APPROACHES TO EVALUATION OF PROLIFERATION RESISTANCE OF NUCLEAR ENERGY SYSTEMS

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ABSTRACT

Over the past several years, the Generation IV International Forum (GIF) has been developing an evaluation methodology for proliferation resistance and physical protection (PR&PP) of nuclear energy systems[1], through collaboration between the countries and international organizations that participate in GIF. Generation IV nuclear energy systems are nuclear reactor technologies that could be deployed by 2030 and would present significant improvements over currently operating reactor technologies. The technology goals for GIF highlight PR&PP as one of the four goal areas, along with sustainability, safety and reliability, and economics. The PR&PP evaluation methodology that has been developed is a result of a consensus among the GIF participants, and has been approved by GIF for broad dissemination and use.

In parallel with this multilateral effort by GIF, and over the same time period, the International Atomic Energy Agency (IAEA) has been sponsoring development of an International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) to help to ensure that nuclear energy is available in the 21st century in a sustainable manner. In particular, INPRO has put forth basic principles, user requirements, and criteria for future nuclear energy systems, with similar broad goal areas to those that are being considered by GIF, including proliferation resistance and physical protection.

This paper describes an effort to address the compatibility and use of the two methodologies, starting with proliferation resistance, in order to more fully understand and articulate the range of applicability and the potential for synergy in their application. “Proliferation resistance” evaluation is in its early stages, and on-going efforts to use the methodologies to assess particular fuel cycles or facilities will shed further light on what proliferation resistance means, how best it can be assessed, and their value to policy-makers, facility designers and users of nuclear facilities. The authors of this paper report on the status of progress on this effort, particularly with regard to the respective objectives, analysis approaches, input requirements, form of results and end uses. The views expressed herein are those of the authors, and do not necessarily reflect the views of the Department of Energy or its laboratories, the IAEA, Atomic Energy of Canada Limited, or the European Commission-Joint Research Centre.

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[1] A Generation IV nuclear energy system includes a nuclear power producing plant and the facilities necessary to implement its related fuel cycle.

INTRODUCTION

In the past, "proliferation resistance" was a widely used term that lacked a standard definition. INPRO and GIF methodologies now employ a common, internationally accepted definition of proliferation resistance: "*… that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material or misuse of technology by States in order to acquire nuclear weapons or other nuclear explosive devices"* (Ref 1). National proliferation threats posed by the host State are carefully distinguished from the potential security threats posed by non-host-State actors. The latter are treated separately as a part of physical protection rather than under "proliferation resistance."

Importantly, this definition of proliferation resistance focuses on the degree to which the characteristics of a nuclear energy system *impede* proliferation. *Proliferation resistance, in this context, should not be construed as implying that development of a nuclear explosive device using a proliferation resistant system is impossible (i.e., that the system is "proliferation-proof").* The degree of proliferation resistance results from a combination of technical design features, operational modalities, institutional arrangements and safeguards measures (Ref. 1). In particular, effective international safeguards are an essential component of proliferation resistance, and proliferation resistance should not be viewed as a substitute for the highest standards of international safeguards, or for other proliferation prevention tools such as effective export controls arrangements.

Proliferation resistance is a multi-faceted concept. It is important not to overstate the significance of minor changes in elements such as "material attractiveness" or "technical sophistication," and to consider possible interaction between all facets of a nuclear energy system. Care must be taken in considering differences in material attractiveness and material type, in the context of proliferation resistance. Also, designs to accommodate effective international safeguards and domestic safeguards and security measures must be maintained at any facility that produces nuclear material that can be used in a nuclear weapon or other nuclear explosive device. Proliferation resistance thus is not a substitute for effective safeguards and security, nor is it a substitute for such elements of the nonproliferation regime as export controls and careful consideration of where particular facilities are located.

