PROLIFERATION RESISTANCE AND PHYSICAL PROTECTION CROSSCUTTING TOPICS
Application to GIF GEN IV Energy Systems and to Siting Study for AMRs and Microreactors

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INTRODUCTION: The Proliferation Resistance and Physical Protection Working Group of GIF has recently revised its white papers of the six energy systems under consideration and has identified crosscutting topics. A new study on siting for advanced modular reactors (AMRs) and microreactors is currently ongoing and has also led to identify crosscutting topics. This contribution details these crosscutting topics and provides salient features. The PR&PP WG of GIF also contributes two other studies for this IAEA Technical Meeting [1, 2].

1. OVERVIEW: REVISION OF THE 6 PR&PP WP OF GIF ENERGY SYSTEMS

The Generation IV International Forum (GIF) is an international initiative set up to perform R&D on six selected reactor technologies: Gas-cooled Fast Reactor (GFR), Lead-cooled Fast Reactor (LFR), Molten Salt Reactor (MSR), Super-Critical Water Reactor (SCWR), Sodium Fast Reactor (SFR), Very High Temperature Reactor (VHTR).

The Proliferation Resistance and Physical Protection Working Group (PRPPWG) was established by GIF to develop, implement and foster the use of an evaluation methodology (PRPPEM) to assess Generation IV nuclear energy systems with respect to the GIF PR&PP goal, whereby "*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*" [3]. The PR&PP evaluation methodology (PRPPEM) provides designers and policy makers a technology neutral framework and a formal comprehensive approach to evaluate, through measures and metrics, the proliferation resistance (PR) and physical protection (PP) characteristics of advanced nuclear energy systems.

The PR&PP features of each of the six GIF reactor technologies were studied collaboratively between the PRPPWG and the System Steering Committees and provisional System Steering Committees (SSCs/pSSCs), resulting in a report published in 2011 containing the six white papers [4]. In 2017, the GIF PRPPWG, the SSCs and pSCCs started to update these white papers. This task has been completed with the release of six new white papers: SFR [5] and LFR [6] in 2021, GFR [7], SCWR [8], and VHTR [9] in 2022, and MSR [10] in 2023.

2. CROSSCUTTING TOPICS FOR GIF GEN IV ENERGY SYSTEMS

In the process of updating the PR&PP white papers of the six reactor technologies, it became clear that several topics crosscut all the considered systems. Crosscutting topics may either be common to all the

various system designs or crosscutting with similar themes across all system designs. As a consequence, an additional companion document has been issued, in 2022, to cover these topics and describe the impact on PR&PP [11]. The 12 crosscutting topics deal with reactor design aspects, fuel cycle and grid compatibility, and finally common interfaces. The table below (Table 1) provides a high-level overview of the considered aspects and some of the high-level findings:

TABLE 1. CROSCUTTING ASPECTS AND HIGH-LEVEL KEY MESSAGES

Aspect considered	High-level key messages
Crosscutting Reactor Design Aspects	
Fuel Type	Fuel type affects theft difficulty and material attractiveness; certain fuels pose challenges for accounting and reprocessing
Coolant/Moderator/reflector	Coolant properties impact inspection ease and sabotage protection.
Refueling Modes	Refueling modes influence opportunities for fuel diversion and verification needs.
Small Modular and Microreactor Options	Small modular and microreactors present unique safeguards and protection challenges due to deployment and operational factors
Fuel Cycle and Grid Compatibility	
Fuel Cycle Architecture	Fuel cycle architecture varies with the considered options, but fuel fabrication is needed by all options and co-location of reactor and back-end on the same site affects Nuclear Material transport and the site PP.
Life Cycle	Safeguards and Security must consider the entire reactor lifecycle
Flexibility	Operational flexibility has limited impact on PR&PP but increased reactor numbers and siting near populations raise protection challenges.
Commons Interfaces	
Safeguards Topics	Traditional safeguards may suffice for evolutionary designs; novel designs require new approaches.
Cyber Threat	Cybersecurity involves risk management, secure systems, data transparency, and supply chain integrity
Operational Transparency	Automation enhances transparency and safeguards effectiveness through secure data sharing
Safety Interface	Integration of safety, security, and safeguards can improve protection against sabotage and theft
Economics	PR&PP costs are relatively small but influence economics; early design integration and innovative protection methods are important

