2016 GIF PRPP International Workshop

October 12

International Workshop on the Proliferation Resistance and Physical Protection Evaluation Methodology for Generation IV Nuclear Energy Systems

09:30	**Registration**	
10:00	**Opening Remarks**	*- J. Park (GIF) / B. Bari (BNL)*
	Welcome Address	*- K. Song (KAERI)*
	Congratulatory Remarks	*- M. Baek (NSSC)*

Opening

10:15	**3S Regulatory Framework for Safe Management of Spent Nuclear Fuel in Korea** *- M. Baek (NSSC)*
11:00	**PRPP Evaluation of Generation IV Nuclear Energy Systems: Implications for Policy Makers and Technology Developers** *- B. Bari (BNL)*
11:45	**GROUP PHOTO**
12:00	**LUNCHON - *Lunch Speech*** *- M. Chang (GIF)*

Session Ⅰ

13:30	**Overview of the GIF PRPP Methodology** *- J. Whitlock (CNL)*
14:00	**PRPP Case Study: Purpose, Results, and Lessons Learned** *- G. Cojazzi (JRC, EU)*
14:30	**PRPP Evaluation and FSA Process: A Comparison** *- B. Bari (BNL)*
15:00	**COFFEE BREAK**

Session Ⅱ

15:15	**Korean Nuclear R&D Activities for Spent Nuclear Fuel Management** *- H. Park (NRF)*
15:45	**Status of SFR Development in Korea** *- T. Kim (SRFA)*
16:15	**IAEA Perspectives on Safeguards for Advanced Nuclear Energy Systems** *- J. Phillips (IAEA)*
16:45	**Safeguardability Assessment for Advanced Nuclear Energy Systems** *- J. Lee (KINAC)*
17:15	**COFFEE BREAK**

Panel Discussion

17:30	**Panel Discussion** *- B. Bari (BNL)*
18:30	**Closing**

PRPP Evaluations of Generation IV Nuclear Energy Systems:

Implications for Policy Makers and Technology Developers

***Presenter*: Robert Bari, Co-chair**

GIF PR&PP Working Group

Workshop on the Proliferation Resistance and Physical Protection Evaluation (PR&PP) Methodology for Generation IV Nuclear Energy Systems
Jeju, Republic of Korea, October 12, 2016

Topics

- *Goals and Objectives of Workshop*
- *Technology Goals for Generation IV*
- *Purpose of PR&PP evaluations in Generation IV*
- *Overview of PR&PP group and its activities*
- *Implications for Policy Makers and Technology Developers*

Goals and Objectives of Workshop

- ***Inform participants of the evaluation methodology and its application.***
- ***Obtain feedback to improve implementation by workshop participants.***
- ***Understand approaches taken in ROK***

Technology Goals for Generation IV

- ***Sustainable Nuclear Energy***
- ***Competitive Nuclear Energy***
- ***Safe and Reliable Systems***
- ***Proliferation Resistance and Physical Protection***

GIF Goals for PR&PP

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.

Purpose of PR&PP evaluations in Generation IV

- ***To introduce PR&PP features into the design process at the <u>earliest</u> possible stage of concept development***
- ***Both the intrinsic (physical and engineering) and extrinsic (safeguards and institutional arrangements) characteristics can benefit from incorporating PR&PP risk reduction into considerations of the design***
- ***While only the most general features of the design are known initially, PR&PP concepts can be applied to manage risk reduction***
- ***As the design matures, increasing detail can be incorporated in the PR&PP evaluation model of the system: progressive refinement***

Current Terms of Reference

- ***Advise*** *the PG and EG on PR&PP issues related to Gen IV nuclear energy systems*
- ***Maintain capability*** *to perform or direct PR&PP studies on request of GIF*
- ***Monitor*** *the integrity and quality of PR&PP evaluations for GIF (peer review on request)*
- ***Maintain configuration control*** *over the PR&PP methodology, its documentation and revisions*
- ***Strengthen the link*** *with Gen IV system designers, in particular with GIF SSCs*
- ***Promote and facilitate*** *early consideration of PR&PP in the development and design of Gen IV systems*
- ***Maintain cognizance*** *of related GIF activities, e.g., safety, economics*
- ***Maintain cognizance*** *of and interactions with non-GIF activities such as IAEA initiatives and specific national initiatives*
- ***Promote*** *PR&PP goals and broad acceptance of the PR&PP methodology*

Some Important Definitions

- ***Proliferation resistance*** ***is that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material, or misuse of technology, by the host State in order to acquire nuclear weapons or other nuclear explosive devices.***

- ***Physical protection*** ***(robustness) is that characteristic of a nuclear energy system that impedes the theft of materials suitable for nuclear explosives or radiation dispersal devices, and the sabotage of facilities and transportation, by sub-national entities and other non-host State adversaries.***

Assessment Paradigm

CHALLENGES → **SYSTEM RESPONSE** → **OUTCOMES**

Threats ***PR & PP*** ***Assessment***

Intrinsic
- Technical Design Features

Extrinsic (Safeguards/Protection)
- Institutional Arrangements

Proliferation, theft and sabotage involve **<u>competing</u> actors**.
Important to recognize actors' perspectives and the human interplay.

Major Accomplishments

- ***The Methodology*: developed through a succession of revisions – currently in Revision 6 report**
- ***The "Case Study"* approach: an example (sodium-cooled) reactor system was chosen to develop and demonstrate the methodology – resulted in major report**
- ***Joint Efforts with six GIF design* areas (System Steering Committees or SSCs) - resulted in major report**

All three reports can be obtained at:

https://www.gen-4.org/gif/jcms/c_9365/prpp

Implications

- ***Fundamental differences between host-state proliferation threats and non-state adversary***
- ***Some advanced technologies can offer benefits against non-state threats—but not against host-state adversary***
- ***For Host State, safeguards and safeguardability essential, as well as controls on technology***
- ***Country context of paramount importance to determining proliferation risks associated with Host State***
- ***No such thing as "proliferation proof"—take great care in using term Proliferation Resistance***

Potential Future Applications for PR&PP Approach

- ***Enhancing GIF Designs—begins with the designers***
- ***Enabling Safeguards by Design***
  - ***Usability of analytical tools by designers and its safeguards team: critical to designers analyzing safeguardability***
- ***Proliferation and security should be part of future global fuel cycle architectures***
- ***PR&PP as a Quality Assurance Tool***
- ***Integration of safeguards and security with safety and other performance objectives— challenge of how to do this well***
- ***Harmonize with related efforts (national and international)***

  e.g. IAEA/INPRO

Some Recent Activities

- ***Conducted 26th PRPPWG meeting, UC-Berkeley, November 2015;***
- ***Held workshop UC-Berkeley, November 2015***

  → focused on students and scholars
- ***Participated in 10th GIF-INPRO Interface Meeting, IAEA HQ, April 2016***
- ***Participated in 12th INPRO Dialogue Forum on GIF systems, IAEA HQ, April 2016***
- ***Participated in PG/EG meeting in Paris, April 2016***

Recent Activities (cont'd)

- *Participated in GIF RSWG meeting in Orai, Japan June 2016*
- *PRPPWG paper presented at ANS Nonproliferation Conference, Santa Fe NM, USA, September 2016*
- *FAQ for PR&PP on GIF open website and now as a tri-fold handout*
- *Bibliography of PR&PP-related reports has been assembled and now on GIF open website*

Current PR&PP Activities

- 27th PRPPWG meeting: October 13-14, 2016,
  ROK, host
  - includes today's workshop
- Progress report to GIF EG/PG, October 17-20, 2016, in Seoul, Republic of Korea
- Interface meeting with IAEA/INPRO, March 2017
- PRPP-SSC workshop, OECD/NEA, Paris, April 2017

Questionnaire to SSCs

February 2016

Questions motivated by:

1) Developments in the six GIF design concepts including changes in the reference concepts

2) Evolving information in the PR&PP area,

3) Design and institutional developments outside of GIF,

4) Changes in SSCs representatives and the need for familiarization of new members with the PR&PP approach within GIF.

Questions Asked of SSCs (1)

- Is there some aspect of the PRPP methodology that you would like to see changed, in order to improve its ease of implementation?
- Is there any particular aspect of the PR&PP approach that you need more information on?
- Is there new information about your design that might impact its PR&PP characteristics?
- Based on your reading of the 2011 joint report, is it warranted to produce an update for your particular design concept?

Questions Asked of SSCs (2)

- ***If so, would it be beneficial to the designers to hear about the methodology steps that would be useful for realization of PRPP-by-design?***
- ***Would it be helpful to have a joint workshop between the PRPPWG and designated representatives of each SSC design?***
- ***Can you suggest an appropriate time to have a SSC-PRPPWG workshop? Fall 2016? Spring 2017?***
- ***Are there other ways to enhance the information exchange between SSCs and the PRPPWG? Please suggest.***
  - ➢ ***Workshop with SSCs planned for 12-13 April 2017 at OECD/NEA HQ in Paris, France***

PRPPWG Membership: Countries and Organizations

- Canada
- China
- Euratom
- France
- IAEA - Observer
- Japan
- NEA - Secretariat
- Republic of Korea
- Russia
- USA

PRPP Evaluations of Generation IV Nuclear Energy Systems:

Overview of the GIF PRPP Methodology

<u>Presenter</u>: Jeremy Whitlock, Co-chair

GIF PR&PP Working Group

Workshop on the Proliferation Resistance and Physical Protection Evaluation (PR&PP) Methodology for Generation IV Nuclear Energy Systems
Jeju, Republic of Korea, October 12, 2016

Assessment Paradigm

CHALLENGES → SYSTEM RESPONSE → OUTCOMES

Threats | *PR & PP* | *Assessment*

Intrinsic
- Technical Design Features

Extrinsic (Safeguards/Protection)
- Institutional Arrangements

Proliferation, theft and sabotage involve **competing actors**.
Important to recognize actors' perspectives and the human interplay.

Evaluation Framework

Challenges
- Threat Definition

↓

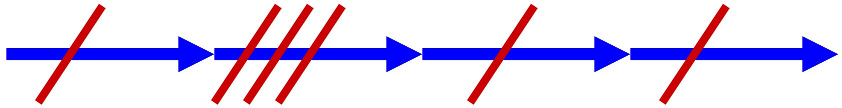
System Response
- System Element Identification
- Target Identification and Categorization
- Pathway Identification and Refinement
- Estimation of Measures

↓

Outcomes
- Pathway Comparison
- System Assessment & Presentation of Results

Approach

- ***Pathway analysis: Intuitive way to describe & analyze proliferation, theft or sabotage scenarios***
- ***Pathways: Potential sequences of events followed by the proliferant state or adversary to achieve its objectives***
  – ***Along any pathway the proliferant state or adversary will encounter difficulties, barriers, or obstacles, all of which are collectively called "proliferation resistance" or "physical protection robustness"***

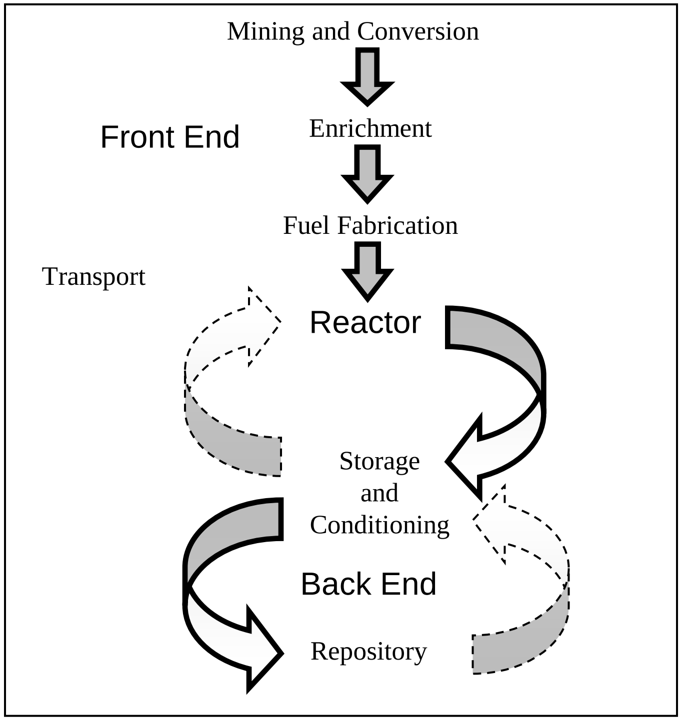


Summary of PR & PP Threat Dimensions

	Proliferation Resistance	Physical Protection
Actor Type	• Host State	• Outsider • Outsider with insider • Insider alone • Above and non-Host State
Actor Capabilities	• Technical skills • Resources (money and workforce) • Uranium and Thorium resources • Industrial capabilities • Nuclear capabilities	• Knowledge • Skills • Weapons and tools • Number of actors • Dedication
Objectives (relevant to the nuclear fuel cycle)	Nuclear weapon(s): • Number • Reliability • Ability to stockpile • Deliverability • Production rate	• Disruption of operations • Radiological release • Nuclear explosives • Radiation Dispersal Device • Information theft
Strategies	• Concealed diversion • Overt diversion • Concealed facility misuse • Overt facility misuse • Independent clandestine facility use	• Various modes of attack • Various tactics

