Chapter 5. **Methodology Working Groups**

EMWG: Economic Modelling Working Group

The Economic Modelling Working Group (EMWG) was established in 2003 to provide a methodology for the assessment of the Generation IV systems against the two economic-related goals as follows:

- To have life cycle cost advantage over other energy sources (i.e. to have a lower levelized unit cost of energy); and
- To have a level of financial risk comparable to other energy projects (i.e. to have similar total investment cost at the time of commercial operation)

In 2007, the EMWG published the Cost Estimating Guidelines and an Excel-based software package G4ECONS v2.0 for calculating two figures of merit; the levelized cost energy and the total investment cost, to assess the Generation IV systems against GIF economic goals. These EMWG tools were made available to the public trough GIF Technical Secretariat which resulted in several publications demonstrating the EMWG methodology for economic assessments of Generation III and Generation IV systems, as well for the cogeneration applications such as hydrogen production.

G4ECONS v2.0 was also benchmarked against the economic tools of the International Atomic Energy Agency (IAEA); namely the Nuclear Economics Support Tool (NEST) and the Hydrogen Economic Evaluation Program (HEEP) and the results have been published in peer-reviewed publications [2, 3]. The lessons learnt from the benchmarking exercise and the feedback from the users informed the refinement of the G4ECONS tool. The EMWG released the new version, G4ECONS v3.0, with improved user interface, in October 2018.

In 2016, the EMWG started to investigate the challenges and opportunities for deployment of the Generation IV systems in the emerging energy markets with increasing share of renewable energy resources. The terms of reference for the EMWG were amended in 2018 to incorporate the expanded mandate to inform the GIF Policy Group and the Experts Group on the policies and the research and development needs for the future deployment of Generation IV systems.

Since October 2016, the EMWG worked collaboratively with the Senior Industry Advisory Panel (SIAP) to investigate challenges and opportunities for deployment of Generation IV systems in the electricity markets with significant penetration of renewable energy resources, and produced a position paper for the Policy Group. An abridged version of the EMWG position paper on the impact of increasing share of renewables on the deployment prospects of Generation IV systems was presented at the 4th GIF Symposium and an executive summary has been posted on the GIF external website. The study found that the Generation IV systems will have to be more flexible compared to the current reactors for deployment in the low-carbon energy systems and such requirements are already being proposed by the utilities. Large-scale energy storage and cogeneration applications would allow flexible dispatch, while ensuring high capacity utilization. Nuclear-renewable hybrid energy systems with adequate energy storage and cogeneration applications could, thus, meet the flexible demand from the grid while operating the power generators to full capacity to ensure overall economically viable operation. However, such flexibility considerations impose additional requirements on the research and development of Generation IV systems.

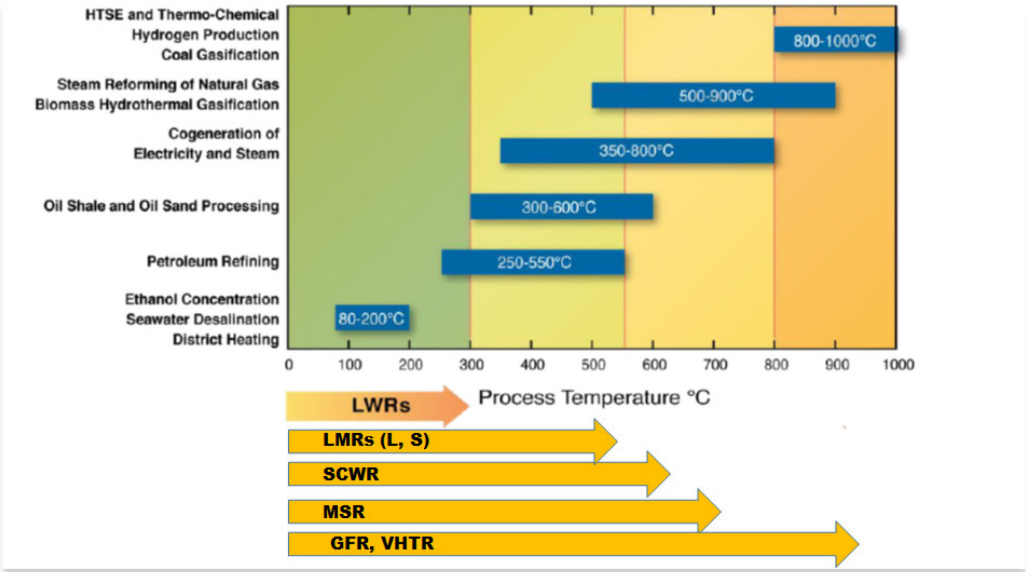
Activities in 2019

Main focus of the EMWG activities in 2019 was on flexibility considerations for the Generation IV systems. The advanced Generation IV reactors are significantly different compared to Gen III reactors. The Generation IV reactors use different fuels, different coolants and operate at higher temperatures, making the reactors suitable for applications beyond electricity production. Therefore, to evaluate the flexibility of Generation IV type reactors, Electrical Power Research Institute (EPRI) developed expanded flexibility criteria and proposed Technology Readiness Scales for Advanced Reactors, such as Generation IV systems. EPRI's expanded flexibility criteria consists of a set of three sub-criteria or attributes, as follows:

- operational flexibility;
- deployment flexibility;
- product flexibility.

