The GIF Proliferation Resistance and Physical Protection (PR&PP) Evaluation Methodology:

Status, Applications and Outlook

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Abstract. Methodologies have been developed within the Generation IV International Forum (GIF) to support the assessment and improvement of system performance in the areas of sustainability, safety and reliability, economics, proliferation resistance and physical protection (PR&PP). The last of these four areas was assigned to the GIF Working Group on Proliferation Resistance and Physical Protection (PRPPWG). The PRPPWG developed the methodology through a series of development and demonstration case studies, by use of a hypothetical "Example Sodium Fast Reactor" (ESFR). This is a generic design of Generation IV reactor based on the US Advanced Fast Reactor (AFR) developed by Argonne National Laboratory.

The PR&PP ESFR assessment was the first opportunity to exercise the full methodology on a complete system, and many insights were gained from the process. In particular, the approach of breaking the assessment into subtasks, each focusing on a separate area of PR&PP (for PR: diversion, misuse, breakout; for PP: theft and sabotage) handled by a dedicated subgroup with diverse international membership, was useful in generating new insights and concept development. In addition, over the past few years various national and international groups have applied the methodology to inform nuclear energy system designs, as well as to support the development of approaches to advanced safeguards. A number of international workshops have also been held which have introduced the methodology to design groups and other stakeholders.

In this paper we summarize the PR&PP methodology, its application to the ESFR case study, and other accomplishments of the PRPPWG. Current challenges with the efficient implementation of the methodology are outlined, along with the path forward for increasing its accessibility to a broader stakeholder audience - including supporting the next generation of skilled professionals in the field of nuclear non-proliferation and security.

Key Words: The GIF Working Group on Proliferation Resistance and Physical Protection (PRPPWG), the RPPWG methodology for PR&PP evaluation for all GIF systems, hypothetical case study "Example Sodium Fast Reactor" (ESFR), workshops and interactions with the IAEA.

1. Introduction

Following the publication of the Generation IV International Forum (GIF) Roadmap [1] in 2002, the Proliferation Resistance and Physical Protection Working Group (PRPPWG) was established, and charged with developing measures for expressing proliferation resistance and physical protection, and incorporating these into an associated evaluation methodology. Overall, the method would enable evaluation of the performance of different Generation IV systems (or options for a given system) against the GIF PR&PP goal. As the 2002 Roadmap outlines, each GIF design would support R&D on material deployed, potential vulnerabilities, protective barriers, safeguards approaches, potential misuse, material protection, control and accounting for each step in the fuel cycle, etc. While each GIF design has not yet formally explicitly addressed all nine tasks given in the 2002 Roadmap for PR&PP R&D, there has been interaction between each of the System Steering Committees (SSCs) and the PRPPWG on the status of designs with regard to PR&PP R&D, including a joint report between the PRPPWG and the SSCs [2]. Since the issuing of the GIF Roadmap and the establishment of the PRPPWG, the importance of considering safeguards needs as early as possible in the technology design process ("Safeguards by design") has become widely recognized. In this respect the interaction of the SSCs with the PRPPWG, the engagement of the individual design teams with the PR&PP process, and the dual consideration of security and safeguards concerns within the PR&PP process, demonstrates the alignment and leadership of GIF in the area of international PR&PP development over the last decade as discussed hereafter.

2. The PR&PP Evaluation Methodology & Lessons learned from Case Study

In a succession of revisions beginning in 2004, the PRPPWG has developed a methodology for PR&PP evaluation for all GIF systems, including measures and associated metrics. Consensus was achieved amongst all participating GIF members and observers (IAEA), and Revision 6 of the methodology report was approved by GIF for open distribution in 2011 [3].

The methodology was developed, demonstrated, and illustrated by use of a hypothetical "Example Sodium Fast Reactor" (ESFR), by members of the PRPPWG. The ESFR assessment was the first opportunity to exercise the full methodology on a complete system, and many insights were gained from the process. In particular, the approach of breaking the assessment into subtasks, each focusing on a separate area of PR&PP (for PR: diversion, misuse, breakout; for PP: theft and sabotage) handled by a dedicated subgroup with diverse international membership, was useful in generating new insights and concept development [4].

As is discussed in reference [4], 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 methodology; that the role of experts is essential; that there is a need for PR&PP experts and expert elicitation techniques; and that qualitative analysis offers valuable results, even at the preliminary design level.

Completeness in identifying potential diversion pathways is a key goal. It was 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 pathway segments can be developed and the PR measures for each pathway can be determined.

The methodology can compare and distinguish how different design choices affect PR.

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.

It was found that, given a proliferation strategy, some measures are likely to dominate 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 on intent and aggressiveness, and ultimately the proliferation time assumed by a proliferant state. Furthermore, measures can be assessed differently within the breakout threat, depending on the breakout strategy chosen. Note that 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 light water reactor (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.