System Element Identification

- ***Decomposes nuclear system into system elements to permit pathways analysis***
  - *Materials, facilities, processes, fuel cycle facilities, reactors, storage for fresh and spent fuel, nuclear research facilities, transportation links, etc.*
- ***Considers the location of operations and materials, their accessibility and characteristics, and elements such as***
  - *Material Balance Areas (MBAs),*
  - *Key Measurement Points (KMPs),*
  - *Safeguards and physical protection systems.*
- ***Identifies interfaces with other (nuclear) systems that are not part of the Gen IV system being evaluated.***



When detailed design information is not available, assumptions are documented and become a part of the system design bases

Target Identification

PR Target:

1. ***Nuclear material that can be diverted,***
2. ***Equipment and process that can be misused to process undeclared nuclear materials, or***
3. ***Equipment and technology that can be replicated in an undeclared facility.***

PP Target

1. ***Nuclear material to be protected from theft,***
2. ***Information to be protected from theft, or a***
3. ***Set of equipment to be protected from sabotage.***

Outcome: Identify potential targets that:
1) designers should consider protecting, and with which
2) decision makers should be concerned.

Pathway Identification and Refinement

- ***Pathways: Potential sequences of events/actions followed by the proliferant state or adversary to achieve its objective (proliferation, theft or sabotage). A pathway is composed of segments***
  - ***Segment={Action, Target, System Element(s)}***
    - » ***Internal: Within the system being assessed***
    - » ***External: Outside of the system being assessed***
- ***Can be illustrated using: logic diagrams, event trees, adversary sequence diagrams, verbal descriptions, etc.***

Estimation of Measures

Outcome: Results available from early in the design process based on available information.

Progressive Approach

- ***Initial coarse path analysis uses qualitative assessment of measures (Expert Judgement***
- ***Progressive refinement of me quantitative and sophisticate***
- ***Quantitative assessment***

Outcome: More detailed and comprehensive results with lower uncertainty available when more detailed evaluation is conducted using more detailed information.

Some measures are estimated for:

- ***individual segments then aggregated to estimate the value of the measure for each pathway***
  - ***e.g. Proliferation Time***
- ***a complete pathway, and are not meaningful on a segment basis.***
  - ***e.g. Consequences; Material Type***

The PR Measures

- *Proliferation resistance*
  - Proliferation Technical Difficulty
  - Proliferation Cost
  - Proliferation Time
  - Fissile Material Type
  - Detection Probability
  - Detection Resource Efficiency

Each measure represents major system characteristics that would be important impediments to the strategy of a proliferant nation (PR).

The PP Measures

- *Physical protection*
  - Probability of Adversary Success
  - Consequences
  - Physical Protection Resources

Each measure represents major system characteristics that would be important impediments to the strategy of a non-host-state group attempting theft or sabotage (PP).

Example Metrics and Estimated Measure Scales

Measures and Metrics	Estimated Measure Value Bins (Median)	Proliferation Resistance Qualitative Descriptor[b]
Proliferation Resistance Measures Determined by Intrinsic Features		
Proliferation Technical Difficulty (TD) Example metric: Probability of segment/pathway failure from inherent technical difficulty considering threat capabilities	0-5% (2%)	Very Low
	5-25% (10%)	Low
	25-75% (50%)	Medium
	75-95% (90%)	High
	95-100% (98%)	Very High
Proliferation Cost (PC) Example metric: Fraction of national military budget required to execute the proliferation segment/pathway, amortized on an annual basis over the Proliferation Time	0-5% (2%)	Very Low
	5-25% (10%)	Low
	25-75% (50%)	Medium
	75-100% (90%)	High
	>100% (>100%)	Very High
Proliferation Time (PT) Example metric: Total time to complete segment/pathway, starting with the first action taken to initiate the pathway	0-3 mon (2 mon)	Very Low
	3 mon-1 yr (8 mon)	Low
	1-10 yr (5 yr)	Medium
	10 yr-30 yr (20 yr)	High
	>30 yr (>30 yr)	Very High
Fissile Material Type (MT) * Example metric: Dimensionless ranked categories (HEU, WG-Pu, RG-Pu, DB-Pu, LEU)[a]; interpolation based on material attributes (reflecting the preference for using the material and not it's usability in a nuclear explosive device)	HEU	Very Low
	WG-Pu	Low
	RG-Pu	Medium
	DB-Pu	High
	LEU	Very High

Measures and Metrics	Estimated Measure Value Bins (Median)	Proliferation Resistance Qualitative Descriptor[b]
Proliferation Resistance Measures Determined by Extrinsic Measures and Intrinsic Features		
Detection Probability (DP) Example metric: Probability that safeguards will detect the execution of a diversion or misuse segment /pathway	0-5% (2%)	Very Low
	5-25% (10%)	Low
	25-75% (50%)	Medium
	75-95% (90%)	High
	95-100% (98%)	Very High
Detection Resource Efficiency (DE) Example metric: GW(e) years of capacity supported (or other normalization variable) per Person Days of Inspection (PDI) (or inspection $)	<0.01 (0.005 GWyr/PDI)	Very Low
	0.01-0.04 (0.02 GWyr/PDI)	Low
	0.04-0.1 (0.07 GWyr/PDI)	Medium
	0.1-0.3 (0.2 GWyr/PDI)	High
	>0.3 (1.0 GWyr/PDI)	Very High

*** Material Type Description**

HEU = high-enriched uranium, nominally 95% 235U;
WG-Pu = weapons-grade plutonium, nominally 94% fissile Pu isotopes;
RG-Pu = reactor-grade plutonium, nominally 70% fissile Pu isotopes;
DB-Pu = deep burn plutonium, nominally 43% fissile Pu isotopes;
LEU = low-enriched plutonium, nominally 5% 235U.

Comparison of Material Categorization

IAEA Category[1]	IAEA Verification Time[1]	IAEA Conversion Time[1]	PR&PP[2]	M&M[3]	DOE attractiveness level[4]
(unirradiated) DIRECT USE	1 month	HEU, Pu, U233 metal (7-10 days)	VL (HEU)	WG-Pu, HEU>90% U235, U233 with U232<25 ppm	B
			L (WG-Pu)	Pu, Np, HEU>70% U235 U233 with U232>25 ppm	
		HEU, Pu, U233 in unirradiated compounds (1 - 3 weeks)	M (RG-Pu)	HEU≥20% U235, Fresh TRU, Pu w/ Pu238 > 5%	C
(irradiated)	3 months	HEU, Pu, U233 in irradiated compounds (1 - 3 months)	H (DB-Pu)		
(unirradiated) INDIRECT USE	1 year	U < 20% U235 and U233, Th (1 year)	VH (LEU)	Am+Cm, LEU<20% U235, Pu w/ Pu238 > 80%,	D
				Cm, LEU<10% U235, HLW solution,	E
(irradiated)				LEU<5% U235, NU, DU, Th	

Table 2.10,
GIF PRPP Methodology,
Rev. 6 (2011)

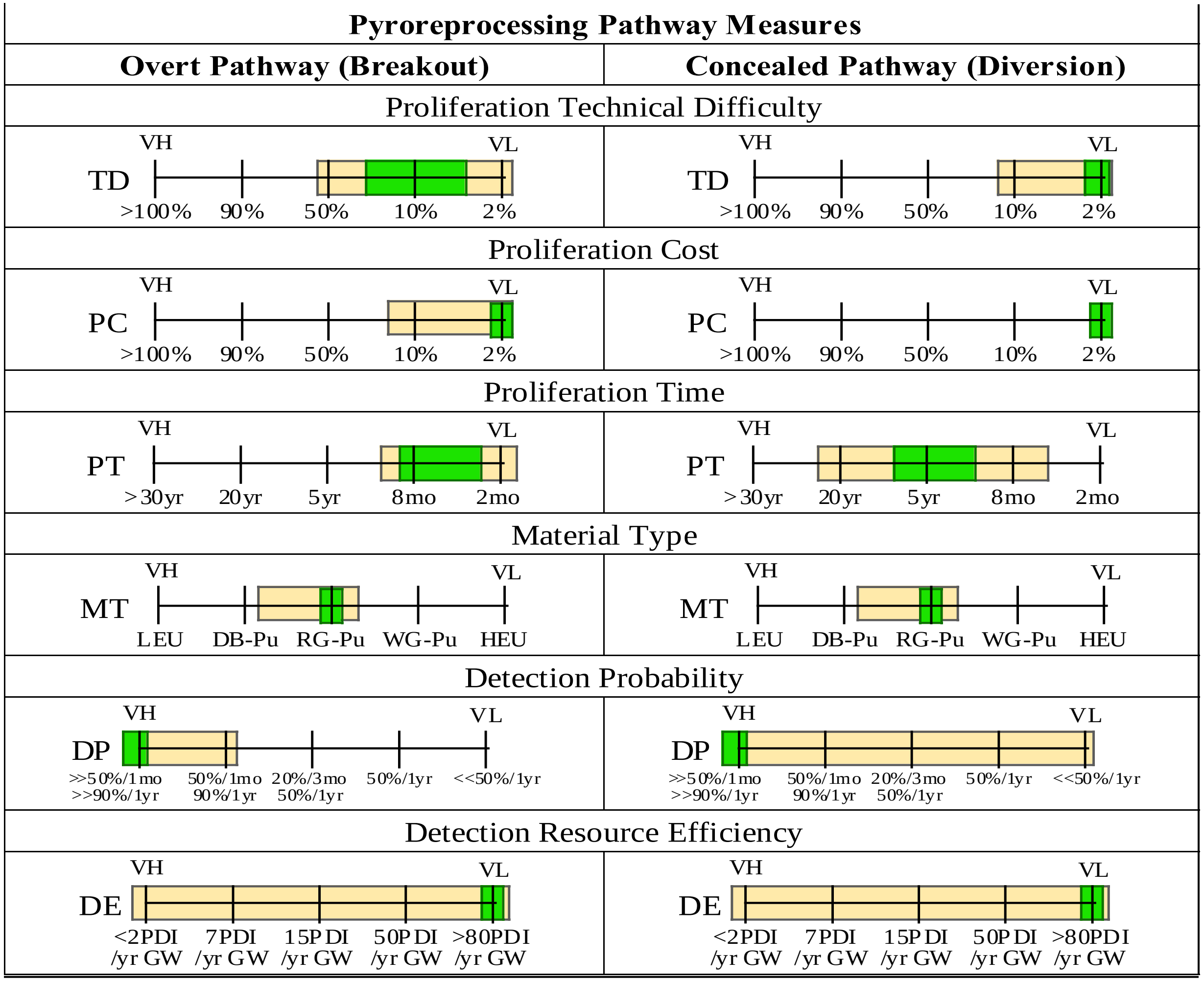
Pathway Comparison

- ***Pathway analysis considers multiple pathways.***

Key goals

1. Identify the most important pathways, and feed back useful information to designers to reduce or eliminate these pathways as early as possible.
2. Allow program managers and policy makers to compare options for R&D, the deployment of fuel cycles, and the deployment of other elements of nuclear technology.

