Proliferation Resistance of Innovative Nuclear Systems

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Introduction

- Future energy needs will require use nuclear energy as one of the most reliable energy source.
- Nuclear energy always has dual nature – destructive and constructive
- Only human responsibility which side of NE will be used
- State (government) is responsible how NE will be used on its own territory
- Same time State is responsible in front of international community for proper and safe use of NE and all means involved in implementation of NE (nuclear materials, technology, facilities, radioactive wastes as results of NE use)

Introduction
cont.

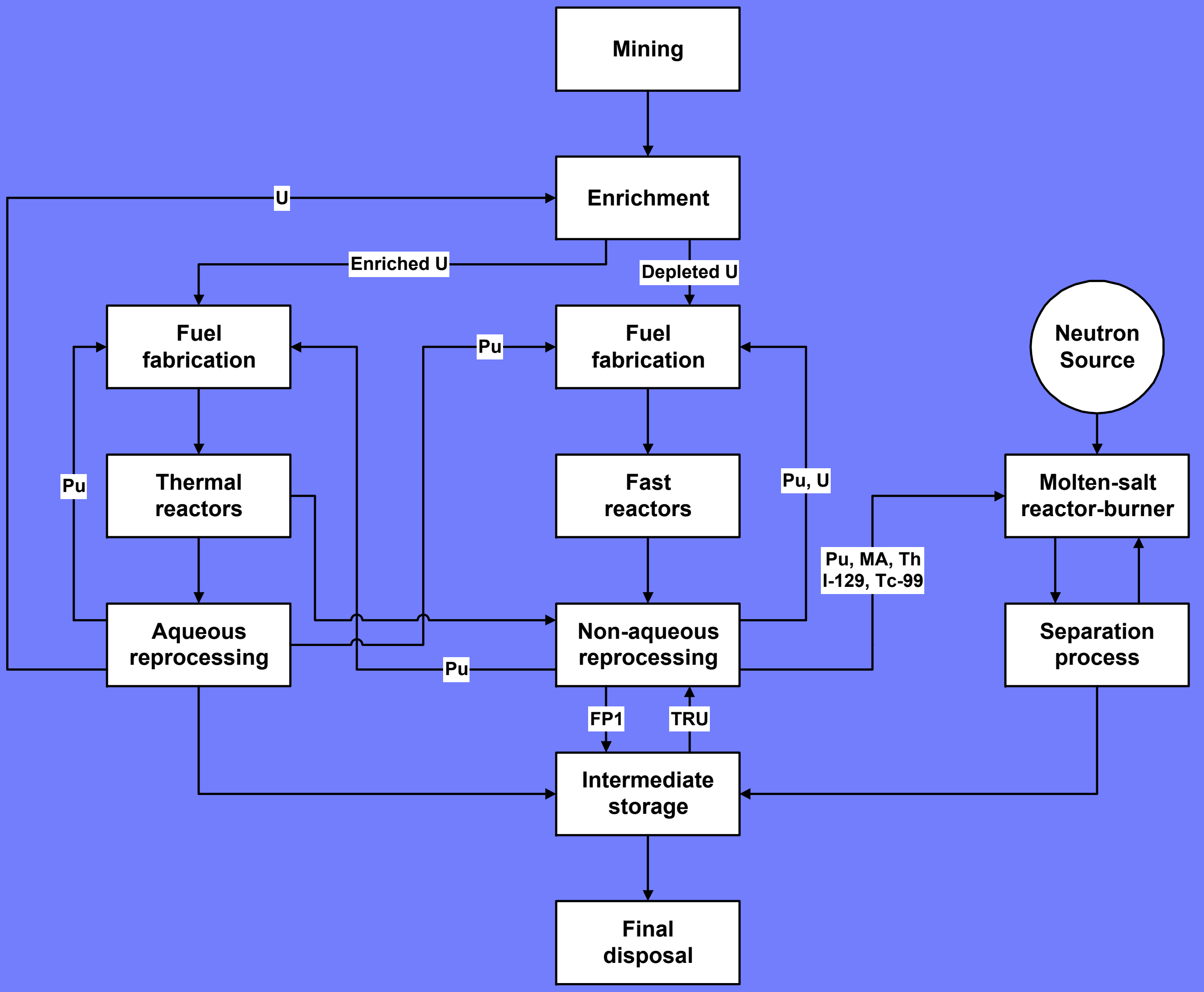
- Since all (any) fissile nuclear materials can be used with certain extend of difficulties to construct nuclear explosive device (by using any INS or its components) the nuclear fuel cycle can not be made completely free of proliferation risk. The assessment can identify most vulnerable elements of INS and relevant fuel cycle which could be weak from proliferation resistance point of view and which require special attention from designers and users. It also must be taken into account - who is doing the assessment. National experts intentionally or unintentionally can leave beside some points which could have serious impact on final results of assessment and recommendations. It makes extremely important that the methodology approach, principals, criteria, variables and acceptance limits have to be internationally accepted that the evaluation use objective parameters.
- The goal of INS and relevant fuel cycle proliferation resistance (PR) assessment is investigation of level of difficulty for to-be-proliferator create nuclear explosive devices using INS or its components by covered diversion of nuclear materials, misuse of technology or facilities. The methodology for PR assessment based on basic principals (BP), user requirements (UR), criteria and indicators developed and agreed by INPRO experts working group and published in IAEA TECDOC – 1434

Definition and key concepts

- Definition of PR :

  PR is that characteristic of a nuclear energy system that impedes the diversion or undeclared production of nuclear material (NM) or misuse of technology, by States in order to acquire nuclear weapons or other nuclear explosive devices
- Internationally agreed definition
  - Ref : IAEA's organized T.M. Oct. 2002 / STR-332, Dec 2002, IAEA TECDOC – 1432, Como meeting 2002
  - Used widely : GIF (Gen IV), INPRO, ….
- Physical Protection (PP) is complementary, but different
  - It addresses the theft of material suitable for making a nuclear explosive devise or a "dirty bomb"
  - There are some overlaps (e.g. : location and protection of N.M.). PP is sometimes extended to sabotage

