INPRO
International Project on
Innovative Nuclear Reactors
and Fuel Cycles

INPRO Methodology

for Nuclear Energy System Assessment (NESA)

regarding sustainability

Basic and Simplified STRUCTURE

Handout – Working Material for the
Workshop on IAEA Tools for Nuclear Energy System Assessment (NESA)
for Long-Term Planning and Development. 20-23 July 2009
INPRO METHODOLOGY

FOR NUCLEAR ENERGY SYSTEM ASSESSMENT (NESA)
Basic Principles, User Requirements and Criteria

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Energy and related products and services from Innovative Nuclear Energy Systems shall be affordable and available.</td></tr>
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<tr><td rowspan="2">UR1 Cost of energy:
The cost of energy from innovative nuclear energy systems, taking all relevant costs and credits into account, C_N, should be competitive with that of alternative energy sources, C_A that are available for a given application in the same time frame and geographic region.</td><td>IN1.1: Cost of nuclear energy, $\mathbf{C_N}$.</td><td rowspan="2">AL1: $\mathbf{C_N \leq k{*}C_A}$</td></tr>
<tr><td>IN1.2: Cost of energy from alternative source, $\mathbf{C_A}$.</td></tr>
<tr><td rowspan="2">UR2 Ability to finance:
The total investment required to design, construct and commission innovative nuclear energy systems, including interest during construction, should be such that the necessary investment funds can be raised.</td><td>IN2.1: Financial figures of merit.
• EP2.1.1: Internal Return Rate(IRR)
• EP2.1.2: Return of Investment (ROI)</td><td>AL2.1: Figures of merit are comparable with or better than those for competing energy technologies of comparable size.</td></tr>
<tr><td>IN2.2: Total investment.</td><td>AL2.2: The total investment required should be compatible with the ability to raise capital in a given market climate.</td></tr>
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	UR3 Investment risk: *The risk of investment in innovative nuclear energy systems should be acceptable to investors taking into account the risk of investment in other energy projects.*	**IN 3.1:** Licensing status.	**AL3.1.1:** *For deployment of first few NPPs in a country:* Plants of same basic design have been constructed and operated.
			AL3.1.2: *For deployment* of a FOAK plant in a country with experience operating NPPs: Design is licensable in country of origin.
			AL3.1.3: *For development*: Plan to address regulatory issues available and costs included in development proposal.
		IN 3.2: Evidence that project construction and commissioning times used in financial analyses are realistic.	**AL3.2.1:** *For deployment of first few NPPs in a country*: Construction schedule times used in financial analyses have been met in previous constructions projects for plants of the same basic design.
			AL3.2.2: *For dep*loyment of a FOAK plant: A convincing argument exists that the construction schedule is realistic and consistent with experience with previous NPP construction projects carried out by the supplier and includes adequate contingency.
			AL3.2.3: *For technology development:* Schedules analyzed to demonstrate that scheduled times are realistic taking into account experience with previous NPP construction projects.
		IN 3.3: Financial robustness index of INS, RI.	**AL3.3:** RI $\geq$ 1
		IN 3.4: Long term commitment to nuclear option.	**Al3.4:** Commitment sufficient to enable a return on investment.
	UR4 Flexibility: *Innovative energy systems should be compatible with meeting the requirements of different markets.*	**IN 4.1:**Are the INS components adaptable to different markets?	**AL4.1:** Yes.

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<tr><td colspan="4">Volume 3: Area of INFRASTRUCTURE</td></tr>
<tr><td rowspan="4">Infrastructure</td><td colspan="3">Infrastructure basic principle (BP)
Regional and international arrangements shall provide options that enable any country that so wishes to adopt, maintain or enlarge an INS for the supply of energy and related products without making an excessive investment in national infrastructure.</td></tr>
<tr><td rowspan="2">User Requirement (UR)</td><td colspan="2">Criteria (CR)</td></tr>
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Evaluation Parameters (EP)</td><td>Acceptance Limit (AL)</td></tr>
<tr><td>UR1 Legal and institutional Infrastructure:
Prior to deployment of an INS installation, the legal framework should be established to cover the issues of nuclear liability, safety and radiation protection, environmental protection, control of operation, waste management and decommissioning, security, and non-proliferation.</td><td>IN1.1: Status of legal framework.
• EP1.1.1: Scope of the nuclear law
• EP1.1.2: Adequacy of nuclear law
• EP1.1.3: International legal arrangements
• EP1.1.4: Completeness and adequacy of regulations and guidelines</td><td>AL1.1: Legal framework has been established in accordance with international standards</td></tr>
</table>