Presentation of results: one example – a qualitative assessment comparison table



Results tailored (in scope and timing) to meet end-user needs:

- ***SYSTEM DESIGNERS:* detailed analysis (facility, target level), perhaps incomplete design as it evolves, to facilitate design decisions**

- ***POLICY MAKERS, EXTERNAL STAKEHOLDERS:* high-level analysis (dominant, system-level pathways), to facilitate policy-level decisions, or high-level decisions between technology options**

- ***Different levels of detail tailored to suit end-user, but must remain transparently connected***

- ***In all cases must convey:***
  - ***credibility,***
  - ***accuracy,***
  - ***comprehensiveness (representative pathways, efficient frontier),***
  - ***level of uncertainty,***
  - ***sensitivity analysis, and***
  - ***insight gained from qualitative expert judgment***

Summary

- ***Pathways provide an intuitive, comprehensive approach that promotes understanding and designer innovation***
- ***Analytical and capable of producing objective results***
- ***Facilitates assessment during the design process and throughout the full life cycle***
  - ***Assumptions are documented and become a part of the system design bases and functional requirements***
- ***Guides designers to develop systems that are more resistant to proliferation and robust against sabotage and theft***
- ***Provides information to program policy makers to aid in making decisions***
- ***Form of results: Depends on user's needs and intended audience – can be qualitative or quantitative***

Summary (cont'd)

- ***Expertise needed*: familiarity with PR&PP methodology, the system design, and the general requirements of non-proliferation (e.g. international safeguards) and physical protection. Can be a team-effort.**
- ***Level of effort*: depends on user's needs, and stage of design – from a "pared-down" scoping study involving one expert, to a full-blown analysis involving a team**
- ***Time needed*: Depending on type of application, from a few weeks to a year (for full analysis with multiple scenarios)**

More detailed information describing the PR&PP methodology can be found in the PR&PP Methodology Report (Rev.6, 2011), https://www.gen-4.org/gif/jcms/c_9365/prpp

PRPP Case Study:
Purpose, Results, and Lessons Learned (including lessons learned from and other selected applications)

***<u>Presenter</u>*: Giacomo G.M. Cojazzi**

GIF PR&PP Working Group (EURATOM)

Workshop on the Proliferation Resistance and Physical Protection Evaluation Methodology for Generation IV Nuclear Energy Systems
Jeju, Republic of Korea,· October 12, 2016

Summary

1st part: ESFR PR&PP methodology case study

- Background/objectives
- The ESRF-NES
- PR&PP evaluation, hints
- Insights and Methodology Lessons Learnt

2nd part: Other PR&PP studies/applications (ex. RoK)

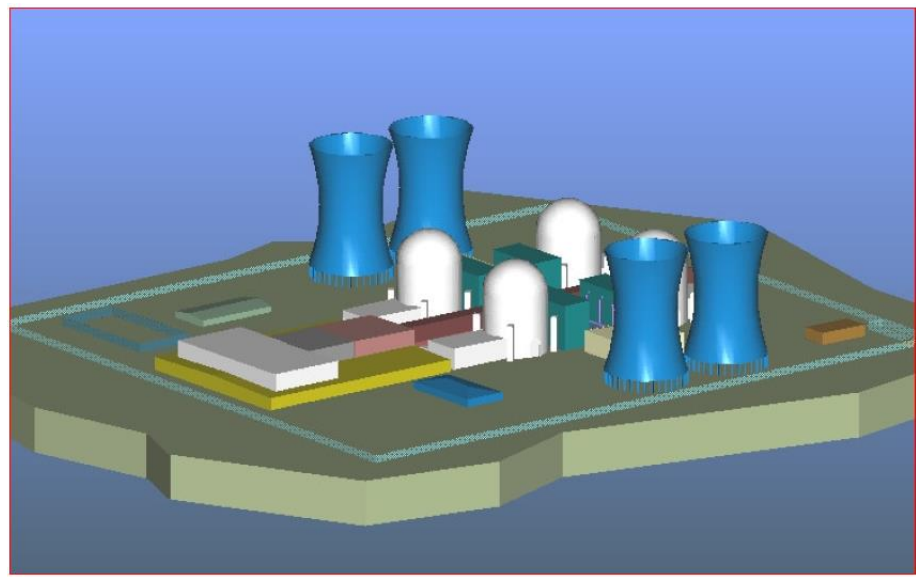
- USA
- Canada
- Japan
- EU

PR&PP Case Study Background

- ***The PR&PP Evaluation Methodology was developed with the aid of a series of studies that considered a hypothetical "Example Sodium Fast Reactor" (ESFR) nuclear energy system***
- ***Further progress required a more comprehensive evaluation of a complete reactor/fuel cycle system***
  - ***to gain practical experience within the application process***
  - ***to discern the needs for further methodology development and presentation of results***
  - ***to confirm the usefulness and usability of the evaluation methodology***
  - ***to demonstrate that designers can obtain practical guidance through application of the methodology***
  - ***to demonstrate the capability to apply the PR&PP evaluation framework at different levels of detail, corresponding to different efforts and resources.***
- ***For these reasons, the PR&PP Working Group undertook a two-year Case Study.***

ESFR studies objectives

1. Exercise the GIF PR&PP Methodology for a complete Gen-IV reactor/fuel cycle system
2. Demonstrate, via the comparison of different design options, that the Methodology can generate meaningful results
   - For designers
   - For decision makers
3. Provide examples of PR&PP evaluations for future users
   - Facilitate transition to other studies
   - Facilitate other ongoing efforts (e.g., INPRO)

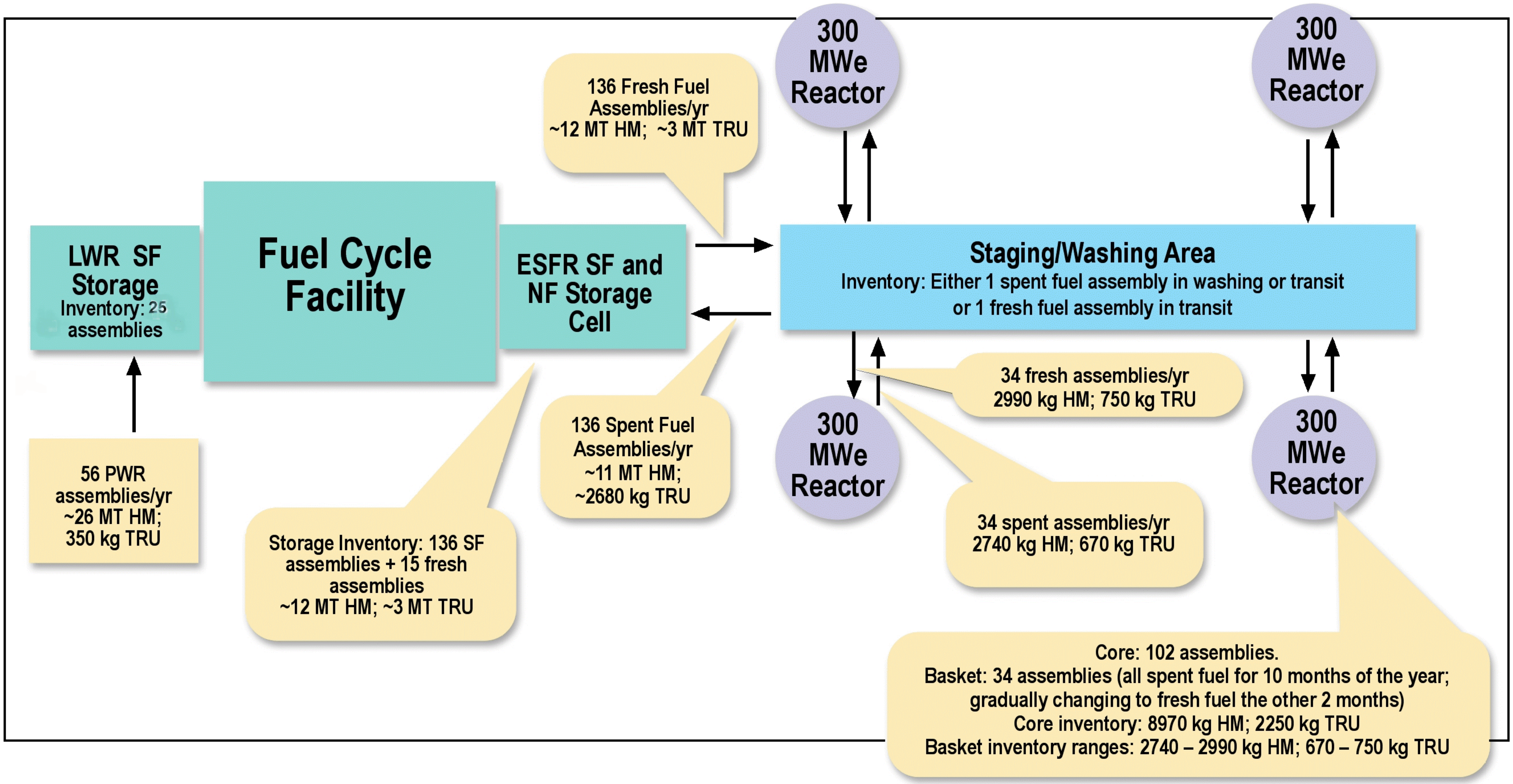


ESFR System

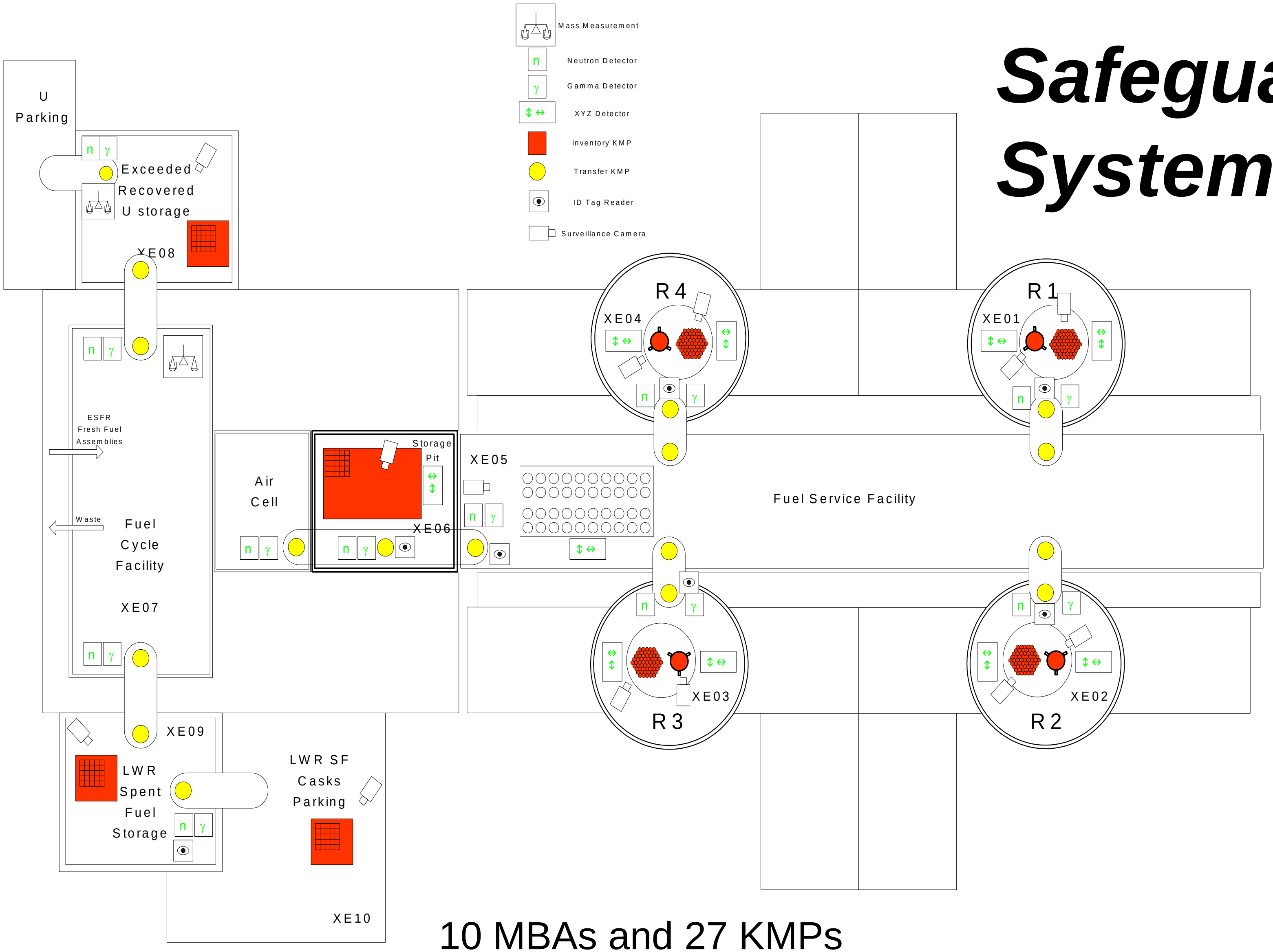
A hypothetical Gen IV system that includes, at a single site:

