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Proliferation Resistance and Physical Protection Working Group: Methodology and Applications

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Abstract

We summarize the technical progress and accomplishments on the evaluation methodology for proliferation resistance and physical protection (PR&PP) of Generation IV nuclear energy systems. We intend the results of the evaluations performed with the methodology for three types of users: system designers, program policy makers, and external stakeholders. The PR&PP Working Group developed the methodology through a series of demonstration and case studies. Over the past few years various national and international groups have applied the methodology to nuclear energy system designs as well as to developing approaches to advanced safeguards.

INTRODUCTION

After the Generation IV International Forum (GIF) Roadmap [1] was issued in 2002, the Proliferation Resistance and Physical Protection Working Group (PRPPWG) was established and charged with developing measures and metrics for expressing proliferation resistance and physical protection and an associated evaluation methodology. In the R&D program for PR&PP, it was envisioned that R&D would be conducted in three areas: (1) safeguards and physical protection technology R&D for each GIF system, (2) formulation of PR&PP criteria and metrics, and (3) evaluation of the criteria and metrics. The PRPPWG was established in late 2002 with a charter that covered items (2) and (3). Specifically, the Working Group was charged with developing a methodology for the systematic evaluation of proliferation resistance and physical protection of Generation IV energy systems. Overall, the method would enable comparative evaluation of the performance of different systems

(or options for a given system) against the GIF PR&PP goal. The Working Group would also determine the measure (or measures) for expressing proliferation resistance and physical protection, and develop an evaluation approach that is comprehensive and quantitative to the extent possible.

The PRPPWG was not given a specific mandate with respect to item (1). 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 [1] for PR&PP R&D, there has been interaction between each of the System Steering Committees (SSCs) and the PRPPWG on the status of each design with regard to PR&PP R&D and a joint report between the PRPPWG and the SSCs was approved by the GIF Policy Group in 2011 (see discussion below).

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, as well as the importance of integrating the considerations of safeguards, security, and safety (the 3S approach – see Reference [2]). 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.

In parallel to the development of the methodology, the group has promoted the concept of safeguardability defined as the degree of ease with which a system can be effectively and efficiently placed under international safeguards [3].

DEVELOPMENT AND APPLICATIONS OF THE PR&PP METHODOLOGY WITHIN GIF

In a succession of revisions beginning in 2004, the PRPPWG has developed a methodology for PR&PP evaluation for all GIF systems. Measures and associated metrics were included in each revision. Consensus was achieved amongst all participating GIF countries and related organizations (IAEA, EU) and Revision 6 of the methodology report was approved by GIF for open distribution in 2011 [3].

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.***

Threats *PR&PP* *Assessment*

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

The challenges to the nuclear energy system (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.

The methodology was developed, demonstrated, and illustrated by use of a hypothetical "example sodium fast reactor" (ESFR), by members of the PRPPWG [4]. The ESFR case study 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 (diversion, misuse, breakout) handled by a dedicated subgroup with diverse international membership, was useful in generating new insights and concept development.

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, and (most recently) Russia. This has helped to address one challenge with PR&PP, which is the engagement of designers since PR&PP has typically been a topic tackled in the latter stages of design and at the initiation of external bodies like the IAEA or EURATOM. 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 collect in a systematic way GEN IV design concepts, information, and PR&PP features and issues. This work culminated with (six) reports written jointly by the PRPPWG and the SSCs for each design. An overall report was approved by GIF for open distribution in 2011 [5]. 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.

A summary of the work of the PRPPWG over the past decade appears in a special issue of the ANS journal *Nuclear Technology* in July 2012, Volume 179, Number 1 on the topic of safeguards. Several papers on the methodology and its applications, authored by members of the PRPPWG, appear in this issue.

APPLICATIONS OF THE PR&PP METHODOLOGY WITHIN NATIONAL PROGRAMS

Others, in national programs, have adapted the PR&PP methodology to their specific needs and interests:

- In the USA, the methodology has been used to evaluate alternative spent fuel separations technologies [6].
- In Canada there has been a safeguards-by-design use of the PR&PP methodology in the licensing process for two new CANDU designs [7].
- In Belgium the PR&PP methodology was used in the PR analysis of the MYRRHA accelerator-driven system [8].