METHODOLOGY DESCRIPTIONS

The INPRO proliferation resistance assessment methodology is structured in the same fashion as other INPRO assessment methodologies (economics, safety, etc.), employing a hierarchical structure of top-level basic principles, user-requirements, indicators, evaluation parameters and acceptance limits. The INPRO approach (Ref. 2) is primarily designed for nuclear energy system *users* (and thus guides the INPRO assessor in confirming that adequate proliferation resistance has been achieved in the nuclear energy system under consideration), but it can also give guidance to the *developer* of nuclear technology on how to improve proliferation resistance. The INPRO proliferation resistance approach identifies a *Basic Principle of Proliferation Resistance* and five *User Requirements* for meeting this Principle, along with seventeen indicators with specific criteria and acceptance limits. Assessors review the non-proliferation characteristics of the nuclear energy system in a given State to determine how well the requirements are met. An

INPRO *assessment* may require additional *analysis* to provide information needed to determine whether some of the user requirements are met.

The GIF approach (Ref. 3) considers a nuclear energy system primarily from the standpoint of the designer of the system and identifies specific proliferation *challenges*, *system responses*, and *outcomes*. A "*pathway analysis*" is performed to identify acquisition *scenarios* that a State could pursue to obtain nuclear weapons by taking advantage of its peaceful nuclear materials and facilities. Six proliferation resistance *measures*, which follow from the GIF technology goals, have been identified to quantify and compare pathways. Metrics that enable the evaluation of the GIF measures are also provided in the methodology. Analysts may use qualitative, semi-quantitative, or quantitative analyses to estimate these measures. The results are intended for three types of users: system designers, program policy makers and external stakeholders. Program policy makers will likely be interested in high-level results that discriminate among choices, while system designers will be more interested in information that directly relates to design options that will improve proliferation resistance of the nuclear energy system.

It is important to note that neither approach is limited in application to the specific context (INPRO or GIF) in which it was developed. For example, one could use either approach to assess the proliferation resistance of both existing and future nuclear energy systems.

SIMILARITIES

The approaches share certain similarities, beginning with a common definition of proliferation resistance. Both approaches have a hierarchal analytical structure involving proliferation resistance principles, high-level evaluation factors and multiple measures or criteria related to each high-level factor. Both approaches treat proliferation resistance as a function of multiple *extrinsic measures* (e.g. safeguards, etc.) and *intrinsic features* (e.g. material attractiveness, etc.), and characterize proliferation resistance in terms of each (Figure 1). Both approaches recognize the concept of *barriers* to proliferation, but implement the concept differently. Neither approach aggregates its results into a single numerical value or grade, so that strengths and weaknesses under each of the main evaluation criteria are explicitly considered. Both approaches are primarily technical evaluations that incorporate institutional and policy contexts for the systems under consideration.

DIFFERENCES

There are several notable differences between the two approaches. The INPRO approach focuses on the proliferation resistance of a declared, safeguarded nuclear energy system in a specific State, and implicitly excludes from the analysis clandestine facilities (including those that might be needed to complete a proliferation pathway) or a breakout scenario (in which a facility is *overtly* misused for proliferation purposes). In comparison, the GIF approach considers both declared and undeclared facilities and activities, to complete the proliferation pathway from acquisition and processing of material to fabrication of a nuclear explosive device as well as overt misuse following breakout.

INPRO examines the whole system, sets explicit User Requirements, and asks how the system meets these User Requirements. In particular, INPRO explicitly takes into account a State's non-proliferation commitments and agreements in one of its User Requirements (UR1). In the GIF approach these commitments are treated implicitly in estimating the GIF *detection probability* measure of a segment or of a pathway. The GIF approach lends itself to comparing the relative proliferation resistance of different nuclear energy systems. A GIF analysis involves separation of a system into components (system elements) and performing a pathway analysis that provides the basis for a proliferation resistance evaluation.

