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Opportunities for Meeting Growing Energy Demand without Increasing Proliferation Risks through Building Multilateral Approaches

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1. Introduction

- Nuclear energy (NE) limited role at present
- Opportunities for NE to increase its role significantly in 21 century
- Challenges in economic, safety, waste, resource, infrastructure and non-proliferation areas
- National and international activities (INPRO, GEN-IV, DG MNA group and others) aim to find responses
- Contradicting views and proposals in non-proliferation area.

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1.1 Different views and solutions

Is NPT sufficient or not? If not, what else have to be done?:

- NPT regime is a sufficient response. A need to enhance safeguard
- A need to develop technologies with enhanced proliferation resistant features
- A need to build Multilateral Nuclear Approaches (MNA).
- A need to restrict further dissemination of enrichment and reprocessing.

What to do with Pu accumulated by thermal reactors?:

- Dispose all spent fuel with Pu in repositories.
- Burn Pu in LWRs or in specially developed burners.
- Recycle Pu in fast reactors
- Fast reactors are least proliferation resistant choice

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1.2 Causes for differences

1. Differences in subjects of PR analysis:
   - Subject for analysis (Back-end part of fuel cycle, or reactor, or complete NES)
   - Type of NES (thermal or fast reactors, open or cloaked fuel cycle)
   - Geography (a specific country, or world)
2. Differences in scope of PR analysis:
   - Paths of NES misuse. (Covert misuse of NES, or covert parallel weapons program, or break-out scenario, or all paths together)
   - Type of responses (political, or institutional, or technical, or their combination)
   - Time perspectives (near or long term solutions)
   - Consideration of other challenges (security of energy supply, environment, economic, safety, waste, resources)
3. Differences in PR evaluation approaches:
   - INPRO, GEN-IV, DG MNA group, AFCI (USA), and many others

Existing differences in PR evaluation approaches and controversy in proposed solutions, if not openly discussed and understood, might complicate realization of efficient responses in non-proliferation area, and as a result, hinder realization of NE opportunities for global sustainable development.

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1.3 Objectives of the paper.

1. To present an approach for PR evaluation that:
   - take into account different possible paths of NE misuse
   - can be applied for analysis at national, regional and global levels
   - of different type of nuclear energy system (NES) with complete or incomplete fuel cycle
   - consider impact of both, technical and institutional, solution on PR and other NE related challenges.

2. To present preliminary results of application of the approach:

   indicating responses in technological and institutional areas that have to be done in near term in order

   to realize opportunities for large scale NE global growth in 21 century without increase of proliferation risk.

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2. Five steps PR evaluation approach*)

1. **Motivation.** Assess for a selected zone (country, region or world) risk of existence or emergence in future of a motivation to acquire nuclear weapon through covert nuclear weapon program CNWP.
2. **Opportunities.** Select type of NES and evaluate opportunities that it might provide in helping to acquire fissile materials for CNWP
3. **Barriers.** Evaluate sufficiency and efficiency of existing barriers taking into account level of motivation risk in a selected zone, features of NES and possible paths of its misuse. If needed propose additional technical, or institutional responses, or their mix. Evaluate their impact on safeguard efforts.
4. **Energy impact.** Evaluate impact of proposed PR responses on other energy system features – economics, safety, waste management, resource security.
5. **PR responses**. Select efficient PR responses taking into account results at 3d and 4st steps.

*) Analysis is limited to proliferation by states and does not include terrorist groups.

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2.1 Motivation.

Factors that might lead to existence or emergence in future of a government motivation to start CNWP:

- Regional or global political tension
- National security
- National ambitions
- International reaction

Understanding and minimizing factors leading to weapon motivation is a key in minimizing risk of proliferation.

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2.1 Motivation. How to evaluate risk?

- No basis to quantify motivation risk
- At the same time pooling all regions and countries in one “motivation risk” level basket contradict to realities

Our approach –

- **High**, **Medium** and **Low** qualitative marks based on expert assessment of factors favoring emergence of CNWP in the area.

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2.2. Opportunities for NES misuse.

If a country has launched CNWP then national NES might provide opportunities for its misuse to acquire fissile materials for weapon.