3. Workshops and Outreach

The methodology was intended for three types of generic users: system designers, program policy makers, and external stakeholders. Workshops with GIF designers and other stakeholders, to familiarize them with the methodology and to understand their needs for the design process, were held in the USA, Italy, Japan, the Republic of Korea, the Russian Federation and France. This has helped to address one challenge with PR&PP, which is the engagement of technology designers; PR&PP has typically been a topic tackled in the latter stages of design, and at the initiation of external bodies like the IAEA. These workshops have spread awareness of the PR&PP methodology beyond the GIF community, which is appropriate since the methodology itself is applicable to the whole range of nuclear technology.

Starting in 2007, the PRPPWG and the six SSCs conducted a series of workshops on the PR&PP characteristics of their respective designs and identified areas in which R&D is needed to further include such characteristics and features in each design. A common template was developed to systematically collect design information, including PR&PP-related features. This work culminated with reports, internally referred to as white papers, written jointly by the PRPPWG and the SSCs for each design. An overall report was approved by GIF for open distribution in 2011 [2]. The intent is to generate preliminary information about the PR&PP merits of each system and to recommend directions for optimizing their PR&PP performance.

The report captures the current salient features of the GIF system design concepts that impact their PR&PP performance. It identifies crosscutting studies to assess PR&PP design or operating features common to various GIF systems; and it suggests beneficial characteristics of the design of future nuclear energy systems, beyond the nuclear island and power conversion system, that should be addressed in subsequent GIF activities. The PRPPWG and SSCs are now in the process of updating progress on implementation of the PR&PP concepts in each of the six designs promoted by GIF. Through a series of workshops and others interactions, it is anticipated that a new joint study will be issued by the PRPPWG and the SSCs by the end of the decade.

A summary of the work of the PRPPWG over the past decade appears in a special issue on PR&PP of the ANS journal Nuclear Technology in July 2012 [5], where several papers are derived from contributions to Global 2009.

A status paper on the PR&PP methodology and its application has been prepared for the 2014 IAEA Safeguards Symposium [6] and was updated for the Global 2015 International Conference [7]. Several national programs have adapted the PR&PP methodology to their specific needs and interests [8-15].

4. IAEA Interactions

The PRPPWG has coordinated closely with the IAEA since its inception; i.e. there has always been an IAEA representative in the PRPPWG who has contributed to the work and direction of the group.

In terms of methodology development there has been considerable interaction between GIF and the IAEA's INPRO program [16], beginning with a comparison of the respective PR methodologies [17] of the two organizations with an aim towards understanding how prospective users could benefit from each or from a joint application of the approaches. INPRO projects, such as PRADA (Proliferation Resistance: Acquisition/diversion Pathways Analysis) [18] and PROSA (Proliferation Resistance and Safeguardability Assessment) as well as other IAEA projects in nuclear energy or safeguards [19], involved some experts that were also members of the GIF PRPPWG. This has provided a useful catalyst to further cooperation.

There are, in fact, several benefits that accrue from continued interaction between GIF and the IAEA, and there is a strong argument for the complementary nature of the two methodologies:

The IAEA/INPRO methodology for nonproliferation provides "rules of good practice" for design concepts. It thus provides a checklist that ensures that technology assessors "did things right".

The GIF/PR&PP methodology is a systematic approach to evaluating vulnerabilities in designs. It thus provides the assessment approach that ensures that assessors "did not do things wrong".

Together, both products are potentially useful in national programs.

5. Current Situation Assessment

Today the PR&PP methodology is likely the most comprehensive publicly available evaluation methodology for any nuclear technology – despite being developed specifically to meet GIF goals. The PR&PP methodology is reasonably complete as an overarching framework; however, specificity of techniques and applications are needed, primarily as determined by the user.

With the interaction with designers, a need has emerged for simplified scoping PR&PP evaluations. Such scoping applications are a valid application of the methodology, and in fact support the view that PR&PP can be implemented at the earliest stages of design when a focused and simplified approach is appropriate. The application of the PR&PP methodology in Canada [12], was a pared down implementation in this category. The application of the PR&PP framework within the European CP-ESFR project is another example in this direction [14].

In the international safeguards community, the concept of "Safeguards by Design" (SBD) has emerged as a key "cultural shift" to be encouraged amongst designers, and as noted earlier GIF was one of the first development organizations to embrace this concept through its creation of the cross-cutting PRPPWG. There are ongoing and planned efforts both in national programs and internationally, by the IAEA and by the European Commission, to promote and implement SBD in the nuclear facility design process. IAEA has efforts underway on SBD. A generic guidance document was published in 2013 [20], the first facility-specific document dedicated to nuclear reactors was published in 2014 [21] and additional facility-specific documents are currently under preparation.

There is an increased emphasis worldwide on the development and deployment of small modular reactors (SMRs). Since some of the GIF designs are in the SMR category it is important to maintain cognizance of SMR issues and developments as they pertain to PR&PP. While some SMRs share with conventional reactors many characteristics of relevance to PR&PP, others – particularly those with advanced fuel cycles or those destined for remote operation – represent novel designs or implementations that will benefit from a consistent and comprehensive PR&PP evaluation at various stages of the design process.