- Elsewhere in the EU, the PR&PP methodology is also being applied for providing PR consideration within a European R&D project on a Sodium Fast Reactor [9].

IAEA INTERACTION

The PRPPWG has coordinated closely with the IAEA since its inception; i.e., there has always been an IAEA representative on 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 International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) PR assessment methodology [10], beginning with a comparison of the respective methodologies of the two organizations with an aim towards understanding how prospective users could benefit from each and from a joint application of the approaches. Some members of GIF have participated in INPRO projects and other IAEA projects in nuclear energy and safeguards which has provided a useful catalyst to further cooperation. Moreover the regular annual meetings between GIF and INPRO have provided an excellent forum for information exchange and for defining future collaborative efforts.

Work that has recently been initiated under INPRO's PROSA (Proliferation Resistance and Safeguardability Assessment) project will be monitored for potential application in the GIF program. One of the goals of PROSA is to develop a workable assessment approach that will potentially draw upon the GIF PR&PP methodology to fill gaps in the INPRO approach, leading to a unified process.

There are 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 non-proliferation provides "rules of good practice" for design concepts. It thus provides a useful checklist that ensures that technology assessors "did things right".
- The GIF/PRPP methodology is a systematic approach to evaluating vulnerabilities in design concepts. It thus provides the analysis approach that an INPRO assessment might utilize (as currently discussed in the PROSA project), and helps to make sure that assessors "did not do things wrong".

Together the methods could provide users with an overall approach to assuring robust future designs. IAEA/INPRO is more broadly known to IAEA community; GIF/PRPP provides a powerful analytical tool for evaluating strong and weak spots and therefore reducing proliferation risk in a design. Together, both products are potentially useful in national programs.

CURRENT SITUATION ASSESSMENT

Currently the PR&PP methodology is the most comprehensive publicly available evaluation methodology for any 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, noted above, was a pared-down implementation in this category.

Some observers are calling for a more simplified version of the PR&PP methodology to enable usage by newcomers. It is the view of the PRPPWG that, while it might be beneficial to create a high-level "guidance document" that lays out the steps to an evaluation and directs users to the relevant sections of the methodology, it is not advisable to simplify

the methodology itself for generic application, since this carries a risk of omitting relevant components. However, each evaluation should define its scope and goals including a possible tailoring of the needed approaches.

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 IAEA and by the EC, to promote and implement SBD in the nuclear facility design process. IAEA has efforts underway on SBD [11] and is likely to publish a guidelines document in 2012 and facility-specific guidance documents are expected to be published in 2013-14. As noted above, IAEA also has the PROSA program underway which will have relevance to SBD and PR&PP.

There is an increased emphasis world-wide on the development and deployment of small modular reactors (SMRs). Since some of the GIF designs are in the SMR category it will be important to maintain cognizance of issues and developments as they pertain to PR&PP. While some SMRs share many characteristics of relevance to PR&PP with conventional reactors, 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.

It will be important to maintain cognizance of post-Fukushima lessons-learned for their potential relevance to PR&PP.

A committee of the US National Academies is currently studying how methodologies for "proliferation risk assessment" relate to the needs and questions of policy makers in this area. Their findings and recommendation will be issued in March 2013.

FUTURE PR&PP ACTIVITIES

Working with GIF 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 emerging and viable 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 step for joint activity between the SSCs and the PRPPWG should be to designate one or two concept designs for an in-depth pilot study. This would involve applying the PR&PP methodology to the development of a model of the design and would be a follow-on effort to the initial joint studies between the PRPPWG and the SSCs that have been described above. The model would be rather high-level and attempt to capture the broad features of the design in terms of expressing its robustness for PR&PP characteristics. The pilot study would include participation by nuclear energy system designers as specified by the SSCs and members of the PRPPWG who would bring modeling expertise to the collaboration. In addition, subject matter experts in safeguards and physical protection would be needed to provide specific context for the development of the models.

This study could fit well within the scope of one of the GEN IV System Integration and Assessment (SIA) projects.

In the longer term, when the results and insights from these pilot studies become available, other GIF design concepts would also engage 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 cost-effectively provide for safeguards and security before the design has fully matured (and to thus avoid costly retrofits). This would ultimately be a useful approach to minimizing project risk for the emerging GIF concepts.