Three possible paths of NES misuse:

1. **Direct NES misuse.** Covert diversion of NES materials or covert misuse of NES technologies for CNWP purposes
2. **Misuse of knowledge.** Misuse of knowledge and/or human resources associated with NES in parallel CNWP.
3. **Break-out scenario.** Break-out from NPT and open misuse of NES materials and technologies

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2.2 Indicators for evaluating opportunities that a NES might provide for misuse

To evaluate opportunities one has to answer two questions

- *How attractive are Pu or U isotopic vectors used or that can be produced within NES for weapon?*
- *How much efforts might be needed for proliferators to change materials acquired within NES into a weapon usable form?*

They are important for policy makers, as well as for designers of reactors and fuel cycle facilities aiming to improve proliferation resistance features of NES.

Two indicators **Attractiveness (A)** and **Difficulty (D)** with **High/ Medium/ Low** calibration are proposed for this end.

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2.2. Evaluating Attractiveness.

IAEA safeguard glossary pools all possible variety of Pu isotopic content within NES (Pu-238 < 80%) in one category of attractiveness - Direct Use Materials (**DUM**).

This simplified approach might be sufficient for present safeguard needs, but it is too rough to guide a search for efficient measures aiming to reduce opportunities that NES might provide for its misuse.

From open data it is known that level of attractiveness for weapon of nuclear materials (NM) depend on their features, like critical mass, rate of emission of spontaneous neutrons, self-heating.

Based on consultant assessment of the above features for variety of Pu isotopic vectors it is proposed to introduce three subcategories of Pu attractiveness :

High (PU-H), Medium (Pu-M), Low (Pu-L),

depending on content of Pu-239 and Pu-238 isotopes

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2.2. Proposal for categorization of Pu

	Pu-238% < 0.1	0.1< Pu-238% <1	1< Pu-238% <3	3< Pu-238% <80
Pu-239% >95	Pu-H	PU-H	Pu-H	Pu-M
95> Pu-239% >80	Pu-H	Pu-H	Pu-M	Pu-M
80> Pu-239% >60	Pu-M	Pu-M	Pu-M	Pu-M
60> Pu-239%	Pu-M	Pu-L	Pu-L	Pu-L

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2.2. Proposal for categorization of U depending on content of U-235, U-233, U-232 isotopes

High (U-H)

a) HEU, containing U-235 >50% ;

b) U-233, containing U-232 <0,1%

Medium (U-M)

a) HEU, containing 20%< U-235 < 50%

b) U-233, containing 0.1%< U-232< 1%

Low (U-L)

a) U, containing U-235<20%

b) U-233, containing U-232>1%

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2.2 Categories of NES Attractiveness

- **Highly Attractive (HA):** A system would be determined to be **HA**, if it utilizes materials containing U and/or Pu of category **High**, and/or if these materials can be produced by using technologies and source materials available within the system.
- **Medium Attractive (MA):** A system would be characterised as **MA,** if it contained materials with U and/or Pu of categories **Medium** and not higher, and/or if U and/or Pu of category **Medium** and not higher can be produced by using technologies and sources within a system
- **Low Attractive (LA):** A system is qualified as **LA,** if it contains materials with U and/or Pu only of category **Low** and not higher, and/or if only this category of U and/or Pu can be produced by using technologies and source materials available within the system

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2.2 Evaluating Difficulty

- **Low Difficulty (LD):** A system is defined as having **LD**, if there are DUM in a separated form or if they can be produced using technologies and source materials available within a system.
- **Medium Difficulty (MD):** A system is qualified as having **MD**, if there is no DUM in a separated form, and if they can not be produced using technologies and source materials available within the system, and if their separation from materials available in a system would require a reprocessing facility based on a well known technology.
- **High Difficulty (HD):** A system is qualified as having **HD,** if there is no DUM in a separated form, and if they can not be produced in a separated form using technologies and source materials available within the system, and if for their separation from materials available in a system a sophisticated reprocessing facility or enrichment facility would be needed.

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2.3 Barriers

Political measures

NPT regime with its main verification component, – IAEA safeguard, is a political basis for providing assurance to international community of non-misuse of national NES.

Before revelation of Iraq's CNWP safeguard' main emphasis was on blocking "NES direct misuse".

After Iraq case with introduction of "Additional Protocol" (AP) IAEA safeguard provide assurance of absence also of parallel activities- "Misuse of knowledge" for those countries that signed AP.

After DPRK case discussions aim to find adequate political or institutional responses (MNA) to hinder use of - "Break-out scenario".

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2.3 Barriers

Technical solutions:

Different proposals aiming to enhance intrinsic proliferation resistant features are discussed, including within GEN –IV, INPRO, AFCI(USA) and initiatives.