The PRPPWG produced a set of Frequently Asked Questions (FAQ) about its methodology and applications [22], intended for a broad audience wishing to know about the methodology at an introductory level.

The PRPPWG has assembled a comprehensive bibliography (publicly available on the PR&PP web site) comprised of its papers and reports by the group as well as related documents prepared by others [23]. The bibliography is updated yearly.

In addition to the workshops held in the past dedicated to the designers and stakeholders, workshops targeted to scholars and students have been also initiated [24], and new ones have been held [25].

6. Future PR&PP Activities

6.1. Working with SSCs on maturing their designs

As new and innovative design are developed for nuclear energy systems through GIF (and possibly others), the PR&PP methodology approach will be essential to incorporating good design principles for proliferation resistance and physical protection into new concepts.

If the GIF sponsors in the various participating countries wish to advance the utilization of PR&PP methods in the design process, the next major joint activity between the System Steering Committees (SSCs) and the PRPPWG should be to designate one or two concept designs for an in depth pilot study. This study could fit well within the scope of one of the Generation IV System Integration and Assessment (SIA) projects.

In the longer term, when the results and insights from pilot studies become available, other GIF design concepts would also be engaged in such model development with the assistance of the PRPPWG.

The overall benefit would be to introduce PR&PP early in the design process in order to provide an analysis of for making cost effective safeguards and security built in the design before final design stages (and to thus avoid costly retrofits). This would ultimately be a useful approach to minimizing project risk for the emerging GIF concepts. The PRPPWG is currently contacting the six SSCs on the need to update the reports on the PR&PP merits of each GIF system based on the evolution of the designs occurred since the issue of [2].

6.2. Enabling “Safeguards by design”

Robust safeguards are essential to the PR&PP characteristics of all of the emerging GIF designs. In conjunction with the PRPPWG effort with the SSCs, the PRPPWG will maintain cognizance of technology developments and good practices that would foster “safeguards by design” in the GIF designs.

The Facility Safeguardability Analysis (FSA) [26] is a methodology designed to enable the introduction of safeguards by design in each stage of the design/construction cycle of a nuclear energy system. While the FSA is more qualitative than the PR&PP methodology and of narrower scope, the methodologies are mutually consistent in the sense that a PR&PP study can be used to inform an FSA study or, alternatively an FSA can be an early step in a PR&PP evaluation.

In addition, it is important to maintain cognizance of post-Fukushima lessons-learned for their potential relevance to PR&PP and linkage of safety to security and safeguards.

6.3. Small Modular Reactors

To the extent that it is relevant to GIF designs, the PRPPWG will maintain cognizance of this area and enable the incorporation of robust PR&PP features in the SMRs. To have reasonable physical security force size and costs, SMRs must include design features that increase intrinsic security characteristics, such as use of passive safety systems. The emergence of SMRs as a major design consideration in the second decade of GIF, with potential impact on the GIF designs themselves (particularly in scaling of designs, as required) indicates the importance of crosscutting evaluation methodologies that are as generic as possible. The flexibility allowing non-GIF users to apply the PR&PP methodology also maintains the methodology's relevance to GIF design teams as specifications change.

6.4. IAEA/INPRO Interaction

The PRPPWG will continue to coordinate with IAEA in areas of mutual interest. In general, the PRPPWG will maintain cognizance of developments in safeguards concepts and approaches, and assess and respond to any potential impact on the PR&PP methodology.

6.5. Continued interaction between the PRPPWG and the other GIF methodology groups

Coordination with the Risk and Safety Working Group (RSWG) and with the Economic Modeling Working Group (EMWG) should be pursued to assure effective implementation of approaches in the GIF design.

To this aim several joint meetings have been organized by the RSWG and PRPPWG groups, most recently in US in 2015, with the decision to strengthen the collaboration by focusing on the interface between Safety and Security.

7. Conclusion

The PRPPWG has developed an evaluation methodology that likely represents the most comprehensive publicly available PR&PP tool that can inform the design process of any nuclear technology.

The PR&PP methodology is aligned with international efforts to improve the effectiveness and efficiency of safeguards. It represents an enabling tool for "Safeguards by design", and, in conjunction with the Risk and Safety Working Group of GIF, a natural manifestation of the integration of the previously noted Safety, Security, and Safeguards (sometimes called "3S") linkage within the culture of nuclear technology design.

The PRPPWG will continue to work with the SSCs to implement pilot applications of the PR&PP methodology, as well as maintain cognizance of international developments and engagement with other groups within the international nonproliferation community. The PR&PP methodology will be maintained as necessary to retain its relevance and applicability to the development of new and emerging nuclear systems, primarily within GIF but also for the broader nuclear community.

8. Acknowledgement & Contributors

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