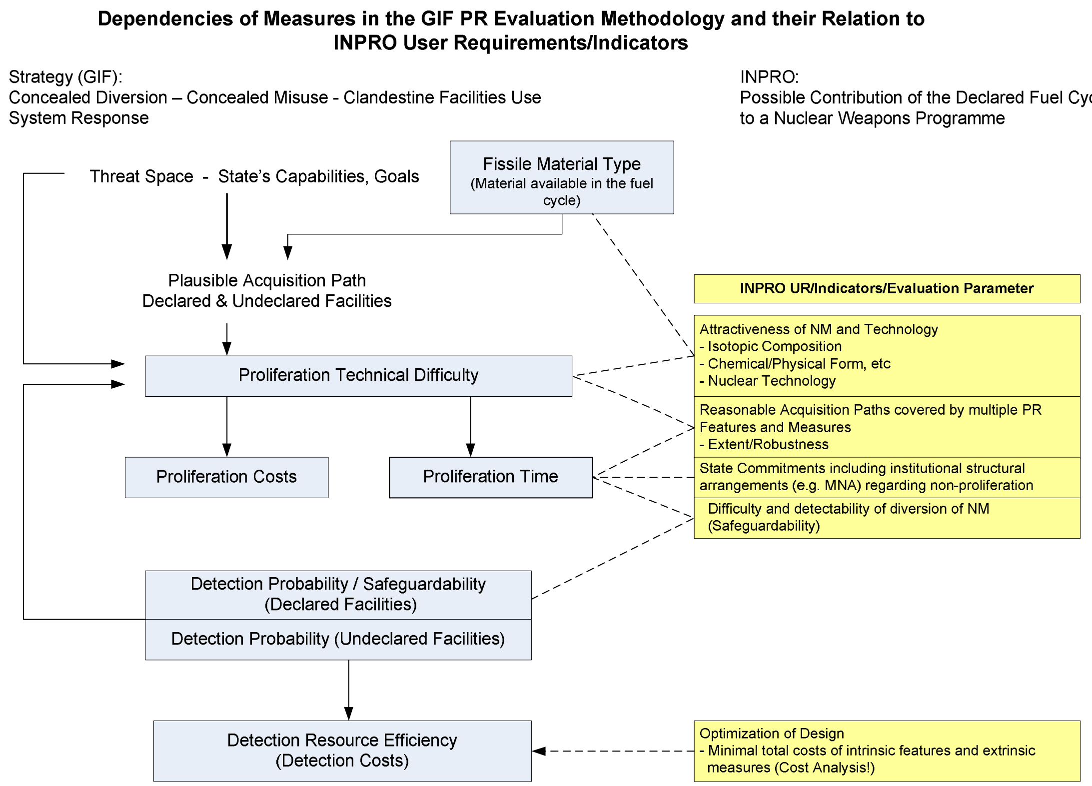

Figure 1

COMPATIBILITIES

At the highest level, the INPRO Basic Principle and the GIF Technology Goal of proliferation resistance manifestly parallel each other. While each has a different emphasis, the results of either can also be used to provide guidance and insight. The results of each can and should be used to ensure that proliferation resistance goals will be met for nuclear energy systems.

Both approaches treat proliferation resistance as a multi-faceted issue. The degree of proliferation resistance found in a system using either approach will reflect strengths and weaknesses against all evaluation parameters, although how best to communicate such results to varying audiences remains an area for further refinement. Both approaches endorse the need for proliferation resistance considerations to be taken into account as early as possible in the design and development of a nuclear energy system. Finally, the results of either approach should demonstrate how an optimal combination of intrinsic features and extrinsic measures, compatible with other design considerations, e.g., operations, safety, and security, can be achieved in a nuclear energy system.