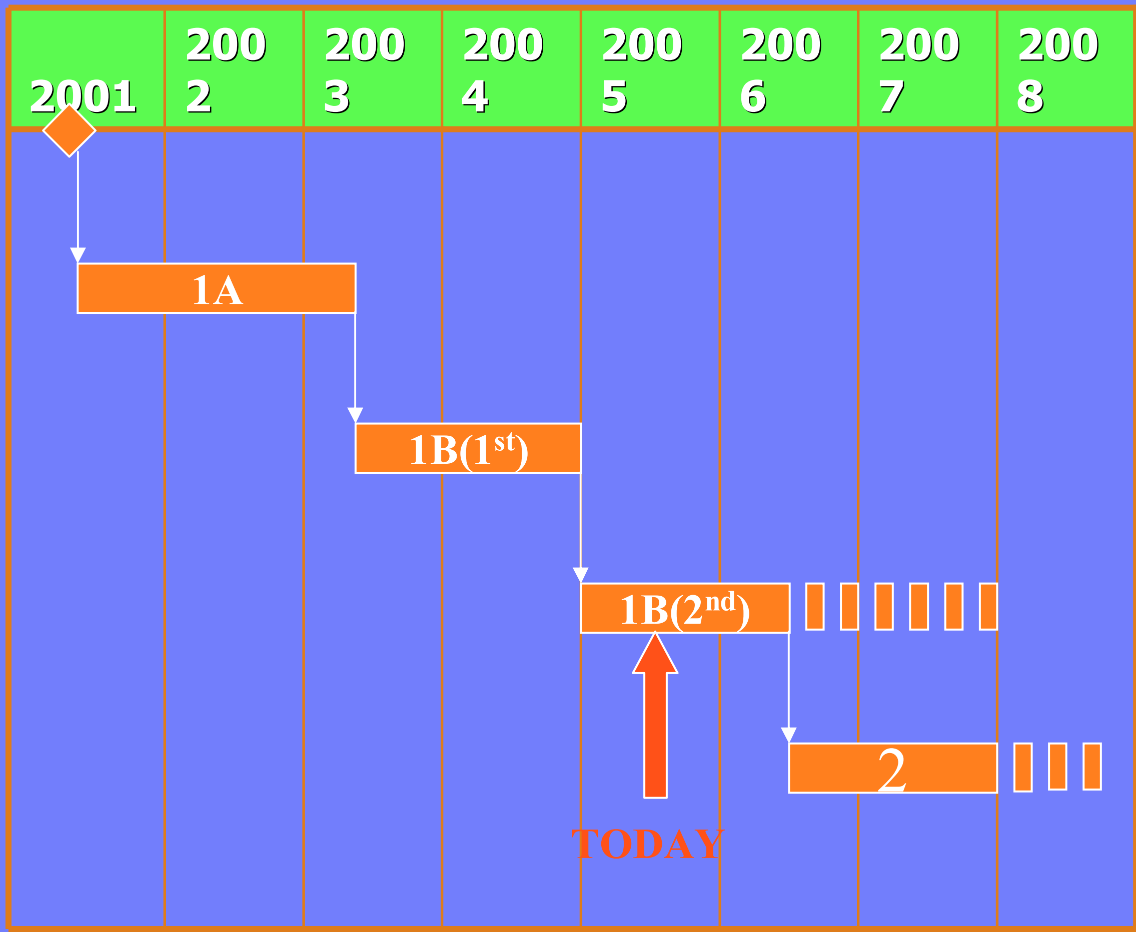
“Zero” approach of Innovation Nuclear System



Multi-component nuclear power system with closed fuel cycle for all actinides, including Pu and dangerous long-lived fission products (principle of coexistence)

Schedule of INPRO

- **Initiation**
  (in response to GC Res. 2000)
- **Phase 1A**
  (Methodology Development)
- **Phase 1B (1st part)**
  (Methodology Validation)
- **Phase 1B (2nd part)**
  (Methodology Application)
- **Phase 2**
  (International Cooperation)



Main Results of INPRO

- Results of Phase 1A(Jun. 2003)
  - TECDOC-1362, "Guidance for the evaluation of innovative nuclear reactors and fuel cycles"

- Results of Phase 1B 1st Part(Dec. 2004)
  - TECDOC-1434, "Methodology for the assessment of innovative nuclear reactors and fuel cycles"

Assessments of INS by MSs

- To improve the revised INPRO Methodology -

1. **Joint assessment of INS based on closed fuel cycle and fast reactors(China, France, India, Korea, Russia and Japan);**
2. **Assessment of hydrogen generating INS (India);**
3. **Study on transition from LWRs to Gen IV fast neutron system(France);**
4. **Assessment of the introduction of a nuclear bloc of 700 MWe (Argentina);**
5. **Assessment of INS for country with small grid(Armenia); and**
6. **Assessment of whole fuel cycle of DUPIC in the area of PR (Republic of Korea)**

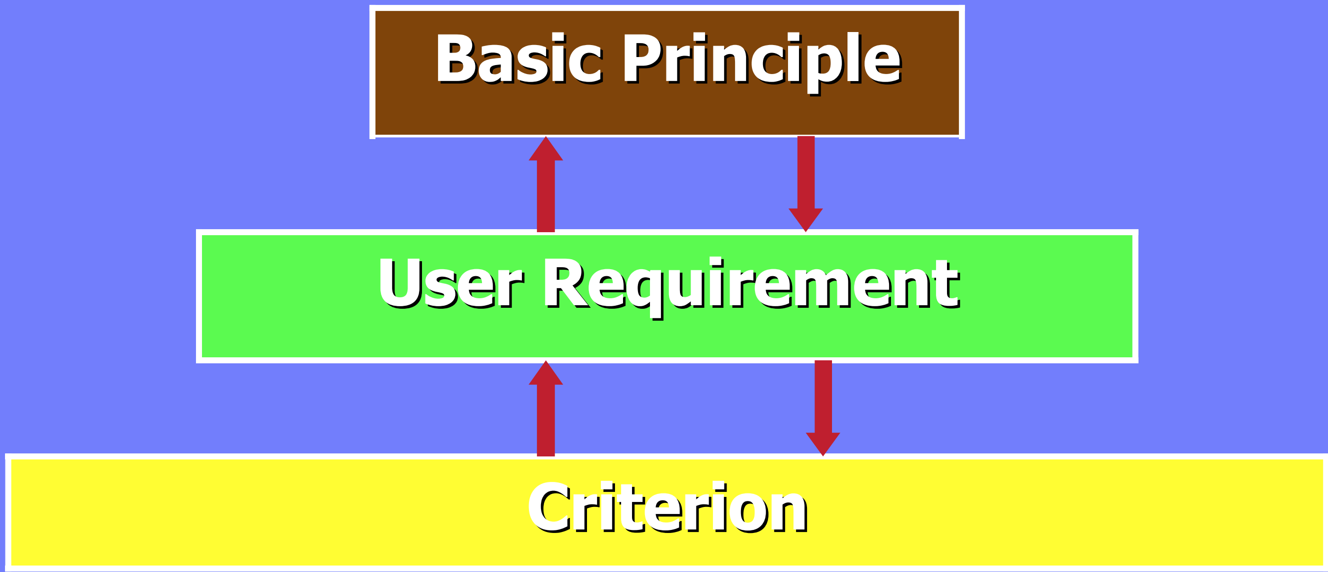
* Additional assessments are expected.