Using these as a basis, EMWG developed a questionnaire to gather information on the extent to which the flexibility aspects are being addressed in the research and development of the six Generation IV systems. Subsequently, a workshop was held in May 2019 with the joint participation of the representatives of the six System Steering Committees, the SIAP, and the EMWG to discuss the R&D needs for flexibility and to identify opportunities for cross-cutting R&D. All Generation IV systems are being developed to be more flexible compared to the Generation III systems in terms of deployment flexibility (scalability and constructability) and the product flexibility (cogeneration applications). All Generation IV systems have higher outlet temperatures and thus are amenable to provide thermal energy for multiple industrial applications as shown in **Figure EMWG 1**.

Figure EMWG 1. **Product Flexibility of Generation IV Systems**



The evaluation of the operational flexibility requires validation through multi-dimensional physics calculations and can be performed after the systems are developed to sufficiently high technological readiness level. The EMWG produced a position paper based on the outcome of the questionnaire survey and the joint workshop and made recommendations to the Experts Group to provide guidance to the system developers to include flexibility requirements as part of the R&D, and to identify opportunities for cross-cutting R&D among the six Gen-IV systems. The EMWG also documented the capabilities of various economic models available for optimization of nuclear-renewable integrated systems.

To accompany the latest version G4ECONS v3.0 released in late 2018, training slides were prepared and are available for use by the GIF community.

Finally, the EMWG developed a set of Frequently Asked Questions and Answers for the GIF external website encompassing a wide range of related topics, including the use of the EMWG tools, benchmarking, figures of merit for economic assessment and external factors affecting the economic viability of nuclear, such as, integration with renewables, flexibility requirements and the system costs.

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PRPPWG: Proliferation Resistance and Physical Protection assessment methodology Working Group

The Generation IV Roadmap defined the following Proliferation Resistance and Physical Protection (PR&PP) goal for future nuclear energy systems:

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.

The Proliferation Resistance and Physical Protection Working Group (PRPP WG) was created to develop, implement and foster use of an evaluation methodology to assess Generation IV nuclear energy systems with respect to the GIF PR&PP goals. The current version of the methodology is presented in a document entitled Evaluation Methodology for Proliferation Resistance and Physical Protection of Generation IV Nuclear Energy Systems, Rev. 6, which was released for general distribution in 2011.

The methodology provides designers and policy makers a generic and formal comprehensive approach to evaluate, through measures and metrics, the Proliferation Resistance (PR) and Physical Protection (PP) characteristics of advanced nuclear systems. As such, the application of the evaluation methodology offers opportunities to improve the PR and PP robustness of system concepts throughout their development cycle. Other major outcomes from the group are available to the GIF community and more broadly through the GIF public website, including the Example Sodium Fast Reactor (ESFR) Case Study Report. The compendium report with white papers on the PR&PP characteristics of each of the six GIF nuclear energy systems prepared with the SSCs, and a set of Frequently Asked Questions and materials from workshops. In 2016 PRPPWG launched a questionnaire for the SSCs to assess the need to update the white papers. A joint SSCs-PRPPWG workshop was then held at the OECD NEA in Paris, April 2017. The PR&PP WG and the six SSCs/pSSCs are currently in the process of updating the six white papers to reflect changing and updated designs and new work on several of these systems.

As a first task the template for the white papers was updated. The SSCs updated first the description of the systems, considering both changes occurred in designs and new designs not considered in the 2011 white papers. After having updated the systems description, the PRPPWG, in collaboration with the SSCs, started updating the parts related to the PR and PP features of the considered designs. For each design option, the PRPP evaluation begins by identifying the relevant system elements with respect to potential adversary targets and applicable safeguards and physical protection approaches. The evaluation then proceeds to assess the design against potential threats using the technical design information to gauge the response of the system. A first draft, providing an overview of technology characteristics and status of design development for each of the six GIF systems was completed by the SSCs/pSSCs in the fall of 2018. A special session with the SSCs/pSSCs was held during the 29th meeting of the PRPPWG, in Oc. 2018. Members of the collaborative team provided status updates on the PR&PP white papers. A roundtable discussion identified information gaps in the white papers and the team developed a work plan to address all parts of the white papers in 2019. In 2019, the PRPPWG focused its activities on:

- continuing collaborative work with SSCs/pSSCs in the updating the white papers on PR&PP aspects of the six GIF systems;
- publicising the methodology and its applications within and outside GIF; and
- monitoring related activities in the areas of proliferation resistance and physical security for their relevance to the GIF programme.

