verified that these tools can be used within the paradigm of the PR&PP methodology.

The Case Study indicated that the methodology for Proliferation Resistance could be improved by:

- Application of the measures to a broader range of targets and pathways to gain additional experience with their practical application;
- Investigation of the specific forms of the metrics used to express the measures; there is an ongoing effort to improve the metrics in Revision 6 of the methodology report.

<u>Interactions with Nuclear Energy System Designers</u>

As part of the effort to familiarize GIF participants, particularly system designers and program policy makers, with the PR&PP methodology and to better understand the needs of the designers, a series of workshops were held, beginning in the US in 2005, in Italy and Japan in 2006, and in the Republic of Korea in 2008. Useful mutual information exchange occurred during these workshops which helped to further define the methodological approach. A subsequent workshop is planned for Japan in 2011.

In 2007 informal discussions began between the PR&PP WG and representatives of the GIF System Steering Committees (SSCs) for each of the six Gen IV design concepts on the exploration of ways that the two entities could cooperatively pursue joint projects. Workshops of interested parties were held in May 2008, July 2009, and January 2010 which have resulted in a program plan for joint activities. Three broad goals were defined for these activities: 1) capture in the near term salient features of the design concepts that impact their PR&PP performance , 2) conduct crosscutting studies that assess against PR&PP criteria design or operating features common to various Gen IV systems, and 3) derive functional requirements for the global layout of future nuclear energy systems. See paper by F. Carre and S. Felix, Proceedings of Global 2009, for further details [5].

Draft white papers on the PR&PP aspects and issues each of the six design concepts have been developed jointly by representatives of the SSCs and the PR&PP WG. An integrated compendium of these white papers, including a discussion of crosscutting issues, is now in preparation and will be issued to GIF later in 2010.

<u>Interactions with GIF RSWG</u>

In addition to the establishment of the PR&PP WG, the GIF has recognized the need for a Risk and Safety Working Group (RSWG) to address the approach to be adapted to safety of future nuclear energy systems. The GIF also recognized that an interface with the activities of the PR&PP WG would be needed, and thus noted:

- A need for integrated consideration of safety, reliability, proliferation resistance and physical protection approaches in order to optimize their effects and minimize potential conflicts between approaches.
- A need for mutual understanding of safety priorities and their implementation in PR&PP and RSWG evaluation methodologies.

The efforts of these two groups continue to be carefully coordinated. Advances by either group have relevance to the other and can be mutually beneficial to both. It also continues to be important to assess and understand the impact of all specific design features in relation to objectives of safety performance, physical protection, and proliferation resistance. See Khalil et al, Proceeding of Global 2009, for further details [6].

Safeguards by Design

There are ongoing efforts, both nationally [7] and internationally [8], to promote and implement the concept of safeguards by design (SBD) in the nuclear facility design process. The goals of an SBD program generally consider: 1) design principles that facilitate the effective implementation of safeguards without overly burdening facility operations staff, 2) cost saving measures for implementing safeguards, 3) facility design features that would improve inspection conditions as compared to present standards, 4) better understanding of safeguards principles among facility designers, and 5) information exchange on advancements in safeguards technologies.

An example application of PR&PP methodology to safeguards by design is underway by Atomic Energy Canada Limited (AECL) for an advanced CANDU reactor [9].

The Department of Energy's National Nuclear Security Administration (NNSA) launched the Next Generation Safeguards Initiative (NGSI) [9] to revitalize the international safeguards technology and human resource base by leveraging U.S. technical assets and partnerships to keep pace with demands and emerging safeguards challenges. To address these challenges, NNSA is developing the policies, concepts, technologies, expertise, and infrastructure necessary to sustain the international safeguards system as its mission evolves over the next 25 years.

The deployment of new types of reactors and fuel cycle facilities, combined with the need to make the most effective and efficient use of limited safeguards resources, requires new concepts and approaches. The NGSI is currently exploring the use of the PR aspects of the PR&PP methodology as part of its safeguards by design strategy.

IV. Potential Future Applications

As the world increases its use and reliance on nuclear technologies for energy and other peaceful applications, there will be a need for a corresponding effort to assure that nonproliferation goals, as enunciated by the IAEA, are realized. There are many national and international programs that are aimed at providing this assurance. The PR&PP methodology is an analysis tool that can help to assess and manage the risks posed by threats to the peaceful use of nuclear technologies. Some areas in which PR&PP studies could prove effective in reducing proliferation risk are indicated below.

Guiding Future Global Fuel Cycle Architectures

Both national and international initiatives have proposed schemes for managing fuel cycle arrangements among participating nations. These schemes typically involve assured fuel supply and management of spent fuel. Some studies have been performed [10, 11] in this regard and further evaluations using the PR&PP methodology would be warranted as alternative architectures are proposed.

Enabling Future Nuclear Energy Designs

As new and innovative designs are developed for nuclear energy systems through GIF and INPRO, the PR&PP methodology approach will be essential to incorporating good design principles for proliferation resistance and physical protection into new emerging and viable concepts. The work that is just beginning between the PR&PP WG and the GIF SSCs will serve as a key model for how to implement this process.

Supporting Safeguards by Design

The PR&PP methodology approach can be a useful tool in developing safeguards by design as outlined in the Next Generation Safeguards Initiative and in recent parallel activities by the IAEA. PR&PP evaluations can identify discriminators among design alternatives and could thus help to make choices that reduce proliferation risk.

PR&PP as a Quality Assurance Tool

Evaluations of proliferation resistance and physical protection robustness have been and will be performed by various parties with interest in this area. The results of these studies and the analysis steps can be checked with the PR&PP methodology to understand critical assumptions, uncertainties, and validity of results.

The GIF PR&PP evaluation methodology was initially motivated by the need to have an approach for the assessment of new nuclear energy design concepts that were envisioned within the GIF program. The methodology that has been developed now enjoys wide international consensus and has been used in applications beyond the initial purpose. It is expected that subsequent applications of the methodology will 1) lead to refinement of the approach which will streamline and focus it to address issues of interest to end-users of the results and 2) have relevance to a more diverse set of investigations that will enhance decision making in the PR&PP arenas.

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