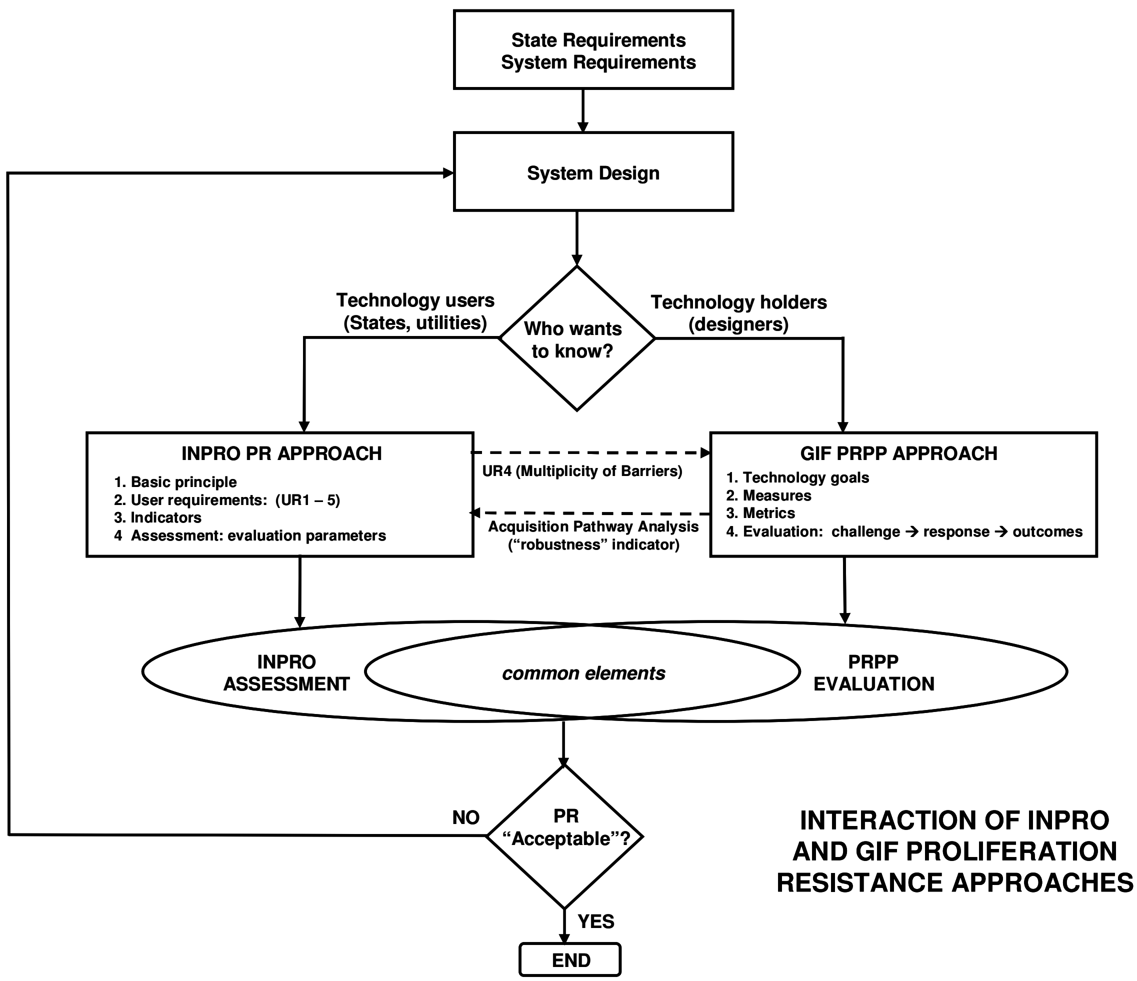

Figure 2

There are areas in which one method can productively be used in conjunction with the other (see Figure 2). For example, User Requirement IV of the INPRO methodology stipulates that there should be both *multiple* and *robust* barriers to proliferation for each reasonable proliferation pathway. However, the INPRO method does not describe how the robustness of these barriers should be evaluated. The GIF pathway approach is well-suited to conduct such evaluations; however, a means must be developed that allows an effective interface between the two approaches at this level (for example, compatibility of the INPRO evaluation parameters and GIF metrics must be examined).

POTENTIAL USERS OF RESULTS OF STUDIES

Table 1 lists categories of decision makers who may need information about the proliferation resistance of nuclear energy systems and describes illustrative uses of proliferation resistance information by each type of user. This table is a "strawman" formulation intended to stimulate discussion regarding how proliferation resistance information can be used to make various kinds of decisions, and as a basis for further elaboration of both end-user and user information needs that application of proliferation resistance methodologies might help meet. The following is a reference set of users whose decisions might be informed by the results of proliferation resistance assessments:

a. Government officials, including Energy Ministry officials, Foreign Ministry Officials and Legislative officials responsible for program approvals and funding appropriations;
b. National licensing and regulatory authorities, and export control authorities, for State exports, State imports and indigenous development;
c. IAEA safeguards authorities and other safeguards inspectorates;
d. Industrial designers/producers/vendors; and
e. Utility owners and operators.