		IN 1.2: Status of State organizations with responsibilities for safety and radiation protection, environmental protection, control of operation, waste management and decommissioning, security and non-proliferation. • **EP1.2.1:** Independence of regulatory body • **EP1.2.2:** General functions of regulatory body • **EP1.2.3:** Positive review of safety regime • **EP1.2.4:** Positive review of emergency preparedness regime • **EP1.2.5:** Positive review of physical protection regime	**AL1.2:** State organizations have been established, in accordance with international standards.
	UR2 Industrial and economic infrastructure: *The industrial and economic infrastructure of a country planning to install an INS installation should be adequate to support the project throughout the complete lifetime of the nuclear power program, including planning, construction, operation, decommissioning and related waste management activities.*	**IN 2.1:** Availability of credit lines. • **EP2.1.1:** Financing of infrastructure provided by industry • **EP2.1.2:** Financing of infrastructure provided by government	**AL2.1:** Sufficient to cover the program.
		IN 2.2: Demand for and price of energy products.	**AL2.2:** Adequate to enable a satisfactory financial return.
		IN 2.3: Size of installation. • **EP2.3.1:** Energy system expansion plan • **EP2.3.1**: Size of nuclear fuel cycle facilities (other than NPP)	**AL2.3:** Matches local needs. Assumed to have been defined in energy planning study.

		IN 2.4: Availability of infrastructure to support owner/ operator. • **EP2.4.1**: Survey of the existing capabilities of the national industry • **EP2.4.2**: Plan for national participation	**AL2.4:** Internally or externally available.
		IN 2.5: Overall added value of proposed nuclear installation (AVNI). • **EP2.5.1**: Cost benefits study performed by national industry • **EP2.5.2**: Study to define benefits of nuclear program to society	**AL2.5:** AVNI > national infrastructure investment necessary to support nuclear installation.
	UR3 Political support and public acceptance: *Adequate measures should be taken to achieve public acceptance of a planned INS installation to enable a government policy commitment to support the deployment of INS to be made and then sustained.*	**IN 3.1:** Information provided to public • **EP3.1.1**: Existence of a national energy policy • **EP3.1.2**: Communication of benefits of nuclear power to the public • **EP3.1.3**: Information on the operation of nuclear facilities • **EP3.1.4**: Addressing of concerns raised by the public regarding nuclear installations • **EP3.1.5**: Use of communication experts to match information to the needs of public audiences	**AL3.1:** Sufficient according to best international practice.

		IN 3.2: Participation of public in decision making process (to foster public acceptance). • **EP3.2.1:** Appropriateness of participation process • **EP3.2.2:** Acceptability of participation process	**AL3.2:** Sufficient according to national requirements.
		IN 3.3: Public acceptance of nuclear power. • **EP3.3.1:** Surveys to gage public acceptance are performed on a regular basis • **EP3.3.2:** Adequacy of survey • **EP3.3.3**: Acceptable result of survey	**AL3.3:** Sufficient to ensure there is negligible political risk to policy support for nuclear power.
		IN3.4: Government policy.	**AL3.4:** Policy is supportive of nuclear power.
	UR4 Human resources: *The necessary human resources should be available to enable all responsible parties involved in a nuclear power program to achieve safe, secure and economical operation of the INS installations during their lifetime. The owners/operators should have enough knowledge of the INS to be intelligent customers and should keep a stable cadre of competent and trained staff.*	**IN4.1:** Availability of human resources. • **EP4.1.1:** educational and training system for manpower needed in NP projects • **EP4.1.2:** attractiveness of the nuclear power sector • **EP4.1.3:** capacity to accept the additional load of nuclear power program	**AL4.1:** Sufficient according to international experience.
		IN4.2: Attitude to safety and security.	**AL4.2:** Evidence that a safety and security culture prevails provided by periodic safety and security reviews.