Definition

- **Proliferation Resistance**:
  - Characteristics of nuclear energy system that **impedes the diversion** or **undeclared production** of nuclear material or **misuse** of technology
- **Intrinsic Features**:
  - **Technical design** (e.g., core with small reactivity margins), including those that facilitate the extrinsic measures
- **Extrinsic Measures**:
  - **State's decisions** and **undertakings**(e.g., IAEA safeguards)

* Based on the international consensus reached in Oct. 2002 at a meeting held in Como, Italy.

INPRO Hierarchy*



* INPRP Hierarchy of demands on innovative designs of nuclear energy systems

- Basic Principle corresponds to the term '<u>Goal</u>' in Generation IV International Form (GIF).
- User Requirement corresponds to the term '<u>Criterion</u>' in GIF.
- Criterion corresponds to the term '<u>Metrics</u>' in GIF.

BPs, URs, Indicators, and Acceptance Limits
(According to the TECDOC 1434)

Hierarchy / Area	BPs	URs	Indicators	Acceptance Limits
Economics	1	4	8	8
Safety	4	14	38	38
Environment	2	4	9	9
Waste Management	4	7	24	24
Proliferation Resistance	**2**	**5**	**7**	**7**
Infrastructure	1	4	14	14

Hierarchy in the Area of PR (IAEA TECDOC 1434)

Basic Principles	User Requirements	Criteria	
		Indicators	Acceptance Limits
BP 1	UR 1.1	1.1.1	1.1.1
	UR 1.2	1.2.1	1.2.1
	UR 1.3	1.3.1	1.3.1
BP 2	UR 2.1	2.1.1	2.1.1
		2.1.2	2.1.2
	UR 2.2	2.2.1	2.2.1
		2.2.2	2.2.2

* **Based on the feedback from <u>MS's case studies</u> and <u>numerous consultancies.</u>**

Basic Principles

BP 1 : Proliferation resistance features and measures shall be implemented throughout the full life cycle for innovative nuclear energy systems to help ensure that INSs will continue to be an unattractive means to acquire fissile material for a nuclear weapons programme.

BP 2 : Both intrinsic features and extrinsic measures are essential, and shall be neither considered sufficient by itself.

BPs, URs and Indicators of PR in TECDOC 1434

Basic Principles

BPPR1 Proliferation resistance features and measures shall be implemented throughout the full life cycle for innovative nuclear energy systems to help ensure that INSs will continue to be an unattractive means to acquire fissile material for a nuclear weapons programme.

BPPR2 Both intrinsic features and extrinsic measures are essential, and neither shall be considered sufficient by itself.

User Requirements

URPR1.1 States' commitments, obligations and policies regarding non-proliferation should be adequate.

URPR1.2 The attractiveness of nuclear material in an INS for a nuclear weapons programme should be low. This includes the attractiveness of undeclared nuclear material that could credibly be produced or processed in the INS.

URPR1.3 The diversion of nuclear material should be reasonably difficult and detectable. Diversion includes the use of an INS facility for the introduction, production or processing of undeclared nuclear material.

URPR2.1 Innovative nuclear energy systems should incorporate multiple proliferation resistance features and measures.

URPR2.2 The combination of intrinsic features and extrinsic measures, compatible with other design considerations, should be optimized (in the design/engineering phase) to provide cost-efficient proliferation resistance.

Indicators

IPR1.1.1 States' commitments, obligations and policies regarding non-proliferation.

IPR1.2.1 Material Attractiveness.

IPR1.3.1 Difficulty and detectability of diversion.

IPR2.1.1 The extent by which the INS is covered by multiple intrinsic features. "Extent" is the fraction of plausible acquisition paths. It is understood that each acquisition path is covered by appropriate verification measures.

IPR2.1.2 Robustness of barriers covering an acquisition path.

IPR2.2.1 Cost to incorporate those intrinsic features and extrinsic measures, which are required to provide proliferation resistance.

IPR2.2.2 Verification approach with a level of extrinsic measures agreed to between the verification authority (e.g. IAEA, Regional safeguards organizations, etc.) and the State.

Variables

VPR1.1.1.1 ~ VPR1.1.1.14

VPR1.1.2.1 ~ VPR1.1.2.5

VPR1.1.3.1 ~ VPR1.1.3.9

Basic Principles

BP 1 : Proliferation resistance features and measures shall be implemented throughout the full life cycle for innovative nuclear energy systems to help ensure that INSs will continue to be an unattractive means to acquire fissile material for a nuclear weapons programme.

BP 2 : Both intrinsic features and extrinsic measures are essential, and shall be neither considered sufficient by itself.

User Requirements

UR 1.1 : State' commitments, obligations and policies regarding non-proliferation should be adequate.

UR 1.2 : The attractiveness of nuclear material in an INS for a nuclear weapons programme should be low.
This includes the attractiveness of undeclared nuclear material that could credibly be produced or processed in the INS.

UR 1.3 : The diversion of nuclear material should be reasonably difficult and detectable*. Diversion includes the use of an INS facility for the introduction, production or processing of undeclared nuclear material.
(* "Detectable" may be described by the term "Safeguardability")

UR 2.1 : Innovative nuclear energy systems should incorporate multiple proliferation resistance features and measures.

UR 2.2 : The combination of intrinsic features and extrinsic measures, compatible with other design considerations, should be optimized (in the design/ engineering phase) to provide cost-efficient proliferation resistance.