- *The power plant(s) – 4 identical SFRs, based on the AFR-300 Concept*
- *Staging area/subassembly washing station – A building adjacent to the reactor buildings used for fresh and spent fuel in transit and for washing spent fuel subassemblies prior to storage*
- *Fuel Storage building – A facility to store fuel discharged from the reactors prior to processing and re-fabricated fuel to be transferred to the reactors*
- *Fuel Cycle Facility – A spent fuel recycle facility employing pyroprocess separations and associated fuel refabrication*
- *LWR Spent Fuel Storage Facility – A facility to store LWR spent fuel assemblies that are used as a source of make up fissile material for the (actinide burner) reactors*

Baseline ESFR System Material Flows



Safeguards System

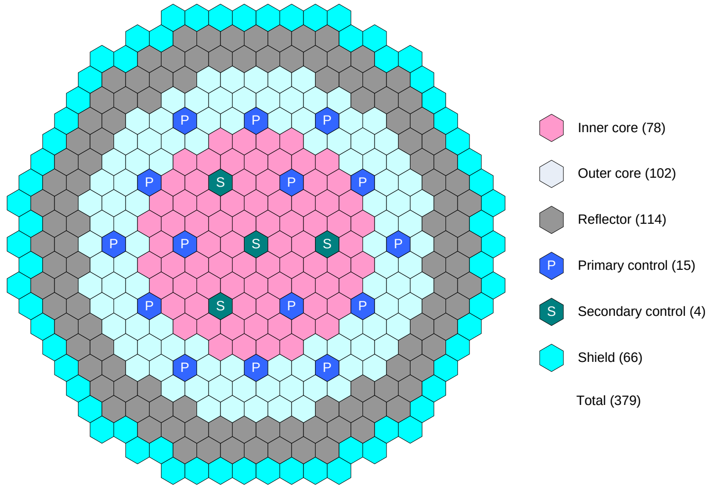


10 MBAs and 27 KMPs

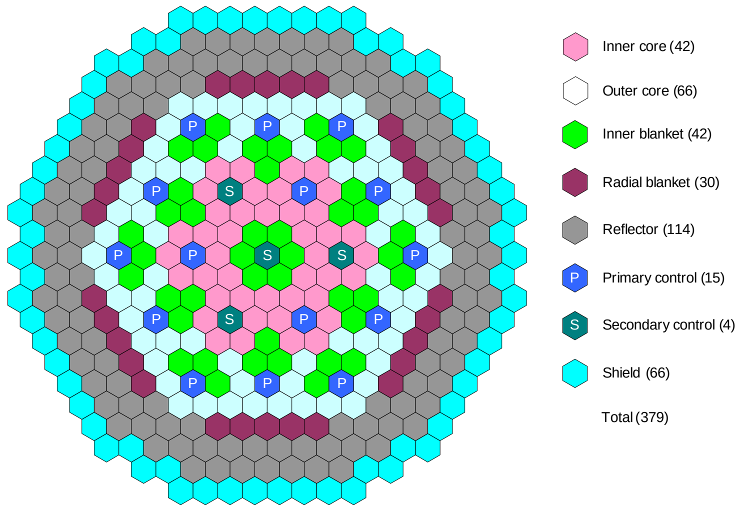
ESFR System Variations

1000 MWth (350 MWe) reactor capacity

- ***Reference core*: Conversion ratio (CR) for transuranic actinides (TRU) = 0.73**
- ***Variation 1*: Lower CR (0.22) requiring fuel of higher enrichment**
- ***Variation 2*: Higher CR (1.00) representing a break-even core without fertile blankets**



- ***Variation 3*: Still higher CR (1.12) representing a breeding core with both external and internal U blankets**



Overview of Analysis Approach

- ***ESFR design, operation and safeguards/protection information was compiled***

- ***Three PR and one PP "threat scenarios" were defined for system evaluation***

- ***Four working subgroups were formed, each focused on a threat scenario***
  - *Identified possible "targets" and "pathways" for each threat scenario*
  - *Selected a few targets and pathways for analysis based on their attractiveness to the adversary*
  - *Characterized ESFR system PR&PP performance/response by estimating PR&PP "measures" for these targets and pathways*

Threat Scenarios

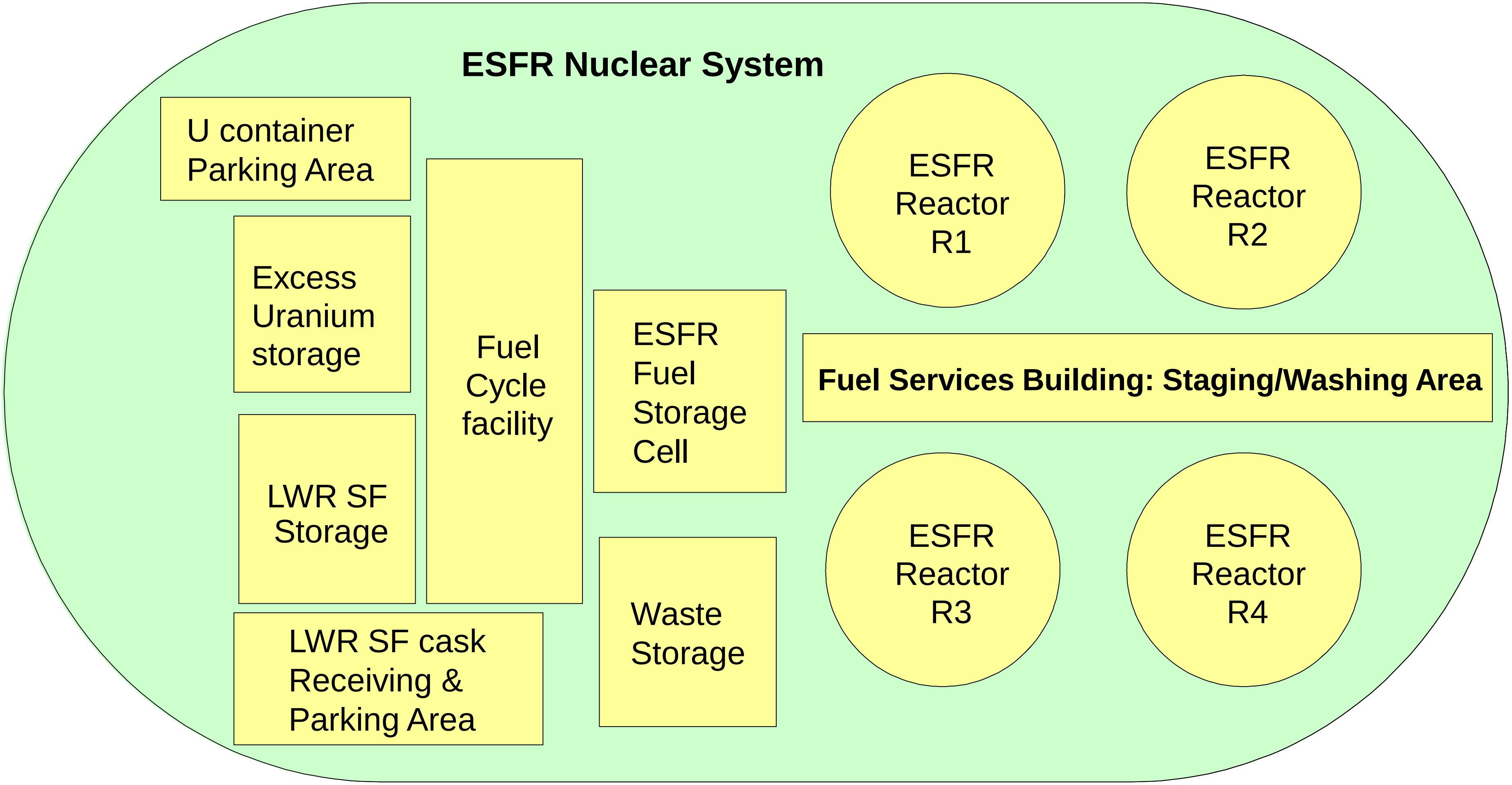
PR

- ***Adversary***: *Host state in control of ESFR facilities*
- ***Objective***: *to obtain at least one significant quantity (SQ) of plutonium for at least one nuclear weapon*
- ***Capabilities***:
  - *typical of a developed industrial nation*
- ***Strategies***:
  1. *Concealed diversion of nuclear material from ESFR facilities*
  2. *Concealed misuse of the ESFR to produce weapons-usable material*
  3. *"Break-out" and overt misuse or diversion*

PP

- ***Adversary***: *Military trained sub-national/ terrorist group (12 outsiders & 1 insider)*
- ***Objective***: *Theft of one SQ of nuclear weapon material*
  - *Radiological sabotage also considered*
- ***Capabilities***:
  - *Knowledge of plant layout, basic PP features, and theft targets of opportunity*
  - *Ability to acquire and use assault equipment and weapons, including specialized explosives and armored vehicles*
- ***Strategy***:
  1. *Surprise assault on ESFR material storage areas*

Baseline ESFR Nuclear System Elements



Targets and Pathways

- ***Specific nuclear material and/or equipment "targets" were identified by each threat/scenario subgroup***
  - *Consideration was given to material stocks and flows; material attributes and accessibility; vulnerability of equipment and processes to misuse, replication, or sabotage*

- ***"Pathways" were generated and analyzed by each subgroup …*** *Sequences of events/actions followed by the proliferant state or sub-national adversary to achieve its objective (e.g., diversion, misuse, theft)*
  - *Proliferation (host state) pathways considered pre-acquisition preparation, acquisition, and post-acquisition material processing stages; weapon fabrication was not considered.*
  - *PP (sub-national) pathways considered only the steps involved in the acquisition stage*
  - *Reasonable assumptions were made regarding detection by safeguards or interruption by protective force*

Diversion Targets and Pathways

- ***Diversion subgroup selected five targets for analysis:***
  - *TRU metal from electrorefiner processing*
  - *Waste containing TRU metal from electrorefiner cleanout*
  - *Cask of LWR fuel assemblies*
  - *LWR spent fuel assembly*
  - *Recycled uranium metal*

- ***Generated a total of 10 pathways***

- ***Performed a coarse estimation of the measures for each diversion pathway (for the reference configuration, CR=0.73)***
  - *Addressing the entire pathway as a whole*

- ***Effects of conversion ratio variations were reviewed but not analyzed in detail:***
  - *Variations judged to have minor impact on the outcome, limited mainly to the isotopic composition of the TRU targets*

Misuse Targets and Pathways

- ***Misuse subgroup identified 6 misuse targets (i.e., equipment and technologies that can be misused or replicated):***
  - *Separation of weapon-usable material in FCF*
  - *Irradiation of uranium (breeding) pins in reactor(s)*
  - *Dismantlement of irradiated uranium pins in FCF*
  - *Fabrication of breeding material in FCF*
  - *Misuse of skills and knowledge in clandestine site*
  - *Replication of technology in clandestine site*

- ***Analyzed the irradiation of U pins in reactor(s) and Pu recovery in a clandestine reprocessing facility***

- ***Generated fairly detailed pathway including acquisition as well as pre- and post-acquisition processing steps***

- ***Estimated the PR measures for this pathway for CR=0.73 (reference) and CR=0.22***