Some consider that technical barriers would play a key role in future, other argue that technical barriers may play only complementary role:

- Technical solutions mostly aim to address first path of NES misuse, -"Direct misuse of NES". Nevertheless no pure technical fix has been found here.
- There are no technical proposals aiming to prevent "Misuse of knowledge" or "Break-out scenario
- Some proposed technical barriers would have negative implications on NES economics and safety

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2.3 Evaluating barriers

No internationally agreed approach for evaluating barriers.

INPRO, GEN-IV, AFCI use different approaches, and different indices

Here it is proposed to use one indicator

"Cost of Assurance" (CoA) – expert assessment of total cost of safeguard efforts and of additional technical measures required to assure non-misuse of a specific NES in a specific country.

To be consistent with measurements of A and D indicators it is propose to use also qualitative marks:

- **High CoA (HCoA)**
- **Medium CoA (MCoA)**
- **Low CoA (LCoA)**

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3. Evaluation of selected NES for global nuclear energy prospects

NES with complete U once-through cycles:

1. Light Water Reactor, LWR(U)-O
2. Heavy Water Reactor, HWR(U)-O
3. High Temperature Gas Reactor, HTGR(U)-O

NES with complete U-Pu cycles

4. LWR(U) +LWR(MOX)
5. LWR(U) + HWR(DUPIC)
6. LWR(U) + Fast Reactor(U-Pu)

NES with partial or no domestic fuel cycle

7. LWR(U)-B back-end fuel cycle facilities
8. HWR(U)-B back-end fuel cycle facilities
9. HTGR(U)-B back-end fuel cycle facilities
10. LWR(U) no domestic fuel cycle

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3. NES facilities

NES	Reactor	Enrich.	U fabric.	U-Pu fabric.	SNF storage	SNF reproc.	SNF repository
1	LWR(U)-O	+	+	-	+	-	+
2	HWR(U)-O	-	+	-	+	-	+
3	HTGR(U)-O	+	+	-	+	-	+
4	LWR(U)+ LWR(MOX)	+	+	+	+	+	+
5	LWR(U)+ HWR(DUPIC)	+	+	+	+	-	+
6	LWR(U)+ FR(U-Pu)	+	+	+	+	+	-
7	LWR(U)-B	-	-	-	+	-	+
8	HWR(U)-B	-	-	-	+	-	+
9	HTGR(U)-B	-	-	-	+	-	+
10	LWR(U)	-	-	-	-	-	-

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3.1 Evaluation of PR indices A, D and CoA

NES	Reactor	Opportunities		Cost of Assurance	
		Attractiveness	Difficulty	Country with motivation risk	
				High /	Low
1	LWR(U)-O	HA	LD	HCoA	LCoA
2	HWR(U)-O	HA	MD	HCoA	LCoA
3	HTGR(U)-O	HA	LD	HCoA	LCoA
4	LWR(U)+ LWR(MOX)	HA	LD	HCoA	LCoA
5	LWR(U)+ HWR(DUPIC)	HA	LD	HCoA	LCoA
6	LWR(U)+ FR(U-Pu)	HA	LD	HCoA	LCoA
7	LWR(U)-B	HA	MD	MCoA	LCoA
8	HWR(U)-B	HA	MD	HCoA	LCoA
9	HTGR(U)-B	HA	HD	MCoA	LCoA
10	LWR(U)	LA	HD	LCoA	LCoA

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3.1 Main findings from PR assessment -1

NES with complete set of fuel cycle facilities (1- 6).

- All complete NES have **HA** mark and all except NES-2 have **LD** mark. That is all complete NES would provide good opportunities for their misuse if not safeguarded.
  - ***HA marks here are due to possibility to produce U-H through misuse of enrichment facilities and/or Pu-H through misuse of reactors.***
  - ***LD marks, for all except NES-2, are due to possibility to get U-H and/or Pu-H in a separated form using NES technologies***
- If complete NES are in countries/regions with **High** motivation risks, than all of them would require **HCoA**, including for NES-2 with HWR operating in continues refueling mode.
- In our knowledge, at present there is no technical proposal blocking in principle possibility of misuse either of enrichment, or reprocessing facilities with country's intention to misuse these facilities in absence of safeguard. Some minor adjustment of these facilities, might be needed.
- **The only way to reduce assurance cost in countries using complete NES is political - to assist in minimization of motivation risks in those countries.**