Indicators, Acceptance Limits, and Variables

- Indicators and Acceptance Limits have been defined to assess the fulfillment of <u>each of the User Requirements</u>.
- Variables have been defined to describe in detail the nature of <u>each of the Indicators</u>.
  - IN 1.1.1 : State' commitment, obligations and policies(14)
  - IN 1.2.1 : Material Attractiveness(5)
  - IN 1.3.1 : Difficulty and detectability of diversion(11)
  - IN 2.1.1 : Extent covered by multiple intrinsic features(11)
  - IN 2.1.2 : Robustness of barriers covering an acquisition path(11)
  - IN 2.2.1 : Cost of intrinsic features and extrinsic measures(1)
  - IN 2.2.2 : Verification approach of extrinsic measures(1)

  * The figures in parenthesis mean <u>the number of variables</u> defined by consultancy.

Methods can be used for PR assessment

- Expert group Delphi techniques (EGD);
- Comparative Value (cost) Measures (CVM);
- Multi-Attribute Utility Analysis/Theory (MAUA);
- Multi-Criteria Optimizations (MCO);
- Risk/Consequence or Probabilistic Risk Analysis (R/CA or PRA);
- Fuzzy Logic Barrier Method (FLBM).

New Proposed Indicators in the area of PR

Basic Principles	User Requirements	Indicators
BPPR1 Proliferation resistance features and measures shall be implemented throughout the full life cycle for innovative nuclear energy systems to help ensure that INSs will continue to be an unattractive means to acquire fissile material for a nuclear weapons programme.	**URPR1.1** States' commitments, obligations and policies regarding non-proliferation should be adequate	**IPR1.1.1**: States' commitments, obligations and policies **IPR1.1.2**: Agreements between exporting and importing States **IPR1.1.3**: Commercial, legal or institutional arrangements that control access to NM and NES **IPR1.1.4**: IAEA verification and, as appropriate, regional, bilateral and national measures **IPR1.1.5**: Legal and institutional arrangements to address violations of nuclear non-proliferation
	URPR1.2 The attractiveness of nuclear material in an INS for a nuclear weapons programme should be low. This includes the attractiveness of undeclared nuclear material that could credibly be produced or processed in the INS.	**IPR1.2.1**: Isotope content **IPR1.2.2**: Chemical form **IPR1.2.3**: Radiation field **IPR1.2.4**: Heat generation **IPR1.2.5**: Spontaneous neutron generation rate
	URPR1.3 The diversion of nuclear material should be reasonably difficult and detectable. Diversion includes the use of an INS facility for the introduction, production or processing of undeclared nuclear material	**IPR1.3.1** Difficulty to modify fuel cycle facilities and process for undeclared production **IPR1.3.2**: Design features that limit access to NM **IPR1.3.3**: Bulk/mass **IPR1.3.4**: Diversion detectability **IPR1.3.5**: Skills, expertise and knowledge required to divert or produce NM and convert it to weapons useable form
BPPR2 Both intrinsic features and extrinsic measures are essential, and neither shall be considered sufficient by itself.	**URPR2.1** Innovative nuclear energy systems should incorporate multiple proliferation resistance features and measures.	**IPR2.1.1** The extent by which the INS is covered by multiple intrinsic features. "Extent" is the fraction of plausible acquisition paths. It is understood that each acquisition path is covered by appropriate verification measures **IPR2.1.2** Robustness of barriers covering an acquisition path
	URPR2.2 The combination of intrinsic features and extrinsic measures, compatible with other design considerations, should be optimized (in the design/engineering phase) to provide cost-efficient proliferation resistance	**IPR2.2.1** Cost to incorporate those intrinsic features and extrinsic measures, which are required to provide proliferation resistance. **IPR2.2.2** Verification approach with a level of extrinsic measures agreed to between the verification authority (e.g. IAEA, Regional safeguards organizations, etc.) and the State.

Indicator in TECDOC-1434	New Proposed Indicators
Indicator 1.1.1 : States' commitments, obligations and policies regarding non-proliferation *14 Variables for evaluation of indicators* 1. Safeguards agreements pursuant to the NPT 2. Nuclear-weapons-free zone treaties 3. Comprehensive IAEA safeguards agreements 4. Additional protocols of IAEA agreements 5. Export control policies 6. Bilateral agreements for supply and return of nuclear material 7. Bilateral agreements governing re-export of NES components 8. Commercial, legal or institutional arrangements to control access to NM and NES 9. Relevant international conventions 10. Multi-national ownership, management or control of a NES 11. Verification activities 12. State or regional systems for accounting and control 13. Safeguards approaches for the State's or regional safeguard system, capable of detecting diversion or undeclared production 14. An effectiveness international response mechanism for violations	**Indicator 1.1.1** : States' commitments, obligations and policies • NPT • Nuclear-weapons-free zone treaties • Comprehensive IAEA safeguards agreements • Additional protocols of IAEA agreements **Indicator 1.1.2** : Agreements between exporting and importing States • Export control policies • Bilateral agreements for supply and return of NM • Bilateral agreements governing re-export of NES components **Indicator 1.1.3** : Commercial, legal or institutional arrangements to control access to NM and NES • Commercial, legal or institutional arrangements that control access to NM and NES • Relevant international conventions • Multi-national ownership, management or control of a NES **Indicator 1.1.4** : IAEA verification and, as appropriate, regional, bilateral and national measures • Verification activities • State or regional systems for accounting and control • Safeguards approaches for the State's or regional safeguard system, capable of detecting diversion or undeclared production **Indicator 1.1.5** : Legal and institutional arrangements to address violations of nuclear non-proliferation • An effectiveness international response mechanism for violations
Note: One Indicator(1.1.1) has same wording with User Requirement 1.1.	Note: Make 5 Indicators according to 5 Categories of "*Extrinsic Measures*" in TECDOC-1434 and rearrange 14 Variables as Evaluation Parameters instead of Indicator 1.1.1 in TECDOC-1434