Breakout Targets and Pathways

- ***Breakout subgroup chose five targets for analysis:***
  - *Diversion of stockpiled ESFR fresh fuel – plutonium separation from in a clandestine PUREX facility*
  - *Misuse of facility to irradiate fertile material in-core*
  - *Misuse of facility to irradiate fertile material in storage baskets*
  - *Misuse of facility to extract high-plutonium-purity TRU in the FCF*
  - *Diversion of inner blanket assemblies from "breeder" case (Variation 3) – plutonium separation in a clandestine PUREX facility*

- ***Identified different breakout strategies:***
  - *<u>Immediate breakout:</u> Proliferant state immediately acts on decision to break out – minimum time, minimum complexity of proliferation activities*
  - *<u>Delayed, optional breakout</u>: Proliferant state covertly misuses or diverts with intent to break out if/when detection occurs – medium time, medium complexity*
  - *<u>Delayed, intended breakout</u>: Proliferant state covertly misuses or diverts under a predetermined schedule for breakout – maximum time, maximum complexity*

- ***Estimated proliferation time (PT) measure for each target and breakout strategy as an indication of target attractiveness***

Theft Targets and Pathways

- ***Theft subgroup identified many potential theft targets:***
  - *Ingots of U metal and TRU/U metal (FCF inert hot cell)*
  - *Makeup TRU material from reprocessed LWR spent fuel (inert hot cell)*
  - *ESFR fresh fuel slugs and fuel pins (inert hot cell)*
  - *ESFR fresh fuel assemblies (air hot cell or fuel staging/washing)*
  - *ESFR spent fuel assemblies (fuel staging/washing or FCF air hot cell)*
  - *Full length ESFR spent fuel pins (FCF air hot cell)*
  - *Chopped ESFR spent fuel pins (FCF inert hot cell)*
  - *Cask of LWR fuel assemblies (LWR Cask shipping/receiving)*
  - *LWR spent fuel assemblies (LWR spent fuel storage)*

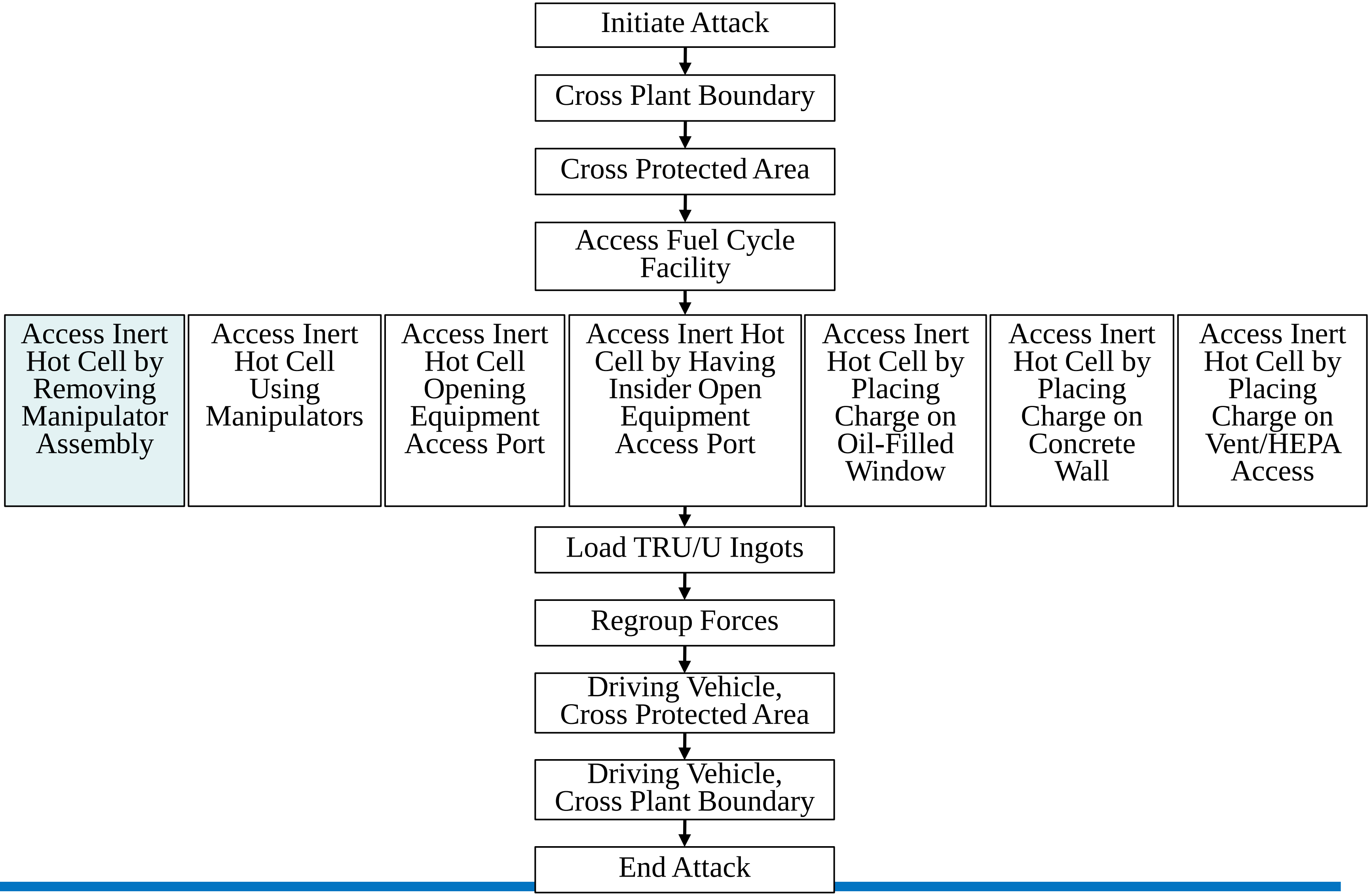
- ***Outlined pathways to targets using Adversary Sequence Diagrams (ASDs)***
- ***Analyzed pathway for theft of TRU/U metal ingot from FCF inert hot cell***
- ***Limited pathway to removal of the target to the site boundary, did not address activities beyond the site boundary***

- ***Estimated PP measures***
  - *Determined probability of detection and delay time for each pathway segment*
  - *Used Estimate of Adversary Sequence Interruption (EASI) software to estimate the probability of adversary success for different response times by protective force*

Representative Case Study Results

Threat Scenario	Diversion		Misuse	
	Reference ESFR Diversion Pathway 1	Reference ESFR Diversion Pathway 2	Reference ESFR, CR=0.73 Misuse Pathway 1	ESFR Variation 1, CR=0.22 Misuse Pathway 1
Pathway Description	Diversion of TRU/U ingot material using a new fuel assembly hardware container and transporting it out of the FCF through the assembly hardware portal.	Diversion of TRU/U ingot material using recovered uranium container and transporting it out through recycled U container portal.	Irradiation of ad-hoc U targets in reactor(s) and Pu recovery in a clandestine reprocessing facility.	Irradiation of ad-hoc U targets in reactor(s) and Pu recovery in a clandestine reprocessing facility.
Technical Difficulty (TD)	Low	Low	Medium	Medium
Proliferation Time (PT)	Medium	Medium	Medium	Medium
Proliferation Cost (PC)	Very Low	Very Low	Very Low	Very Low
Material Type (MT)	Medium (RG Pu)	Medium (RG Pu)	Low (WG Pu)	Low (WG Pu)
Detection Probability (DP)	Medium	High	Low to High	Low to High
Detection Resource Efficiency (DE)	High	High	Low to High	Low to High

PP: Adversary Sequence Diagram for Theft of TRU/U Ingot



Insights from Analysis of Proliferation Pathways

- ***Diversion*** ***pathway analysis requires consideration of how attractive the material is to potential proliferators for use in a weapons program, how difficult it would be to access and remove the material, and whether the facility can be designed and operated in such a manner that all plausible acquisition pathways are covered by a combination of intrinsic features and extrinsic measures***

- ***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.***

- ***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 on the proliferation time targeted by a proliferant state.***

Insights from Analysis of PP Pathways

- ***The theft (and sabotage) analyses found that multiple targets and pathways exist***
  - *The most attractive theft target materials appeared to be located in a few target areas*
- ***While containment of the adversary is adequate to prevent theft, a deterrence strategy that denies adversary access to targets is required to prevent sabotage***
- ***The proximity of theft and sabotage targets will likely require a deterrence strategy because the PP system will not be able to determine adversary intent (i.e., theft or sabotage) early enough***
  - *Implies need for a robust perimeter detection system and effective use of the passive barriers provided by hot cell radiation shielding structures and reactor passive safety systems*

Methodology Lessons Learned

- **Methodology can be applied during the conceptual stage of system development and design**
- **Completeness in identifying attractive targets and pathways is important**
  - *They can be systematically identified, and plausible scenarios can be described*
- **Assessment frequently requires assumptions about the system and its safeguards/protection**
  - *These assumptions provide the basis for functional requirements and design bases documentation for the system*
- **Assessment requires considerable technical expertise on system design and operation, as well as on safeguards and physical protection measures**
- **Greater standardization of the methodology and its use is needed**
  - *More detailed guidance for assessments should be provided (->Rev. 6)*

Summary

1st part: ESFR PR&PP methodology case study

- Background/objectives
- The ESRF-NES
- PR&PP evaluation, hints
- Insights and Methodology Lessons Learnt

2nd part: Other PR&PP studies/applications (ex. RoK)

- USA
- Canada
- Japan
- EU

PR&PP Implementation Activities Within National Programs

- **USA**
  - **Comparison of alternative fuel separation technologies (relative to PUREX)**
    - **COEX, UREX, pyroprocessing**
    - **Primarily improvements regarding non-state actors**
    - **Potential measurement challenges for large bulk facilities**
  - **Multi-laboratory assessment of reactor designs**
    - **SFR, HTGR, HWR, LWR**
  - **SMR Princeton study**
    - **Gen II vs SMR (LWR and fast-spectrum)**

PR&PP Implementation Activities Within National Programs (cont'd)

- **Canada**
  - ***Pre-licensing assessment of two advanced CANDU designs (ACR-1000 and EC6)***
  - ***"Pared-down" PRPP approach, incorporating designer, SSAC and IAEA***
  - ***Design improvements identified***

PR&PP Implementation Activities Within National Programs (cont’d)

- **Japan**
  - Evaluation of the methodology (JAEA and U. Bologna)
  - Comparison of SFR and LWR (presented at 2014 IAEA SG Symposium)
  - Important to consider PR measures in a particular order
  - Difficulty incorporating impact of Additional Protocol
  - Facilitated a better understanding of PR, and how the methodology can help meet researchers’ needs

PR&PP Implementation Activities Within National Programs (cont'd)

- ***Europe***
  - ***"Collaborative Project for a European Sodium Fast Reactor" (CP-ESFR): study of impact of alternative core design options (another pared-down PRPP application, see Back-up)***
  - ***MYRRHA (Belgium) – accelerator-driven research reactor: comparison with existing high flux test reactor and study of impact of alternative design variations.***

PR&PP Considerations & Feedbacks

- ***PR&PP comprehensive evaluation methodology for any technology, although conceived for GIF goals.***
- ***Complete evaluation framework; specificity of techniques needs to be determined by users.***
- ***Emerging need for simplified scoping PR&PP evaluation that can be implemented at early design stages and with limited efforts.***
- ***Not advisable to simplify the methodology for generic application, but..***
- ***Possibility to tailor the needed approaches to the specific needs.***

References & Acknowledgements

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- ***J. Cazalet et al., Status of the Gen-IV Proliferation Resistance and Physical Protection (PRPP) Evaluation Methodology, GLOBAL 2015, 21st International Conference & Exhibition: Nuclear Fuel Cycle For a Low-Carbon Future, Paris, September 21-24, 2015.***

- ***G.G.M. Cojazzi et al., The GIF Proliferation Resistance and Physical Protection (PR&PP) Evaluation Methodology: Status and Outlook, ANS Advances in Nuclear Nonproliferation Technology and Policy Conference: Bridging the Gaps in Nuclear Nonproliferation, 25-29 September, 2016, Santa Fe, USA***

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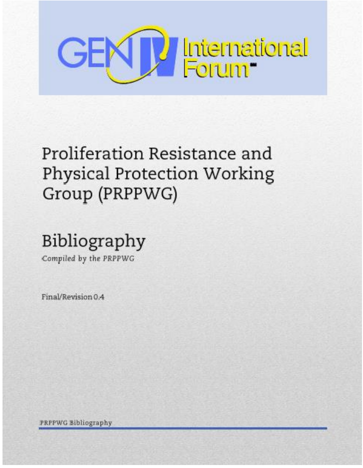
- ***Acknowledgments: thanks is due to all PRPPWG members for material produced***

PR&PP bibliography

Table of Contents


Proliferation Resistance and Physical Protection Working Group (PRPPWG)

Bibliography

Compiled by the PRPPWG

Final/Revision 0.4

PRPPWG Bibliography

PRPP Evaluation and Facility Safeguardability Analysis (FSA) Process: Comparison

***Presenter*: Robert Bari, Co-chair**

GIF PR&PP Working Group

Workshop on the Proliferation Resistance and Physical Protection Evaluation (PR&PP) Methodology for Generation IV Nuclear Energy Systems
Jeju, Republic of Korea, October 12, 2016

GIF Goals for PR&PP

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.