An updated draft of the white papers was completed in November 2019 and an in-depth review of each white paper was planned for the 30th meeting. **Table PRPP 1** presents the high-level structure of the white papers.

During this meeting an extended working session of one and a half days was dedicated to the revision and discussion of the PR&PP white paper updates. Each PRPPWG Point of Contact for the six GIF systems had to:

- introduce the paper, and the reason for the update with regard to the 2011 version; to point out the main differences with regard to the 2011 version;
- illustrate the paper structure and content; drive the discussion on the paper, in general and section by section; execute a deep dive in the papers and get feedback; illustrate missing parts and propose a way forward and timeline;
- propose topics for cross-cutting considerations and availability to lead their investigation.

An observer from the IAEA and a representative from the RSWG also attended the meeting.

Table PRPP 1. **High-level structure of the updated SSCs/pSSCs PR&PP white papers**

Section	Type of Information
Overview of Technology	*Description of the various design options in terms of their major reactor parameters, such as: core configuration, fuel form and composition, operating scheme and refueling mode, fresh/spent fuel storage and shipment, safety approach and vital equipment, physical layout and segregation of components, etc.*
Overview of Fuel Cycle(s)	*High-level description of the type, or types, of fuel cycles that are unique to this Gen-IV system and its major design options. Information such as recycle approach, recycle technology, recycle efficiency, waste form(s)*
PR&PP Relevant System Elements and Potential Adversary Targets	*For each design option, identification and description of the relevant system elements and their potential adversary targets, safeguards and physical security approaches*
Proliferation Resistance Features	*High-level, qualitative overview developed jointly by the SSC and the PR&PP working group, to identify and discuss the features of the system reference designs that create potential benefits or issues for each of the representative proliferation threats. Ideally the section should highlight the response of the system to a) the concealed diversion or production of material, b) the use of the system in a breakout strategy, and c) the replication of the technology in clandestine facilities*
Physical Protection Features	*High-level, qualitative overview developed jointly by the SSC and the PR&PP working group, to discuss those elements of the system design that create potential benefits or issues for potential subnational threats, with specific discussion on the general categories of PP threats (a) theft of material for nuclear explosives or dispersal device and b) radiological sabotage)*
PR&PP Issues, Concerns and Benefits	*Review of the outstanding issues related to PR&PP for the concepts and their fuel cycles, the areas of known strength in the concept, and plans for integration and assessment of PR&PP for the concept. This section would ideally terminate with a bullet list of identified PR&PP R&D needs for the system concept*

The white paper team is preparing a new draft of the white papers incorporating review comments that arose during the review sessions. The team expects to release a final draft for approval by the SSC/pSSC by spring 2020. In addition to the peculiarities of each of the six GIF reactor technologies, addressed by the corresponding White Papers, there are topics that are common to all the six families. The 2011 white papers identified some of the cross-cutting areas, but others are being identified in the course of the update. Cross-cutting topics will be dealt with in the course of 2020.

In 2019, new members were nominated to the PRPPWG, two representatives from the United Kingdom, one additional representative from Canada and two substitute observers from Korea.

The working group continues to publicise its methodology within and outside the GIF through presentations in national and international fora and publications in scientific journals. The group contributed papers on PR&PP to the 4th GIF Symposium 2018, the IAEA Symposium on International Safeguards 2018, the 41st ESARDA Annual Meeting Symposium on Safeguards and Nuclear Material Management 2019. Presentation of the work of PRPPWG, its methodology and its results at these international fora provided opportunities to discuss with other experts and get feedback on its perceived benefits and drawbacks and potentials for its improvement and collaboration.

In support of knowledge management, the group maintains a bibliography providing a comprehensive list of publications in scientific journals and papers presented at major international conferences, covering all aspects of the PR&PP methodology and its applications within and outside GIF). The 2019 revision of the bibliography is near completion.

Within GIF, collaboration with the Risk and Safety Working Group (RSWG) was strengthened by personal exchanges at each group's meeting. Topics for further discussion between the two groups were identified including: establishment of an integrated framework encompassing the RSWG and PRPPWG methodologies, and identification of synergies and complementarities in the two approaches and evaluations, such as the interface between safety and security.

In its engagement with the IAEA, the PRPPWG maintains regular exchanges with the IAEA INPRO Project and the agency's Department of Safeguards. An observer in the working group from the IAEA, made several presentations for the special session with the SSC at the 29th PRPPWG Meeting covering safeguards needs for Gen-IV reactors, GIF-IAEA interactions and IAEA INPRO update.