Indicator in TECDOC-1434	New Proposed Indicators
Indicator 1.3.1 : Difficulty and detectability of diversion	**Indicator 1.3.1** : Difficulty to modify fuel cycle facilities and process for undeclared production • Degree of difficulty
9 Variables for evaluation of indicators 1. Difficulty to modify fuel cycle facilities and process for undeclared production 2. Design features that limit access to NM 3. Bulk and mass 4. Diversion detectability 5. Skills, expertise and knowledge required to divert or produce NM and convert it to weapons useable form 6. Complexity of, and time required for modifications necessary to use a civilian INS for a weapons production facility (Duplicated with 1.) 7. Time required to divert or produce NM and convert it to weapons useable form (Duplicate with Indicator 1.2.2: Chemical form) 8. Material stocks and flows (Duplicated with 4.) 9. Effectiveness of prevention of diversion of NM (Duplicated with 2.)	**Indicator 1.3.2** : Design features that limit access to NM • Environment between proliferator and NM **Indicator 1.3.3** : Bulk and Mass • Mass for 1SQ (kg) • Size of NM to be diverted (cm) **Indicator 1.3.4** : Diversion detectability • MUF **Indicator 1.3.5** : Skills, expertise and knowledge required to divert or produce NM and convert it to weapons useable form • Degree of skill and knowledge required
Note: One Indicator and same wording with User Requirement 1.3. Variables 6,7, 8 and 9 are duplicated and need to be deleted.	Note: Make 5 Indicators related to "*Difficulty of Diversion*" among intrinsic features in TECDOC-1434 and define "Evaluation Parameters" for each indicator

Indicator in TECDOC-1434	New Proposed Indicators
Indicator 1.2.1 : Material attractiveness	Indicator 1.2.1 : Isotope content • 239Pu/Pu (wt%) • 235U/U (wt%) • 232Ucontamination for 233U (ppm)
5 Variables for evaluation of indicators 1. Isotope content 2. Chemical form 3. Radiation field 4. Heat generation 5. Spontaneous neutron generation rate	Indicator 1.2.2 : Chemical form • Chemical form Indicator 1.2.3 : Radiation field • Dose (rem/hr) Indicator 1.2.4 : Heat generation • 238Pu/Pu (wt%) Indicator 1.2.5 : Spontaneous neutron generation rate • (240Pu+ 242Pu)/Pu (wt%)
Note: One Indicator and same wording with User Requirement 1.2	Note: Make 5 Indicators related to "*Material Attractiveness*" among intrinsic features in TECDOC-1434 and define Evaluation Parameters for each indicator

Indicator in TECDOC-1434	New Proposed Indicators
Indicator 2.1.1 The extent by which the INS is covered by multiple intrinsic features. "Extent" is the fraction of plausible acquisition paths. It is understood that each acquisition path is covered by appropriate verification measures.	**Indicator 2.1.1 (same to left)** • Fraction of the number of plausible acquisition paths of INS to the number of those of the most sensitive facility
Indicator 2.1.2 Robustness of barriers covering an acquisition path	**Indicator 2.1.2 (same to left)** • Extent of robustness of barriers
Indicator 2.2.1 Cost to incorporate those intrinsic features and extrinsic measures, which are required to provide PR	**Indicator 2.2.1 (same to left)** • Sum of the costs for enhancing intrinsic features and IAEA inspection during life time
Indicator 2.2.2 Verification approach with a level of extrinsic measures agreed to between the verification authority(e.g. IAEA, Regional safeguards organizations, etc.) and the State.	**Indicator 2.2.2 (same to left)** • Robustness of verification approach

BP 1: **PR features and measures shall be implemented throughout the full life cycle for innovative nuclear energy systems to help ensure that INSs will continue to be an unattractive means to acquire fissile material for a nuclear weapons programme.**

UR 1.1: **States' commitments, obligations and policies regarding non-proliferation should be adequate.**

Indicators	Evaluation Parameters	Evaluation scale*	
		U	A
Indicator 1.1.1: States' commitments, obligations and policies	• NPT • Nuclear-weapons-free zone treaties • Comprehensive IAEA safeguards agreements • Additional protocols of IAEA agreements	No	Yes
Indicator 1.1.2: Agreements between exporting and importing States	• Export control policies • Bi-lateral agreements for supply and return of nuclear material • Bi-lateral agreements governing re-export of NES components	No	Yes
Indicator 1.1.3: Commercial, legal or institutional arrangements to control access to NM and NES	• Commercial, legal or institutional arrangements that control access to NM and NES • Relevant international conventions • Multi-lateral ownership, management or control of a NES	No	Yes
Indicator 1.1.4: IAEA verification and, as appropriate, regional, bilateral and national measures	• Verification activities • State or regional systems for accounting and control • Safeguards approaches for the State's or regional safeguard system, capable of detecting diversion or undeclared production	No	Yes
Indicator1.1.5: Legal and institutional arrangements to address violations of nuclear non-proliferation	• An effectiveness international response mechanism for violations	No	Yes

* U: Unacceptable, A: acceptable

BP 1: **PR features and measures shall be implemented throughout the full life cycle for innovative nuclear energy systems to help ensure that INSs will continue to be an unattractive means to acquire fissile material for a nuclear weapons programme.**

UR 1.2: **The attractiveness of nuclear material in an INS for a nuclear weapons programme should be low.**

Indicators	Evaluation Parameters	Evaluation scale*				
		U	W	M	S	V
Indicator 1.2.1: Isotope content	• 239Pu/Pu (wt%)	> 93	80~93	70~80	60~70	< 60
	• 235U/U (wt%)	> 90	50~90	20~50	5~20	< 5
	• 232Ucontam. for 233U (ppm)	< 1	1~100	100~4000	4000~7000	> 7000
Indicator 1.2.2: Chemical form	• Chemical form	Pure Pu metal	PuO_2, PuN	Fresh MOX	Spent fuel	Spent fuel with high burnup
Indicator 1.2.3: Radiation field	• Dose (rem/hr)	< 1	1~15	15~100	100~1000	> 1000
Indicator 1.2.4: Heat generation	• 238Pu/Pu (wt%)	< 0.1	0.1~1	1~10	10~80	> 80
Indicator 1.2.5: Spontaneous neutron generation rate	• (240Pu+ 242Pu) /Pu (wt%)	< 1	1~10	10~20	20~50	> 50

* U: Unacceptable, W: weak, M: Moderate, S:Strong, V: Very Strong

BP 1: PR features and measures shall be implemented throughout the full life cycle for innovative nuclear energy systems to help ensure that INSs will continue to be an unattractive means to acquire fissile material for a nuclear weapons programme.

UR 1.3: The diversion of nuclear material should be reasonably difficult and detectable.