Purpose of PR&PP evaluations in Generation IV

- ***To introduce PR&PP features into the design process at the earliest possible stage of concept development***
- ***Both the intrinsic (physical and engineering) and extrinsic (safeguards and institutional arrangements) characteristics can benefit from incorporating PR&PP risk reduction into considerations of the design***
- ***While only the most general features of the design are known initially, PR&PP concepts can be applied to manage risk reduction***
- ***As the design matures, increasing detail can be incorporated in the PR&PP evaluation model of the system: progressive refinement***

Some Important Definitions

- ***<u>Proliferation resistance</u> is that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material, or misuse of technology, <u>by the host State</u> in order to acquire nuclear weapons or other nuclear explosive devices.***

- ***<u>Physical protection</u> (robustness) is that characteristic of a nuclear energy system that impedes the theft of materials suitable for nuclear explosives or radiation dispersal devices, and the sabotage of facilities and transportation, <u>by sub-national entities and other non-host State</u> adversaries.***

Assessment Paradigm

CHALLENGES → **SYSTEM RESPONSE** → **OUTCOMES**

Threats ***PR & PP*** ***Assessment***

Intrinsic
- Technical Design Features

Extrinsic (Safeguards/Protection)
- Institutional Arrangements

Proliferation, theft and sabotage involve <u>**competing**</u> **actors**.
Important to recognize actors' perspectives and the human interplay.

Measures

Physical Protection

- *Adversary Success Probability*
- *Consequence*
- *Cost of Protection*

Proliferation Resistance

- *Technical Difficulty*
- *Detection Probability*
- *Material Type*
- *Proliferation Cost*
- *Proliferation Time*
- *Safeguards Cost*

"Standards" for assessing/understanding Proliferation Resistance and Physical Protection

- ***Consider pathways/scenarios as well as the barriers that impede progress along each pathway***
- ***Include an explicit threat definition***
  - ***Clearly distinguish State proliferation from sub-national theft/sabotage***
- ***Consider the aspects of interest to both the adversary and the defender***

Some lessons learned for PRPP analysis

- ***Each PR&PP assessment should start with a <u>Qualitative</u> Analysis allowing scoping of the study, of the assumed threats and identification of targets, system elements etc.***
  - ***need to include detailed guidance for qualitative analyses in methodology***
- ***Role of experts is essential***
  - ***need for PR and PP experts and expert elicitation techniques***
- ***Qualitative analysis offers valuable results at preliminary design level. Can directly address TD, PT, PC, MT. DE and especially DP are harder to quantify***

Perspectives on PR&PP

- ***Introduce PR&PP at earliest stages of design***

    - A tool for "Safeguards & Protection by Design"

- ***Focus on user needs: Provide decision options for Designers , Policy Makers and Inspectors***
- ***Foster the establishment of a PR & PP culture***
- ***Thus work needs to be continually sustained in this area* – not just a "one-shot" report or study**

    It's not the numbers…it's the process and the insights derived

Safeguardability

- ***Because the probability of detection of a malevolent act by a proliferator is difficult to quantify, for new systems still in the design phase, the notion of Safeguardability has been introduced:***
- ***Safeguardability is defined as the ease with which a system can be effectively [and efficiently] put under international safeguards.***
- ***"Safeguardability" is a property of the whole nuclear system and is estimated for targets on the basis of characteristics related to the involved nuclear material, process implementation, and facility design.***

Safeguards by Design (SBD)

- *SBD: process of incorporating features to support international safeguards into nuclear facility designs starting in its conceptual design phase.*

- *Element of the design process for a new nuclear facility from initial planning through design, construction, operation, and decommissioning.*

- *SBD includes use of design measures that make the implementation of safeguards at such facilities more effective and efficient*

➢ *US Initiative in NNSA/NGSI Program; IAEA Safeguards Department*

Why early in the Design? …some Viewpoints

- ***Analysts and other non-designers (not all):***

"less costly to introduce safeguards at the beginning of the design process'

- ***Facility designers and owners (not all):***

" what do I gain from introducing safeguards early…just meet requirements whenever asked to"

Facility Safeguardability Assessment (FSA)

The methodology supports SBD in three areas:

1. It supports effective operator/designer engagement in the necessary interactions between the IAEA, the State regulator, and the owner/designer of a new or modified facility at the stages where the designer's SBD efforts can be applied most productively.

2. It presents a screening tool intended to help the designer identify potential safeguard issues for a) design changes to existing facilities, b) new facilities similar to existing facilities with established IAEA safeguards approaches, and c) new designs.

FSA - continued

3. It provides a structured framework for the application of the SBD tools such as SBD good practice guides, design guidance, and safeguardability evaluation methods (called here the FSA toolkit). This toolkit can be used by the owner/designer to both identify potential safeguards issues and to develop solutions for potential safeguards issues during the interactions with the State regulator and IAEA.

FSA can help the designer and its safeguards experts identify or anticipate:

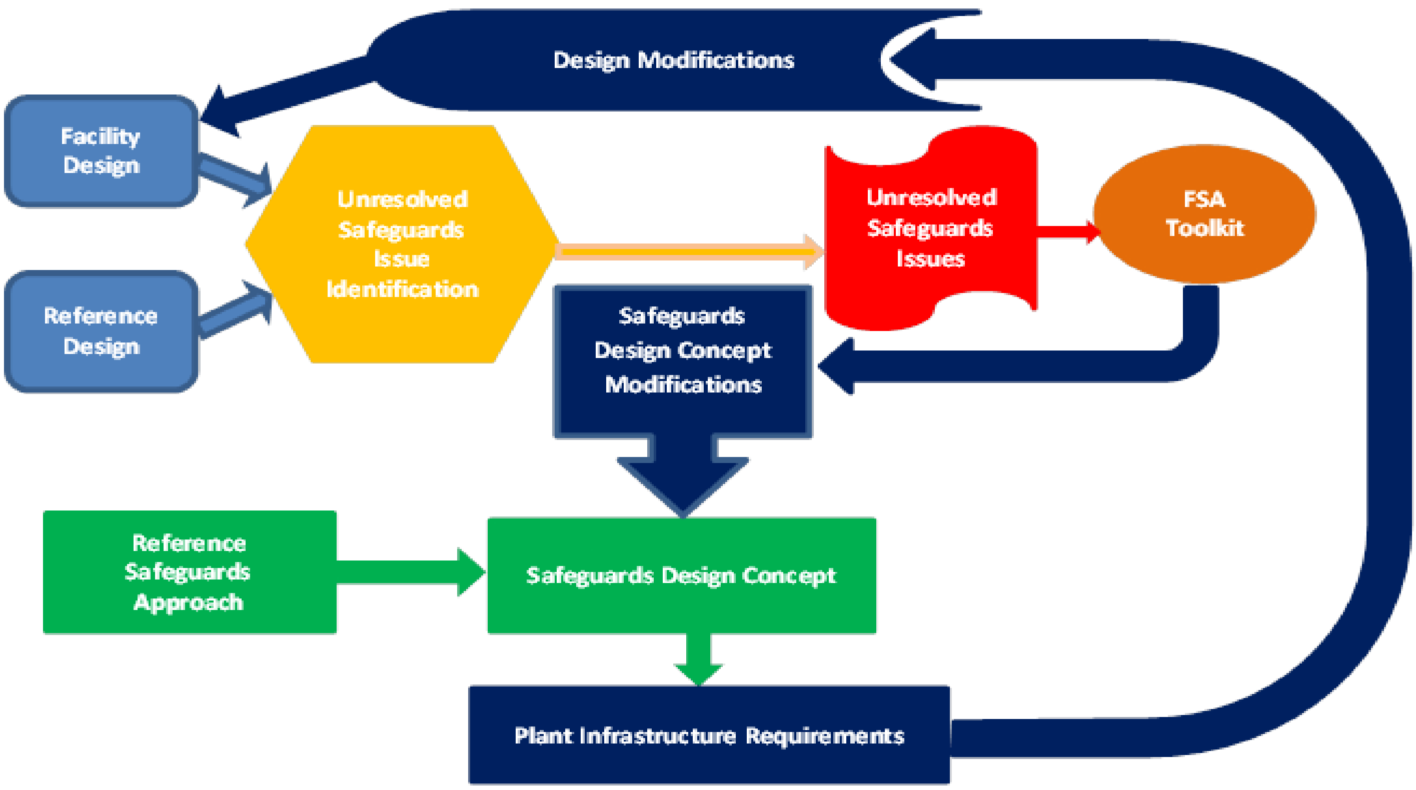
- ***Areas where elements of previous established safeguards approach(es) may be applied to facility modifications or new designs***
- ***Modifications of the facility design that could mitigate a potential safeguards issue or facilitate a more efficient application of the safeguards approach***
- ***Possible innovative ideas for more efficient application of IAEA safeguards tools and measures***
- ***The potential for changes in elements of the safeguards approach that may be required by the IAEA as a result of facility design features and characteristics.***

Benefit of FSA

- *FSA should help ensure that the facility design is compatible with the needs of the safeguards approach of the State and the IAEA.*

- *A key element of SBD is early and iterative interaction among the designer/operator, Safeguards Regulatory Authority (SRA)/Regional Safeguards Regulatory Authority (RSRA), and the IAEA*
- *FSA can be applied rather straightforwardly to new nuclear facilities that reflect modest design extrapolations from existing safeguarded facilities (e.g. current light water reactors), it can also be applied, with additional effort, to designs that are significantly different than the conventional facilities.*

FSA Process


Design Modifications
Facility Design
Reference Design
Unresolved Safeguards Issue Identification
Unresolved Safeguards Issues
FSA Toolkit
Safeguards Design Concept Modifications
Reference Safeguards Approach
Safeguards Design Concept
Plant Infrastructure Requirements

FSA process consists of four steps

1. ***Use of the FSA screening tool to identify aspects of the new design that may create issues for the application of international safeguards when compared to the reference facility.***
2. ***Develop safeguards design concept (SDC) describing suggested safeguards measures for the new design using SBD tools.***
3. ***Conduct a simple diversion pathway analysis to evaluate the effectiveness of proposed SDC.***
4. ***Compile lessons learned about the proposed SDC and a preliminary assessment of the safeguardability of the new design.***

Application of FSA

- ***Applying the FSA to evaluate design options, the designer can optimize the SBD for the overall design by using the established safeguards requirements and the performance requirements of the nuclear energy system as constraints and adjusting the system and safeguards designs to maximize deterrence to proliferation (increase detection probability and technical difficulty) as well as to minimize detection resources.***

Application of FSA –cont'd

- ***The FSA process employs a screening tool in the form of a check list to identify aspects of the new design that may create potential safeguards issues when compared to similar existing facilities for which the IAEA has implemented a safeguards approach.***

Proliferation Pathway Analysis

- *In terms of the six PR measures of PR&PP, the idea of safeguards-by-design (SBD) is to implement design features that enhance the intrinsic barriers to proliferation, i.e. increase technical difficulty (TD), while facilitate effective and efficient implementation of extrinsic barriers, i.e. increase detection probability (DP) and detection resource efficiency (DE).*
- *The other PR measures that may be impacted by good practices of SBD are: increase in proliferation time (PT) and proliferation cost (PC), and decrease in attractiveness of the nuclear material as reflected in the PR measure – material type (MT).*

PPA-cont'd

- ***An integral part of the FSA is the performance of a proliferation path analysis (PPA) to evaluate the proliferation resistance (PR) characteristics of the overall reactor/fuel system and the attendant safeguards measures.***
- ***An established methodology for PPA is the framework developed by the Generation IV International Forum (GIF) Proliferation Resistance and Physical Protection (PR&PP) working group.***

Outline of FSA steps related to PPA

1. Designer gathers information on facility design.
2. Designer performs a coarse, preliminary pathway analysis (see notes on pathways for details) to establish system elements and potential targets in the absence of any specified safeguards systems.
3. Identify most "risky" pathways and introduce safeguards functional requirements that would bring the facility within IAEA goals.
4. Perform refined pathway analysis with safeguards functional requirements present.
5. Consider safeguards sub-functional allocation (MC&A, C/S, DIV, etc.) and re-do analysis.
6. Iterate as additional information becomes available.