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3.1 Main findings from PR assessment - 2

NES with back-end fuel cycle facilities (7-9)

- All NES with back-end fuel cycle facilities have **HA** mark and all have **MD** mark, except NES-9 with **LD**. That is all NES would provide some opportunities for their misuse if not safeguarded, although less than in case of complete fuel cycle systems .
  - *HA marks here are due to possibility to produce Pu-H through misuse of all type of reactors.*
  - *MD marks, for all except NES-9, are due to possibility to get Pu-H in a separated form by using well known Purex reprocessing technology.*
- If NES with back-end fuel cycle facilities are in countries/regions with **High** motivation risks, than all of them would require **MCoA**, except NES-8 with HWR operating in continues refueling mode.

NES without fuel cycle facilities (10)

- **LWR system with fresh fuel provided from outside and with spent fuel taken back has only green PR marks, including low cost of assurance, even in regions with high motivation risk.**

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3.1 Evaluation of NES from economic and resource sustainability perspectives

NES	Reactor	Economics		Resource sustainability		
		National NE		National NE		Global NE
		Small	Large	Small	Large	
1	LWR(U)-O	LE	HE	HRS?	MRS?	LRS
2	HWR(U)-O	LE	HE	HRS?	MRS?	LRS
3	HTGR(U)-O	LE	ME/HE?	HRS?	MRS?	LRS
4	LWR(U)+ LWR(MOX)	LE	ME/HE?	HRS?	MRS?	LRS
5	LWR(U)+ HWR(DUPIC)	LE	ME/HE?	HRS?	MRS?	LRS
6	LWR(U)+ FR(U-Pu)	LE	ME/HE?	HRS	HRS	HRS
7	LWR(U)-B	ME	HE	?	?	N/A
8	HWR(U)-B	ME	HE	?	?	N/A
9	HTGR(U)-B	ME	ME/HE?	?	?	N/A
10	LWR(U)	HE	HE	?	?	N/A

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3.1 Evaluation of NES from global resource sustainability perspective

- From global NE perspective only one system LWR(U)+ FR(U-Pu) can be considered as a system with High Resources Sustainability HRS features.
  - LWR(U) produce cheap energy by involving natural resources of U-235 in nuclear fuel cycle and by accumulating Pu prepare basis for introduction of fast reactors.
  - FR(U-Pu) utilize accumulated Pu and let to shift nuclear energy resource base from limited U-235 to practically unlimited U-238.
- All other type of systems and reactors have LRS features. They may have important values, but only locally and during limited period.
  - HWR and HTGR also use U-235 and generate Pu, but cost of its recycling much higher than in LWR case.
  - LWR(MOX) or HWR(DUPIC) - burners of plutonium may have value in minimizing Pu stocks in some countries. From global perspectives PU burning, as well as its disposal minimize resource base for future large scale global nuclear energy.
- Main challenge today is to develop cost efficient FR operating in closed fuel cycle. International cooperation in R&D is crucial (GEN-IV, INPRO).

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3.1 Overall findings from NES evaluation

Comparing results of two parts of analysis we understood that:

- On the one hand, LWR(U) and FR(U-Pu) may provide opportunity for large scale global development,
- On the other hand, this system like any other complete NES being used in regions with high motivation would provide opportunities for its misuse and would need significant increase of assurance efforts at global level, which might become intolerable.

Is there a way to overcome this challenge – to realize opportunities of large scale global nuclear energy with least PR? Analysis indicates that there is such a way, if :

1. Present technology holders would adopt a practice selling LWRs, in regions with high motivation risk, only with an attractive package of assurance of fresh fuel supply and take back spent fuel.
2. Collected spent fuel with Pu from these regions might be stored in special international storages built in regions with low motivation risks and with large nuclear energy programs.
3. In future, if FRs are developed and prove economical, then international fuel cycle centers with FR might be organized around the international spent fuel storages, not, than international repository of spent fuel.

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Conclusion

1. A holistic approach for evaluating institutional and technical responses in non-proliferation area is developed
2. Preliminary analysis shows that there is a possibility of large-scale global nuclear energy development without increasing proliferation risk.
3. To realize this possibility in future there is a need for international actions today:
   - Cooperation in R&D on FR as part of a closed fuel cycle
   - Building Multilateral Nuclear Approaches (Assurance of fuel supply and Spent fuel take-back policy; Regional LWR SNF fuel facilities)

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