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RSWG: Risk and Safety Working Group

The Risk and Safety Working Group (RSWG) was established in 2005 to provide a harmonized approach and consistent methods for risk and safety assessments of six Gen-IV systems. Since its inception, the RSWG proposed a set of broad safety principles, objectives, and attributes based on GIF safety and reliability goals, as input to R&D plans for specific Gen-IV design tracks (see 2008 report on Basis for Safety Approach):

- developed a technology-neutral Integrated Safety Assessment Methodology (ISAM) to ensure a consistent process to address risk and safety;
- supported the implementation of ISAM for specific Gen-IV design tracks as a toolkit for the entire design cycle from concept development to basic design and licensing;
- established technical interfaces with the International Atomic Energy Agency (IAEA), OECD/NEA's Committee on Nuclear Regulatory Activities (CNRA) Working Group on Safety of Advanced Reactors (WGSAR), and other national regulatory stakeholders and designers.

The RSWG membership currently includes representatives from Canada, China, France, Japan, South Africa, Russia, United Kingdom, and United States as a mixture of designers and regulators forum. The group holds biannual meetings. It proceeded to:

- an update of 2008 version of GIF Basic Safety Approach to reflect the lessons learnt from the Fukushima Daiichi accident;
- interface with GIF PR&PP and ETTF working groups; and
- organize a new joint initiative with WGSAR on development of a technology-inclusive risk-informed approach for selection of licensing basis events and safety classification of systems, structures and components common to Gen-IV systems.

The ongoing RSWG collaborations with the SSCs include:

- development of white papers on pilot application of ISAM to assess its usefulness for self-assessment of select Gen-IV design tracks;
- preparation of system safety assessment reports as summaries of the current state of high-level safety design attributes/challenges and overview of remaining R&D needs after the first decade of system development under GIF; and
- contributions to development of safety design criteria for each system.

By the end of 2019, all but one of the white papers are completed and only MSR white paper pending MSR pSSC revision based on RSWG feedback. The system safety assessment reports for SFR, VHTR, SCWR systems are also completed while the LFR and GFR reports are both pending SSC update based on RSWG feedback. The completed white papers and system safety assessments reports are published and can be accessed through the GIF RSWG public web page. Other than the SFR system (as completed by the SDC-TF), the process for development of safety design criteria is in various stages of preparation for other Gen-IV systems.

The ongoing GIF Basic Safety Approach report update aims to capture the needed revisions more than a decade after its first issuance, mainly focusing on integrating post-Fukushima recommendations and requirements to ensure a level of safety compatible with the expectations of the safety authorities. The update also expands the RSWG efforts to harmonize GIF members' safety approach to:

- converge on a common vision;
- provides common definitions for the plant states considered in a design and their alignment with the levels of defence-in-depth;
- reinforce the independence of prevention/mitigation features in different defence-in-depth levels; and
- clarifies the definition of, and the selection process for, the practically eliminated accidents.

Two separate reports are being prepared:

(1) "Basis for the Safety Approach Update for Design & Assessment of Generation IV Nuclear Systems" as a substantial revision of 2008 version but with a similar outline;

(2) a compendium report on "Impact of Fukushima Accident and Recent Regulations on the Safety Approach for Generation IV Nuclear Systems" as an extension of the focus on post-Fukushima Daiichi recommendations and requirements issued by regulators and international organizations since 2011 to provide insights into their applicability in design and safety assessments of Gen-IV systems.

The GIF-WGSAR joint initiative focuses on development of risk-informed approach for selection of licensing basis events and safety classification of systems, structures and components. This technology-inclusive approach is intended to reinforce common understanding of plant states corresponding to different defence-in-depth levels with emphasis on inherent and passive safety features, and to offer a structured approach for incorporating risk insights in safety assessments and regulatory decisions to supplement deterministic approach for increased confidence and improved safety margins.

As a GIF/CNRA joint initiative, it aims to facilitate a structured dialogue among international designers and regulators. Expected outcome is a report on key considerations for applying the risk-informed approach in a way that:

(a) it is inclusive of all six Gen-IV systems with a flexible implementation recognizing unique and varying sovereign regulatory structures;

(b) it builds on existing GIF safety approaches and methodologies (e.g. Basic Safety Approach and ISAM);

(c) it describes the key constituent parts of the risk-informed approach and provides a process description for its implementation. The two-year project is envisioned for completion of the report with co-ordinated input from GIF System Steering Committees and Safety Design Criteria Task Force before it is presented to WGSAR for their subsequent review and feedback.

The RSWG continues to advice the GIF Policy and Experts Groups on interactions with the nuclear safety regulatory community, international organizations and stakeholders relevant to Gen-IV nuclear systems. In 2019, the RSWG also provided a weeklong ISAM training, sponsored and hosted by China, and presented a Gen-IV risk and safety webinar hosted the GIF Education and Training Task Force.

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