3. CROSSCUTTING TOPICS FOR SITING STUDY FOR AMRS AND MICROREACTORS

The 2022 GIF Industry Forum [12], October 3-7 2022, Toronto, Canada, was an opportunity to present the PRPPWG work and to receive feedback from industry. *Inter alia*, the industry suggested a PR&PP analysis of different siting options and locations for advanced reactors. The PRPPWG has consequently undertaken a dedicated study on this subject, focussing mainly on Generation IV Advanced Modular Reactors. It is worth noticing that many outcomes of this study also apply to light-water based SMRs. The main deployment options that have been studied are Siting in Remote Locations, Siting Near Population Centers, Floating or Underwater Power Stations, Civilian Marine Propulsion. The crosscutting topics emerged from this study are summarized in Table 2. This study should be published in 2025 [13].

TABLE 2. CROSSCUTTING TOPICS DISCUSSED IN THE AMR SITING REPORT

Crosscutting topic	Aspects discussed
Single vs multi-modules	Less movement of technology and fuel for single module site
	Specific physical protections issues for multiple constructions on one site
Ultimate heat sink	Consequences on proliferation resistance depending on the nature of the ultimate heat sink (air or water)

	Loss of decay heat removal systems is a concern in a sabotage scenario
Autonomous and remote operation	Unattended monitoring systems and remote transmission of data are crucial (international safeguards and cybersecurity)
	Cyber threats
High assay low enriched uranium (HALEU) versus Low enriched Uranium (LEU)	Slightly higher material attractiveness of HALEU as compared to LEU
	Differences in protection strategies in fuel cycle facilities and transportation of the fuel depending on the country policy
Transit of reactors	Reactor shipment with and without fuel
	Cost-benefit analysis to determine the optimal number of shipments
	Mode of transportation (roads, rail, water, or air) and impact on physical protection
	Transportation in an urban setting brings different problems compared to transportation in remote areas and across country borders

4. CONCLUSION

While each of the six GIF reactor technologies has its peculiarity and specificity, for all of them effective proliferation resistance and physical protection (PR&PP) require early integration of their needs and provisions into reactor design, considering fuel type, operational modes, and lifecycle. Evolving technologies and deployment models introduce new safeguards and security challenges, particularly in cyber, automation, as well as siting and deployment options for AMRs. The crosscutting topics that have been identified while revising the six PR&PP White Papers of the GIF energy systems and while studying the siting aspects for AMRs and microreactors have been here briefly listed, together with some related high-level findings.

5. APPENDIX: GIF PRPPWG MEMBER LIST AS OF MARCH 11TH, 2025

TABLE 3. GIF PRPPWG MEMBER LIST

Country/organization	status
EURATOM	
NAVA, Elisabetta	Member
RENDA, Guido	Co-chair
INTERNATIONAL ATOMIC ENERGY AGENCY	
SCHERER, Carolynn P.	Observer
CANADA	
CHAUDHURI, Ankur	Member
VAN DER ENDE, Bryan	Member
CHINA	
BAI, Lei	Member
HUANG, Shenghui	Member
WANG, Liming	Member
ZONG, Bo	Member
FRANCE	
NGUYEN Frédéric	Co-chair
JAPAN	
SHIBA, Tomooki	Member
KOREA	
AHN, Seong-Kyu	Member
CHO, Seong-Youn	Member
JUNG, Young-Eun	Observer
LEE, Joung-Hoon	Observer
SOUTH AFRICA	
BOHLOLO, Jones	Member

UNITED KINGDOM	
GROVE, Christopher	Member
HESKETH, Kevin	Observer
HOLMES, Christopher John	Member
UNITED STATES OF AMERICA	
CHENG, Lap-Yan	Observer
CIPITI, Ben	Co-chair
CROFT HOLT, Katherine	Observer
IYENGAR, Anagha	Observer
OTTO, Robert (Ty)	Observer
SCOTT, Logan	Member
SMITH, Ruth	Observer
NUCLEAR ENERGY AGENCY	
OZERETZKOVSKY, Alexiei	Secretary

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