Decisions made by these authorities will set priorities for the activities of the nuclear energy system designers. The context in which the officials and authorities function must take into account:

a. Proliferation resistance decisions likely to be made over the life-cycle of a nuclear energy system, from concept selection, system design, system engineering, prototype development and evaluation, export arrangements, system performance reviews, system upgrades;
b. Information needed to make decisions (including the type and quality of information vs. time). Since decisions are likely to be repeated over time as knowledge and circumstances vary, an approach for how such factors should be taken into account to facilitate knowledge acquisition and experience must be established; and
c. How that information can best be developed, managed, and presented.

FUTURE WORK

One of the next steps in this process is to demonstrate how information about the proliferation resistance of nuclear energy systems, including an understanding of relevant strengths and vulnerabilities of a system using either the INPRO or GIF proliferation resistance approach, can be effectively interpreted and communicated to those who need this information. As one such approach to interpreting results, a set of relevant questions of interest to decision-making officials and authorities concerning the proliferation resistance of particular nuclear energy systems could be developed. Assessments that address these questions may uncover needed system changes, additions or deletions.

Table 1. Users and Uses of Proliferation Resistance Information

Potential Users of a Proliferation Resistance Assessment and Evaluation Methodology	Illustrative Uses of Proliferation Resistance Information
Government officials, including Energy Ministry officials, Foreign Ministry Officials and Legislative officials responsible for program approvals and funding appropriations	a. Ensuring provision of sustainable energy supply from safe, secure, economic and proliferation resistant sources. b. Basing nuclear export control decisions on well-understood and assessed proliferation threats
National licensing and regulatory authorities, and export control authorities, for State exports, State imports and indigenous development	a. Developing guidance on and validation of effective and efficient implementation of proliferation resistance/safeguards requirements in design and operation b. Providing basis for cooperation with regional and international safeguards authorities
IAEA safeguards authorities and other safeguards inspectorates	a. Providing understanding of the role of safeguards measures in proliferation resistance b. Ensuring that facility design and operation facilitate the implementation of safeguards
Industrial designers/producers/vendors	a. Employing usable guidance for effective and efficient implementation of proliferation resistance/safeguards requirements in design and operation b. Ensuring that there are transparent acceptance procedures with assessable cost impacts
Utility owners and operators	a. Enhancing public acceptance of nuclear energy production b. Providing transparent means for demonstrating that perceived threats are adequately controlled c. Optimizing extrinsic and intrinsic proliferation resistance measures with facility safety, operations, and cost

In addition, a common understanding of INPRO Evaluation Parameters and GIF Measures, such as those related to material attractiveness, is needed to ensure that the two methodologies are used consistently. A joint application of the two methodologies to analyze INPRO User Requirement 4, which addresses the need to assess the multiplicity and robustness of barriers, can demonstrate how the methodologies can be used in a complementary manner to complete a full proliferation resistance assessment. Such an analysis is currently underway through an INPRO Collaborative Project, and the results of that study will inform this work.

On-going proliferation resistance analyses are generating valuable lessons-learned concerning how to apply and use the methodologies, and how to meet the needs of different classes of end-users. Considerable work remains in refining proliferation resistance analysis and interpreting the results. The challenge, however, is not simply one of technique. "What" is being communicated is more important than "how" it is being communicated. As the term "proliferation resistance" comes into vogue and proliferation resistance assessment methodologies mature, there will likely be multiple interpretations of what proliferation resistance means, and how the concept should or should not be used in decision-making. Both the GIF and INPRO proliferation resistance user communities will need to confront this challenge, and provide support to the effective use of the terminology and the methodologies.

Over the next few years, important contributions of proliferation resistance assessment will be 1) demonstrating the complexity of proliferation resistance and strengths and weaknesses of the concept and the methodologies, 2) characterizing the relative proliferation resistance risk of proposed fuel cycle systems and facilities, 3) reinforcing the importance of incorporating effective safeguards and barriers to diversion of nuclear materials into the design of new facilities, from the pre-conceptual design stage onwards, and 4) incorporating proliferation resistance in decision-making on such matters as safeguards, process and design selection, and technology exports. If the experience with the evolution of *safety analysis* from the early deterministic to more current risk-based approaches is any guide, this process of using and refining proliferation resistance methodologies and analytical tools will take considerable time. Until more experience is developed in conducting proliferation resistance analyses, it is important to exercise caution in using the proliferation assessment methodologies to draw definitive conclusions about the proliferation resistance of nuclear energy systems.

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