Indicators	Evaluation Parameters	Evaluation scale*				
		U	W	M	S	V
Indicator 1.3.1: Difficulty to modify fuel cycle facilities and process for undeclared production	• Degree of difficulty • Time for modification • Complexity of modification	Very easy	Easy	Medium	Difficult	Very difficult
Indicator1.3.2: Design features that limit access to NM	• Environment between proliferator and NM	Open	Limited open	Glove box, concrete, or metal	Shielded hot cell	Geological media
Indicator1.3.3: Bulk/Mass	• Mass (kg)	< 10	10~100	100~500	500~1000	> 1000
	• Size (cm)	< 10	10~40	40~100	100~300	> 300
Indicator1.3.4: Diversion detectability (MUF)	• Kg Pu or 233U	> 16	8~16	4~8	2~4	< 2
	• Kg 235U with LEU	> 50	25~50	25~12	7~6	< 6
	• Kg 235U with HEU	> 150	37~75	18~37	9~18	< 9
	• Ton Th	> 40	20~40	10~20	5~10	< 5
Indicator 1.3.5: Skills, expertise and knowledge required to divert or produce NM and convert it to weapons useable form	• Degree of Skill and knowledge	Very high	High	Medium	Low	Very low

* U: Unacceptable, W: weak, M: Moderate, S:Strong, V: Very Strong

BP 2: **Both intrinsic features and extrinsic measures are essential, and neither shall be considered sufficient by itself.**

UR 2.1: **Innovative nuclear energy systems should incorporate multiple PR features and measures.**

Indicators	Evaluation Parameters	Evaluation scale*				
		U	W	M	S	V
Indicator 2.1.1: The extent by which the INS is covered by multiple intrinsic features	• Fraction of the number of plausible acquisition paths of INS to the number of those of the most sensitive facility	1~0.8	0.8~0.6	0.6~0.4	0.4~0.2	< 0.2
Indicator 2.1.2: Robustness of barriers covering an acquisition path	• Extent of Robustness of barriers	Very low	Low	Medium	High	Very high

* U: Unacceptable, W: weak, M: Moderate, S:Strong, V: Very Strong

BP 2: Both intrinsic features and extrinsic measures are essential, and neither shall be considered sufficient by itself.

UR 2.2: The combination of intrinsic features and extrinsic measures should be optimized to provide cost-efficient PR.

Indicators	Evaluation Parameters	Evaluation scale*				
		U	W	M	S	V
Indicator 2.2.1: Cost to incorporate those intrinsic features and extrinsic measures, which are required to provide PR	• Sum of the costs for enhancing intrinsic features and IAEA Inspection during life time					
Indicator 2.2.2: Verification approach with a level of extrinsic measures agreed to between the verification authority and the State	• Robustness of Verification approach	Very low	Low	Medium	High	Very high

* U: Unacceptable, W: weak, M: Moderate, S:Strong, V: Very Strong

Sample Table of PR Assessment for INS System

Parameter/ Step	Evaluation Score																										SUM
BPPR	BP1																		BP2								
WF for BP	0.5																		0.5								
URPR	UR1.1						UR1.2						UR1.3						BP	UR2.1			UR2.2			BP	
WF for UR	0.3						0.5						0.2							0.4			0.6				
IPR	1	2	3	4	5	UR	1	2	3	4	5	UR	1	2	3	4	5	UR		1	2	UR	1	2	UR		
WF for Ind.	0.5	0.2	0.1	0.1	0.1		0.3	0.2	0.2	0.2	0.1		0.3	0.1	0.2	0.2	0.2			0.5	0.5		0.5	0.5			
PWR																											
Step P1	5	5	1	5	5	4.6						0						0	1.38			0			0	0	0.69
Step P2	5	5	1	5	5	4.6						0						0	1.38			0			0	0	0.69
Step P3	5	5	1	5	5	4.6						0						0	1.38			0			0	0	0.69
Step P4	5	5	1	5	5	4.6						0						0	1.38			0			0	0	0.69
Step P5	5	5	1	5	5	4.6						0						0	1.38			0			0	0	0.69
Step P6	5	5	1	5	5	4.6						0						0	1.38			0			0	0	0.69
Step P7	5	5	1	5	5	4.6						0						0	1.38			0			0	0	0.69
Step P8	5	5	1	5	5	4.6						0						0	1.38			0			0	0	0.69
Step P9	5	5	1	5	5	4.6						0						0	1.38			0			0	0	0.69
Step P10	5	5	1	5	5	4.6						0						0	1.38			0			0	0	0.69
Step P11	5	5	1	5	5	4.6						0						0	1.38			0			0	0	0.69
DUPIC																											
Step D1	5	5	1	5	5	4.6						0						0	1.38			0			0	0	0.69
Step D2	5	5	1	5	5	4.6	5	4	3	3	4	3.9	4	4	4	3	4	3.8	4.09	4	4	4	3	4	3.5	3.7	3.9
Step D3	5	5	1	5	5	4.6						0						0	1.38			0			0	0	0.69
Step D4	5	5	1	5	5	4.6	5	4	3	3	4	3.9	3	3	2	5	4	3.4	4.01	4	2	3	3	3	3	3	3.51
Step D5	5	5	1	5	5	4.6						0						0	1.38			0			0	0	0.69
Step D6	5	5	1	5	5	4.6						0						0	1.38			0			0	0	0.69
Step D7	5	5	1	5	5	4.6						0						0	1.38			0			0	0	0.69
Step D8	5	5	1	5	5	4.6	5	4	1	3	5	3.6	4	4	4	5	5	4.2	4.02	5	5	5	5	5	5	5	4.51
SUM																											

$$YPR_i = \sum_i w_{i,j} \cdot XPR_{i,j}$$

(***YPR***: UR or BP ; ***XPR***: Indicator or UR; ***w***: Weighting factor)

UR 1.2: Material Attractiveness

Indicators	Evaluation Parameter	Evaluation scale				
		U	W	M	S	V
IPR1.2.1: Isotope content	239Pu/Pu (wt%)	> 93	80~93	70~80	60~70	< 60
	235U/U (wt%)	> 90	50~90	20~50	5~20	< 5
	232Ucontam. for 233U (ppm)	< 1	1~100	100~4000	4000~7000	> 7000
IPR1.2.2: Chemical form	Chemical form	Pure Pu metal	PuO_2, PuN	Fresh MOX	Spent fuel	Spent fuel with high burnup
IPR1.2.3: Radiation field	Dose (rem/hr)	< 1	1~15	15~100	100~1000	> 1000
IPR1.2.4: Heat generation	238Pu/Pu (wt%)	< 0.1	0.1~1	1~10	10~80	> 80
IPR1.2.5: Spontaneous neutron generation rate	(240Pu+ 242Pu) /Pu (wt%)	< 1	1~10	10~20	20~50	> 50

Characteristics of PR

1. **Inherently qualitative, and difficult to quantify many of the elements**
   - Some elements, such as treaties, agreements, and policies are difficult to quantify because of variations in strength, quality and degree of compliance (a political judgement).
   - Others are difficult to quantify because they involve human choices and activities that are outside of the range of normal experience.
   - The technical of extracting Pu from irradiated targets can vary considerably depending on what the potential to-be-proliferator is prepared to do.
   - If human health is not a significant consideration, then extraction can be performed with minimal shielding and protective equipment.