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.

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. 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 cross-cutting evaluation methodologies that are as generic as possible. The flexibility that allows non-GIF users to apply the PR&PP methodology also maintains the methodology's relevance to GIF design teams as specifications are modified.

***IAEA/INPRO*:** The PRPPWG will continue to coordinate with IAEA in areas of mutual interest (an immediate area of coordination being the PROSA project of INPRO). In general, the PRPPWG will maintain cognizance of developments in safeguards concepts and approaches, and assess and respond to any potential impact on the relevance of the PR&PP methodology.

***Continued interaction between the PRPPWG and the other GIF crosscutting groups**:* Coordination with the RSWG and with the Economics Modeling Group should be pursued to assure effective implementation of approaches in the GIF design. As noted earlier, the aggregation of PRPPWG and RSWG represents an implementation of the "3S" approach of the IAEA.

CONCLUSION

The PRPPWG has developed a mature evaluation methodology that is not only ready to assist GIF SSC's in making informed design choices based on PR&PP principles, but also represents the most comprehensive publicly available PR&PP evaluation methodology and can similarly inform the design process of any new nuclear technology.

The PR&PP methodology is aligned with international efforts to improve the effectiveness of and efficiency of safeguards. It represents an enabling tool for Safeguards by Design, and, in conjunction with the Reactor Safety Working Group of GIF, a natural manifestation of the so-called "3S" integration of Safety, Security, and Safeguards 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 maintaining cognizance of international developments and engagement of other groups within the international non-proliferation 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 to the broader nuclear community.

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REFERENCES

[1] *A Technology Roadmap for Generation IV Nuclear Energy Systems,* GIF002-00, December 2002. http://www.gen-4.org/Technology/horizontal/index.htm

[2]http://www.iaea.org/newscenter/news/2008/g8leaders.html

[3] PR&PP WG of GIF, Evaluation Methodology for Proliferation Resistance and Physical Protection of Generation IV Nuclear Energy Systems, Revision 6, September 15 2011, GIF/PRPPWG/2011/003,

http://www.gen-4.org/PDFs/GIF_PRPPEM_Rev6_FINAL.pdf

[4] PR&PP WG of GIF, PR&PP Evaluation: ESFR Full System Case Study Final Report, October, 2009, GIF/PRPPWG/2009/002. http://www.gen-4.org/Technology/horizontal/documents/PRPP_CSReport_and_Appendices_2009_10-29.pdf

[5] PR&PP WG and the SSCs of the, GIF Proliferation Resistance and Physical Protection of the Six Generation IV Nuclear Energy Systems, July 15 2011, GIF/PRPPWG/2011/002, http://www.gen-4.org/PDFs/GIF_PRPPWG_SSC_Report_FINAL.pdf

[6] R. A. Bari, L-Y Cheng, J. Phillips, J. Pilat, G. Rochau, I. Therios, R. Wigeland, E. Wonder, M. Zentner, "Proliferation Risk Reduction Study of Alternative Spent Fuel Processing Technologies," Proceedings of the 50th Institute of Nuclear Materials Management Annual Meeting, Tucson, AZ, July 12-16, 2009.

[7] J. Whitlock, "Incorporating the GIF-PRPP Proliferation Resistance Methodology in Reactor Design," Proceedings of the 51th INMM Conference, Baltimore, MD July 11-15, 2010.

[8] K. van der Meer, C. Turcanu, R. Carchon, "Non-Proliferation Assessment of the XT-ADS MYRRHA," ESARDA Bulletin No. 44, June 2010, pp. 17-28.

[9] See, for example, http://www.cp-esfr.eu/

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems, INPRO Manual - Proliferation Resistance, Volume 5 of the Final Report of Phase 1 of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), IAEA-TECDOC-1575 Rev. 1, IAEA Vienna, 2008' http://www-pub.iaea.org/MTCD/Publications/PDF/TE_1575_CD/PDF/TE_1575_vol5_2008.pdf

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Facility Design and Plant Operation Features that facilitate the Implementation of IAEA Safeguards, IAEA-STR-360, IAEA Vienna, 2009, <http://www.iaea.org/OurWork/SV/Safeguards/documents/STR_360_external_version.pdf