Summary

- ***FSA is an integral methodology for the designer to introduce safeguards by design to the state regulator and to the IAEA.***
- ***It can rely on some of the aspects of the PRPP methodology (i.e. pathway analysis) to conduct essential aspects of the FSA***
- ***PRPP is a comprehensive methodology for evaluating proliferation resistance and physical protection during the design phase of Gen IV nuclear energy systems***
- ***Some of the analysis conducted in a FSA can be used in support of a PRPP analysis.***

INPRO Role in Ensuring Sustainable Nuclear Energy System Development

Jon R. Phillips

INPRO Section

IAEA

International Atomic Energy Agency

Two common questions, comments:

- What role does INPRO play in IAEA Services to Member States?
- What is the relationship between INPRO, GIF PRPP MWG?
- Comments on application of INPRO Methodology assessment of sustainability in the area of Proliferation Resistance.

Strategic Nuclear Energy Planning: Beginning with the End in Mind

- Top-level national policy decisions, supporting nuclear power program, are *often focussed on nearer term progress and goals*
- A single modern NPP represents *nearly a century of commitment* from initial decision to full decommissioning
- Disposition of spent fuel and waste is institutionally complex and *commitments can span much more than a century*
- Near-term deployment of a first NPP implies *a long-term context* that typically involves further deployments: *strategic nuclear energy planning can help rationalise overall program direction.*

Nuclear Energy System (NES) Strategic Planning: 3 linked Parts

IAEA

INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles

Sustainability questions

National Energy Planning: How does ***nuclear energy*** fit into the national energy mix?

Nuclear Energy System (NES) modelling and the 'GAINS Framework': How do we get ***there*** from ***here***?

Nuclear Energy System Assessment (NESA): INPRO Methodology of sustainability assessment What are the ***gaps***?

IAEA

Services and Training Offered for Energy and NES Strategic Planning Tools

IAEA

INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles

- PESS offers training on broad energy planning that can help define the role of nuclear energy in the national energy mix.
- INPRO offers training on nuclear energy system (NES) strategic planning tools:
  - NES Assessment (NESA) using the INPRO Methodology helps develop a detailed technical perspective of actions needed to improve sustainability
  - NES Scenario Modelling and Key Indicator evaluation and analysis helps develop a big picture view of NES strategy and outcomes

Nuclear Energy Systems –
6 Key Sustainability Issues

To measure NES sustainability, metrics covering 6 key issues are assessed:

- Public and occupational safety – *i.e. radiation protection*
- Environmental impact
- High level and long-lived *radioactive waste disposal*
- National and international *security*
- Affordability and competitiveness
- Resource depletion

Among energy technologies, the set of unique nuclear energy sustainability issues are radiation protection, radioactive waste disposal and security.

IAEA-NE Sustainability Metrics – INPRO Methodology

INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles

- Originally derived from UN sustainable development concept (Brundtland Commission, 1987)
- Sustainability measured in a given time frame – within the present century
- Types of INPRO sustainability criteria:
  - Progress toward improved metric within a technology lineage
  - Comparative performance on a metric with respect to technology used for similar purpose (e.g., coal, natural gas)
  - Forward-looking target value of a metric
  - Yes or no answers on certain requirements and good practices
- INPRO Methodology currently being updated

What is INPRO Methodology?
Holistic Sustainability Assessment

IAEA

INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles

6 key issues that influence sustainability of nuclear power:

Existing INPRO Methodology (TECDOC 1575) – 8 manuals:

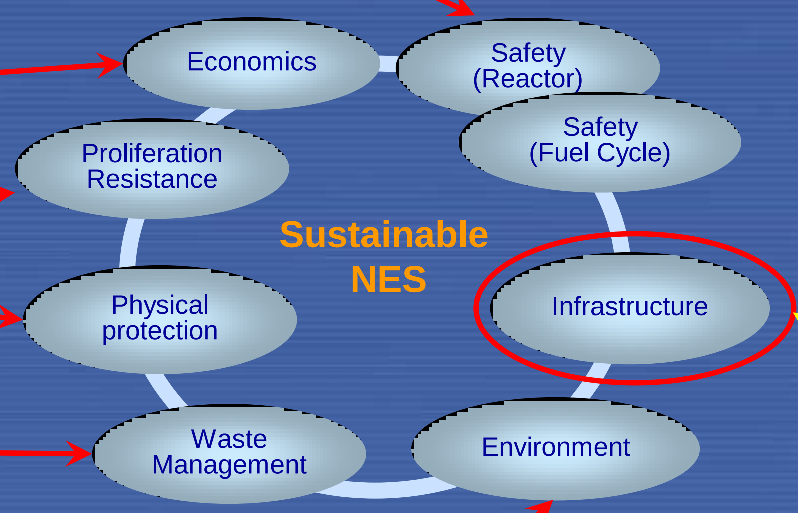
Safety

Affordability

Security

Waste

Environment and Resources



Cursory or unnecessary if INIR mission process is completed

IAEA

Structure of INPRO Methodology Sustainability Assessment

Architecture of the INPRO requirements

Basic Principles

↓

User Requirements

↓

Criteria
with Indicator and Acceptance Limit

Basic Principles:

goals for development of sustainable NES.

User Requirements:

what should be done by designer, operator, industry and/or State to meet goal defined in Basic Principle.

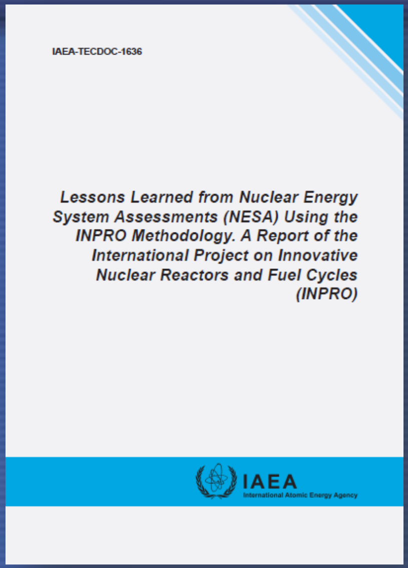
Criteria:

Assessor's tools to check whether a User Requirement has been met .

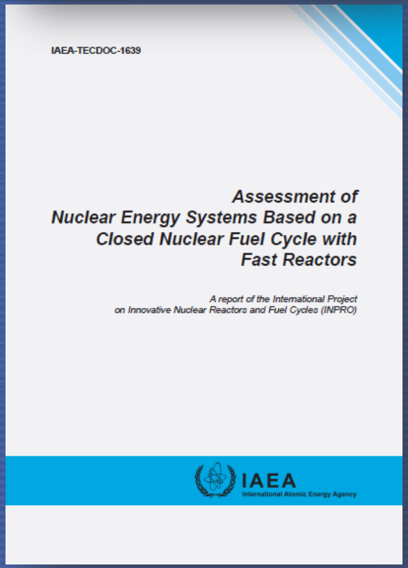
Experience with NESA

INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles

- 6 national assessments:
  - Argentina, Brazil, India, Republic of Korea as technology developer
  - Armenia, and Ukraine as technology user
- Documented in IAEA report TECDOC-1636



- 1 multinational assessment (“Joint Study”):
  - Canada, China, France, India, Japan, Republic of Korea, Russian Federation, and Ukraine
  - Development of NES of sodium cooled fast reactor with closed NFC
- Documented in IAEA report TECDOC-1639



IAEA

Experience with NESA

INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles

- NESA completed in Belarus:
  - Full scope assessment of all INPRO methodology areas
  - Published as TECDOC 1716
- NESA on-going in Indonesia:
  - Full scope assessment of two types of reactors and certain fuel cycle facilities – Indonesia has completed assessment of large reactor case
- NESA on-going in Ukraine:
  - Limited scope: economics, infrastructure, SNF/waste management
- NESA on-going in Romania:
  - Full scope assessment of two types of reactors and certain fuel cycle facilities
- NESA of Kazakhstan – TBD
- New projects: Limited Scope Assessments of Sodium Fast Reactor Designs of Russia, India and China

Modelling NES Development and Progress Toward Sustainability: The GAINS Framework

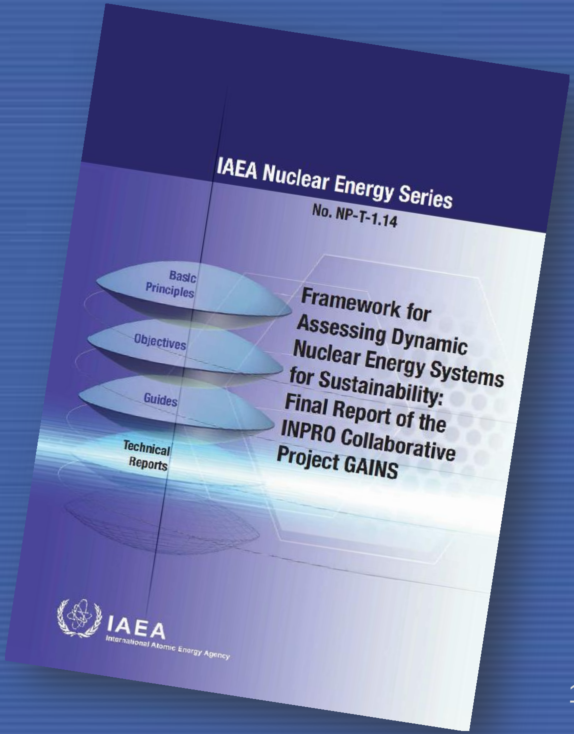
- The *collaborative project GAINS* was *initiated by MS* as a part of INPRO project
- The *objective* was to develop a *framework for modelling and assessing global NES regarding metrics of sustainable development* aiming at facilitating nuclear growth while minimizing financial, environmental, and political risks
- The *GAINS framework* is understood as:
  - Common methodological approach
  - Development of storylines for NP evolution and transition scenarios from current to future NES with thermal and fast reactors
  - Internationally verified data on reactors and associated fuel cycles
  - IAEA models & tools for simulation (in addition to national methods)
  - Agreed metrics for scenario simulation, analyses and assessment
  - Templates for analysis of simulation results and their assessment
  - Sample scenario studies to serve as examples and benchmarks

GAINS Project Organization

- **Strengths**
  - *15 Member States participated, including large supplier States –* **Belgium, Canada, China, Czech Republic, France, India, Italy, Japan, Republic of Korea, Russian Federation, Slovakia, Spain, Ukraine, USA, EC, and Argentina as an observer**
  - Thermal and fast reactor MS ‘communities’ working together
  - Unified criteria of sustainability *based on the INPRO Methodology*

- **History**
  - Project start: July 2008
  - Two meetings each year during 2009-2010
  - Last meeting: April 2011
  - Final report published in 2013: **NP-T-1.14**

  http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1598_web.pdf



Nuclear Energy System Scenario Analysis and Sustainable Future

IAEA

INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles

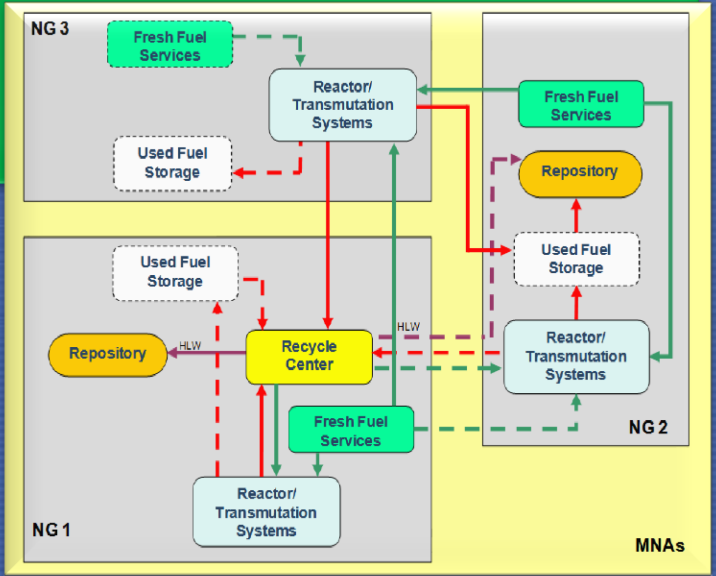
Today

- Reactors
  - water cooled – modest thermal efficiency
  - Large units
- Fuel resource
  - Natural/enriched U – limited natural resource
  - Limited U/Pu mono recycle – MOX
- Most SNF is stored and accumulating
- HL waste and direct SNF disposal
  - National repository development programmes
- Most trade in reactor and front end services

The Future?