2. Malevolent human activity

- Other areas compared to PR are primarily concerned with technical aspects such as equipment/system failures, radioactive releases, costs, human health, etc.
- Whereas in most areas it is assumed that agreements are respected and followed, with proliferation it is assumed that non-proliferation agreements are broken.

3. Involvement of the interaction between two sides such as to-be-proliferator and the safeguard/ defender

- It is sometimes examined using gaming theory.
- The choices that each side makes depend to some extent on what choices they expect the other side to make.
- This human element must be considered in making a comprehensive assessment of PR, and is further complicated because many analysts believe that proliferators would disregard common safety and environmental norms.

4. **Requirement of a means to handle sensitive information without disclosing the sensitive details**
   - The detailed understanding of how the nuclear material characteristics (e.g. isotopic composition, chemical composition, etc.) affect a nuclear explosive is generally classified information.
   - This makes assessment of the PR provided by material characteristics difficult when considered in more than a coarse sense (e.g. HEU versus LEU or WG Pu versus RG Pu)

Some Points to Be Considered

- Aggregation Method
  - Assessment methods may be
    - Required an accepted means using clear and transparent tools
    - Useful by verification regimes to assess the effect of verification (extrinsic measures) to provide effective and cost-effective PR for a NES
    - Composite incorporating scenario-based and attribute-based tools
  - Aggregation methods may be
    - Misleading, possible hiding weak links with a single score for PR based on the strengths and weakness

Some Points to Be Considered (CONT.)

- Dependent and independent State specific information
  - Dependent State specific information
    - The strength of the PR provided by some intrinsic features can depend on state-specific information such as, *inter alia*, the presence of indigenous uranium resources or the presence of other nuclear facilities.
    - State-specific extrinsic measures such as fuel supply agreements for procurement of fresh fuel and return of spent fuel (e.g. commitment to multilateral fuel cycle facilities) can affect the PR of an INS.
  - Independent State specific information
    - Intrinsic features that facilitate verification generally provide PR independent of the State in which the INS is deployed.
  - PR assessments must address both aspects. Where required, credible stylized state descriptions can provide a means to address the state-specific aspects early in the design process.

Recommendations for the future work in PR
(Vienna, Sept. 2004)

1. INPRO continue to seek ways to cooperate closely with other projects on PR (e.g. GIF PR & PP).
2. INPRO compile a list of variables for PR.
3. A further case study should be conducted to test the new BPs, URs, and Criteria for PR.
4. Based on the results of the case study, INPRO should further develop the PR methodology.
5. In parallel with the case study, INPRO examine the relationship between variables and indicators, and consider whether the list of variables is complete.
6. INPRO assess the compatibility of PR assessment in light of the concept of sustainable development.

Purpose of the Assessment Methodology

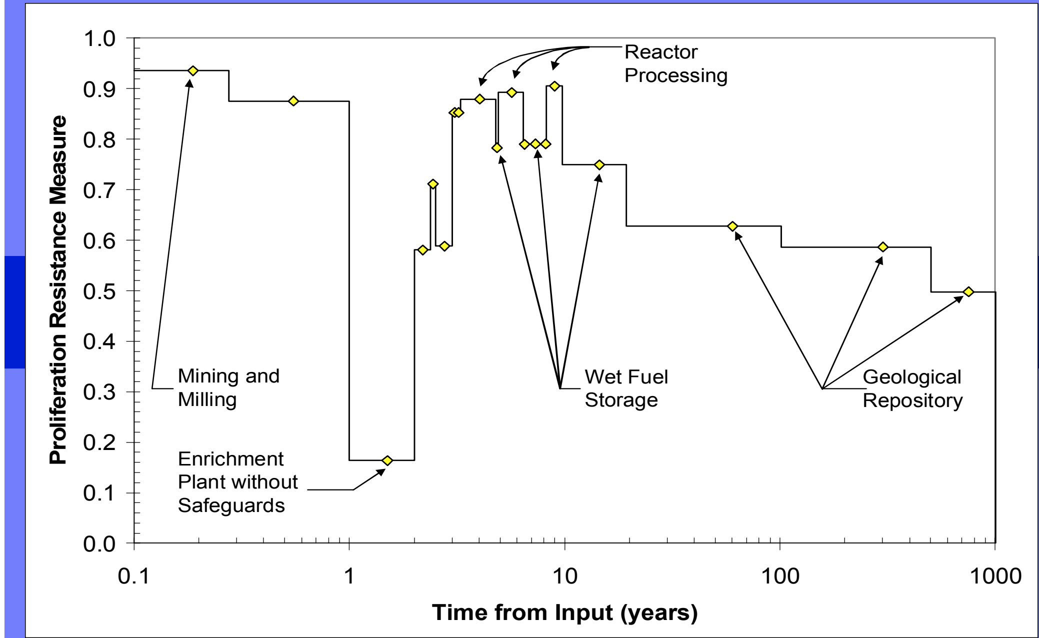
- Present results to authorities responsible for deciding which nuclear concepts to pursue and how the proliferation goals will be met
- Provide guidance for the nuclear energy system development groups that will develop the proliferation resistant technology