- Reactors
  - Water, gas, metal and salt cooled, double the range of thermal efficiencies
  - Large and small modular units
- Fuel resource
  - Diverse and indefinite supply
  - U, U/Pu, Th/U-233
- SNF inventory in equilibrium with reactor fleet capacity
- HL waste and limited direct SNF disposal
  - National and regional repositories in operation
  - MA incinerated and disposed
- Trade distributed more uniformly across sectors improves economics

Developing system analysis and assessment tools to evaluate cooperative strategic paths to a sustainable future…



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SYNERGIES Scenarios: GAINS+

- LWR mono-U/Pu recycling
- Multi-recycling Pu-management in LWR+FR
- FR-centred scenarios
- Transition to Th/^{233}U via U/Pu HWR-LWR-FR Phase
- Alternative Complete U/Pu/Th-cycle
- Scenarios with advanced MA management

SYNERGIES final report is in copy editing for publication

SYNERGIES Case Studies

Attachment 2. Synergies planned deliverables table

#	Task/ Title	Responsible	Country	Status/Deadline
	Task 1			
1	Chapter on SYNERGIES storylines	L. Van den Durpel	France	Second Draft Submitted Complete draft to be provided by February 28th 2014
2	Task 1. Comparative assessment of collaborative fuel cycle options for Indonesia	B. Herutomo	Indonesia	In progress/ April-May 2014
3	Task 1. Recycle of REPU in PHWRs	D. Wojtaszek and G.W.R. Edwards	Canada	In progress/ Draft report in May 2014
4	Task 1. Scenario A.1 EU27 scenario with the extended use of regional fuel cycle centre composed of the La Hague and MELOX facilities and including Scenario A.1.1: Pre-cycling and /or TOP-MOX variant of introducing LWR-MOX in countries before domestically produced Pu can be recycled	L. Van den Durpel	France	In progress/ 31 January 2014
5	Task 1. National Romanian scenarios with reliance on domestic and imported U /fuel supply, by considering regional collaboration in nuclear fuel cycle and including economic analysis	C. Margeanu	Romania	In progress/ Draft report in May2014
6	Task 1.Scenario A.4 – National Argentinean scenario with cooperation options	S. Jensen	Argentina	Submitted
7	Task 1. Scenario B.1 with introduction of a number of fast reactors aimed at supporting the multi-recycle of Pu in LWRs and FRs: EU27 Framework	L. Van den Durpel	France	In progress/ 28 February 2014
8	Task 1. Scenario B.1 with introduction of a number of fast reactors aimed at supporting the multi-recycle of Pu in VVERs and FRs	G. Fesenko and V. Usanov	IAEA and Russia	Submitted
9	Task 1.Scenario B.2: ADRIA study	J. Manzano, M. Ciotti	Italy	In progress/ April 2014
10	Task 1. Scenario C.1 – Demo study on China simple case of NES scenario with Pu multi-recycling based on LWR and FR and CNFC	Keyan Zhou	China	In progress/ request to submit a report needs to be issued from IAEA/ April-May 2014
11	Task 1 Scenario C.2 and Task 3 - Long-term Scenario Study for Nuclear Fuel	K. Mukaida	Japan	Submitted, additional

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				part to be submitted by May 2014
		rov,	Russia,Ukraine, Armenia	Draft prepared/ May 2014
			Ukraine	Draft report under review/ May 2014
			IAEA and Russia	Submitted
			Russia	In progress/ February 2014
			India	In progress/ April 2014
			France	In progress/ 28February 2014
			Russia	In progress/ May 2014
			IAEA and Russia	Submitted, economics to be added
			Japan	In progress/ May 2014 (to be checked)
			Russia	Draft developed/ February 2014
			Ukraine	Started/ May 2014
	Task 3			
23	Task 3. Summary of a French study on radioactive waste transmutation options	L. Van den Durpel	France	TBD, once the report is translated into English, expected by March 2014

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			Belgium	Report in preparation/ Submission of a summary conditioned by a EU permission
			Belgium	In progress/ May 2014
			Spain	Partly completed, economic assessments to be added/ March 2014
			China	In progress/ request to submit a report needs to be issued from IAEA/ April-May 2014
			Canada	In Progress/ Draft report in May 2014
			France Belgium	December 9th 2013
			UK	To be checked
			IAEA	In progress/ current version available on SYNERGIES Web page
	synergistic GAINS scenarios		IAEA	Submitted
31	Task 4 – Report on KI down selection	IV. Dulera, C. Johari, Leaders of Tasks 1-3	India and IAEA	Draft report developed/ Available on SYNERGIES web-page

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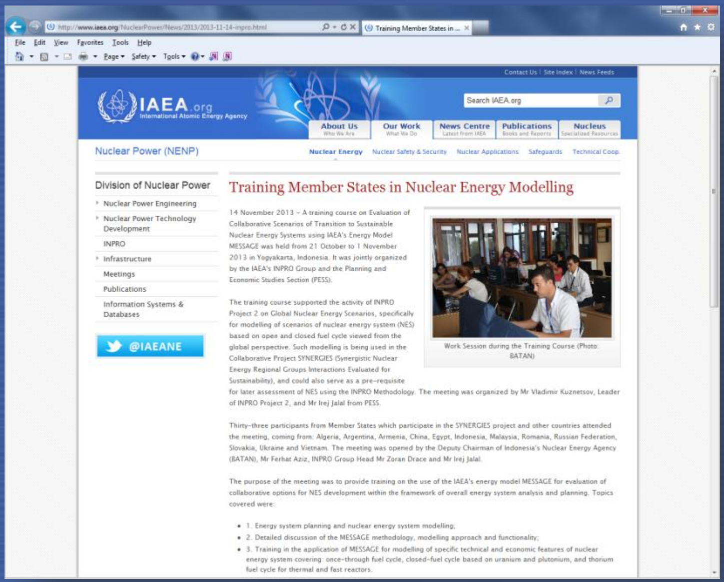
Ongoing Projects: KIND and ROADMAPS

- Key Indicators (KIND) collaborative project further refines key indicators of sustainable development and uses standard multicriteria decision theory approaches to aggregate KI evaluations
- ROADMAPS collaborative project formalizes approaches to document storylines of sustainable development and specific actions necessary

Regional Training Courses: analysis of collaborative scenarios of transition to sustainable nuclear energy systems and NESA

INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles



http://www.iaea.org/NuclearPower/News/2013/2013-11-14-inpro.html

Nuclear Power (NENP)

Division of Nuclear Power

- Nuclear Power Engineering
- Nuclear Power Technology Development
- INPRO
- Infrastructure
- Meetings
- Publications
- Information Systems & Databases

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Training Member States in Nuclear Energy Modelling

14 November 2013 – A training course on Evaluation of Collaborative Scenarios of Transition to Sustainable Nuclear Energy Systems using IAEA's Energy Model MESSAGE was held from 21 October to 1 November 2013 in Yogyakarta, Indonesia. It was jointly organized by the IAEA's INPRO Group and the Planning and Economic Studies Section (PESS).

Work Session during the Training Course (Photo: BATAN)

The training course supported the activity of INPRO Project 2 on Global Nuclear Energy Scenarios, specifically for modelling of scenarios of nuclear energy system (NES) based on open and closed fuel cycle viewed from the global perspective. Such modelling is being used in the Collaborative Project SYNERGIES (Synergistic Nuclear Energy Regional Groups Interactions Evaluated for Sustainability), and could also serve as a pre-requisite for later assessment of NES using the INPRO Methodology. The meeting was organized by Mr Vladimir Kuznetsov, Leader of INPRO Project 2, and Mr Irej Jalal from PESS.

Thirty-three participants from Member States which participate in the SYNERGIES project and other countries attended the meeting, coming from: Algeria, Argentina, Armenia, China, Egypt, Indonesia, Malaysia, Romania, Russian Federation, Slovakia, Ukraine and Vietnam. The meeting was opened by the Deputy Chairman of Indonesia's Nuclear Energy Agency (BATAN), Mr Ferhat Aziz, INPRO Group Head Mr Zoran Drace and Mr Irej Jalal.

The purpose of the meeting was to provide training on the use of the IAEA's energy model MESSAGE for evaluation of collaborative options for NES development within the framework of overall energy system analysis and planning. Topics covered were:

- 1. Energy system planning and nuclear energy system modelling;
- 2. Detailed discussion of the MESSAGE methodology, modelling approach and functionality;
- 3. Training in the application of MESSAGE for modelling of specific technical and economic features of nuclear energy system covering: once-through fuel cycle, closed-fuel cycle based on uranium and plutonium, and thorium fuel cycle for thermal and fast reactors.

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Relationship between INPRO and PRPP MWG

- INPRO, PESS efforts to support sustainable NES development, building along the lines of UN Brundtland Commission definitions.
- Proliferation Resistance is one dimension of sustainable development as defined in Brundtland Commission Report.
- INPRO PR assessment is a sustainability assessment metric.
- GIF PR methodology is a generic PR metric to support innovative design studies in a broader sense.

Relationship between INPRO and PRPP MWG

- INPRO PR assessment is a sustainability assessment metric – what does this mean?
  - In the current update of the INPRO Methodology, we are striving to tailor the Methodology to more clearly address the narrower questions of sustainability.
- What does this imply?
  - INPRO PR assessment will focus more deeply on institutional features of the nonproliferation regime as they apply to a particular NES under a given regime situation – good faith compliance is central to sustainability
  - This includes NPT, SG verification, Export Control behaviors and Trade Agreement effects.

Relationship between INPRO and PRPP MWG

INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles

- Under SG verification, the IAEA is the implementing Agency of the NPT.
  - Safeguards Department is the implementer of the verification regime and INPRO works in coordination and cooperation with SG.
  - INPRO Methodology focusses on concepts of SBD and existence or development of agreement on SG approach and basic compliance indicators.
  - In the case of “novelty” and “innovation” SBD becomes a critical issue.
- To support decisions on generic PR questions, PRPP Methodology is a broad metric.
- To support decisions on sustainable development, INPRO Methodology is an appropriate metric.

In Conclusion…

- INPRO, PESS efforts to support sustainable NES development – PR is one dimension:
  - PESS training on capabilities to support broad energy planning – including nuclear power sector projections
  - Training and use of INPRO Methodology for NES sustainability assessment (NESA)
  - INPRO codes for NES scenario modelling and Key Indicator evaluation and decision analysis methods
  - Collaborative Projects on innovations essential to NES sustainable development
  - INPRO Dialogue Forum brings together member States to discuss NES sustainable development topics

…Thank you for your attention

IAEA

International Atomic Energy Agency