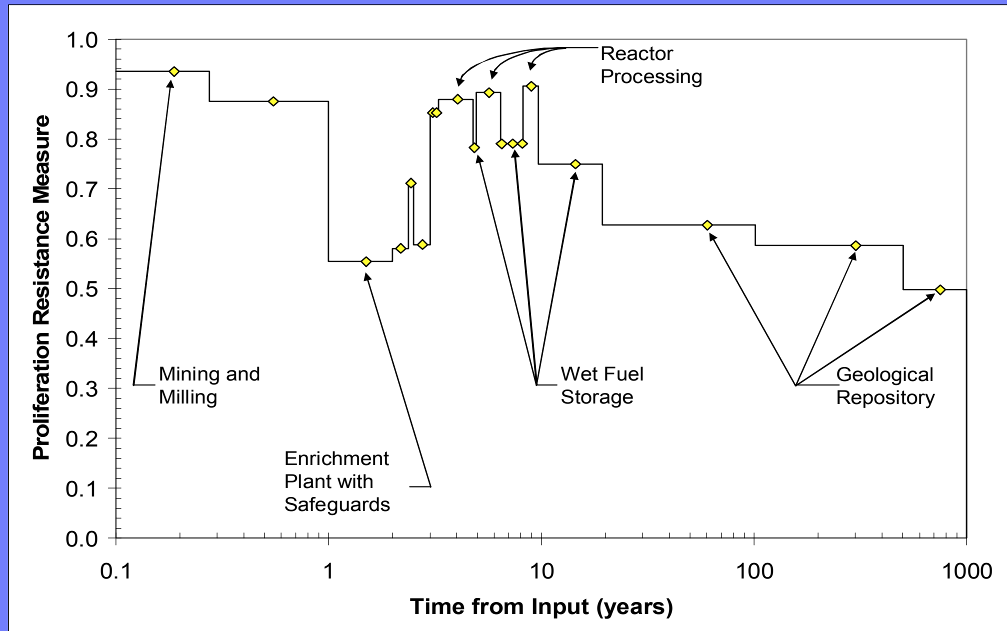
Guidance for Assessment of PR

- I. Introduction
-
- II. General Approach
-
- 2.1. Country Profile
- 2.2. INS (system) Identification
- 2.3.System Elements Identification
- 2.4.Acquisition Paths Analysis
- 2.4.1. Possible Target Identification
- 2.4.2. Concealed Diversion Paths Identification
- 2.4.3. Concealed Production Identification
-
-

Guidance for Assessment of PR (cont.)

- III. PR Assessment Methodology
-
- 3.1. General Provision
- 3.2. BP, UR, Criteria Structure,
- 3.3. Indicators and Acceptance Limits.
- 3.4. Matrix and Variations.
- 3.5. Tools and Methods.
- 3.6. Results Aggregation and selected INS potential judgment.
- 3.7. Conclusion and Recommendations.
- 3.7.1. Identification of Vulnerable points of the selected INS.
- 3.7.2. Identification of R&D for Vulnerable points enhancements.
- 3.7.3. Consideration of International Options for future INS PR general solution.
-
- IV. Demonstration of the Methodology on Min/Max Scenarios
-
- 4.1. Maximal Case – INS Based of Sodium Cooled Fast Reactor (SCFR) with relevant Fuel Cycle.
- 4.2. Minimal Case – INS Based on Imported SCFR and Leasing of Fuel.


Proliferation Resistance Measure
Time from Input (years)
Reactor Processing
Mining and Milling
Wet Fuel Storage
Geological Repository
Enrichment Plant without Safeguards
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.1
1
10
100
1000


Proliferation Resistance Measure
Time from Input (years)
Reactor Processing
Mining and Milling
Wet Fuel Storage
Geological Repository
Enrichment Plant with Safeguards
1.0
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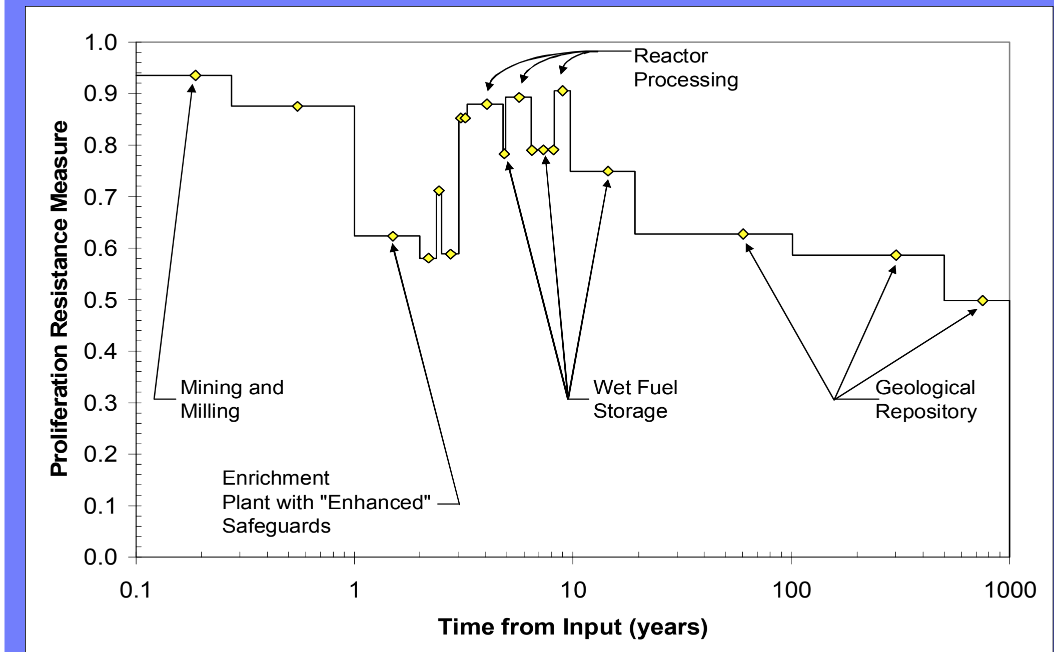
Proliferation Resistance Measure
Time from Input (years)
Reactor Processing
Mining and Milling
Wet Fuel Storage
Geological Repository
Enrichment Plant with "Enhanced" Safeguards
1.0
0.9
0.8
0.7
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0.5
0.4
0.3
0.2
0.1
0.0
0.1
1
10
100
1000

Conclusion

- Proliferation Resistance of INS is one of the key parameters for assessment of INS for future development of nuclear energy.
- Proliferation Resistance of INS can not be solved just by technical means (intrinsic features) of fuel cycle but only with combination of the technical means and institutional and organizational measures (extrinsic measures)
- PR is dependent upon time, facility description, fuel cycle details, and safeguards (or verification regime) implementation
- Assessment of INS Proliferation Resistance so far has few not finalized issues for example quantitative parameters for extrinsic measures, aggregation and presentation of results