Volume 4: Area of Waste Management			
Waste management	**Waste management basic principle (BP1) (Waste minimization)** *Generation of radioactive waste in an INS shall be kept to the minimum practicable.*		
	User requirement (UR)	**Criteria (CR)**	
		Indicators (IN)	**Acceptance Limits (AL)**
	UR1 Reduction of waste at the source: *The INS should be designed to minimize the generation of waste at all stages, with emphasis on waste containing long-lived toxic components that would be mobile in a repository environment.*	**IN1.1.1:**Technical indicators: - Alpha-emitters and other long-lived radio-nuclides per GWa. - Total activity per GWa. - Mass per GWa. - Volume per GWa. - Chemically toxic elements that would become part of the radioactive waste per GWa.	**AL1.1.1:** ALARP
		IN1.1.2: A waste minimization study has been preformed, leading to a waste minimization strategy and plan for each component of the INS.	**AL1.1.2:** The study, strategies and plans are available

Waste management	**Waste management basic principle (BP2) (Protection of human health and the environment)** *Radioactive waste in an INS shall be managed in such a way as to secure an acceptable level of protection for human health and the environment, regardless of the time or place at which impacts may occur.*		
	User requirement (UR)	**Criteria (CR)**	
		Indicators (IN)	**Acceptance Limits (AL)**
	UR2.1 Protection of human health: *Exposure of humans to radiation and chemicals from INS waste management systems should be below currently accepted levels and protection of human health from exposure to radiation and chemically toxic substances should be optimized.*	**IN2.1.1:** Estimated dose rate to an individual of the critical group.	**AL2.1.1:** Meets regulatory standards of specific Member State.
		IN2.1.2: Radiological exposure of workers.	**AL2.1.2:** Meets regulatory standards of specific Member State.
		IN2.1.3: Estimated concentrations of chemical toxins in working areas.	**AL2.1.3:** Meet regulatory standards of specific Member State.
	UR2.2 Protection of the environment: *The cumulative releases of radio-nuclides and chemical toxins from waste management components of the INS should be optimized.*	**IN2.2.1:** Estimated releases of radio-nuclides and chemical toxins from waste management facilities.	**AL2.2.1:** Meet regulatory standards of specific Member State.
		IN2.2.2: Estimated releases of radio-nuclides and chemical toxins from all other INS facilities.	**AL2.2.2:** Meet regulatory standards of specific Member State.

Waste management	**Waste management basic principle (BP3) (Burden on future generations)** *Radioactive waste in an INS shall be managed in such a way that it will not impose undue burdens on future generations.*		
	User requirement (UR)	**Criteria (CR)**	
		Indicators (IN)	**Acceptance Limits (AL)**
	UR3.1 End state: *An achievable end state should be specified for each class of waste, which provides permanent safety without further modification. The planned energy system should be such that the waste is brought to this end state as soon as reasonably practicable. The end state should be such that any release of hazardous materials to the environment will be below that which is acceptable today.*	**IN3.1.1:** Availability of technology.	**AL3.1.1:** All required technology is currently available or reasonably expected to be available on a schedule compatible with the schedule for introducing the proposed innovative fuel cycle.
		IN3.1.2: Time required.	**AL3.1.2:** Any time required to bring the technology to the industrial scale must be less than the time specified to achieve the end state.
		IN3.1.3: Availability of resources.	**AL3.1.3:** Resources (funding, space, capacity, etc.) available for achieving the end state compatible with the size and growth rate of the energy system.
		IN3.1.4: Safety of the end state (long-term expected dose to an individual of the critical group).	**AL3.1.4:** Meet regulatory standards of specific Member State.
		IN3.1.5: Time to reach the end state.	**AL3.1.5:** As short as reasonably practicable.
	UR3.2 Attribution of waste management costs: *The costs of managing all waste in the life cycle should be included in the estimated cost of energy from the INS, in such a way as to cover the accumulated liability at any stage of the life cycle.*	**IN3.2.1:** Specific line item in the cost estimate.	**AL3.2.1:** Included.

Waste Management	**Waste Management Basic Principle (BP4) (Waste optimization)** *Interactions and relationships among all waste generation and management steps shall be accounted for in the design of the INS, such that overall operational and long-term safety is optimized.*		
	User requirement (UR)	**Criteria (CR)**	
		Indicators (IN)	**Acceptance Limits (AL)**
	UR4.1 Waste Classification: *The radioactive waste arising from the INS should be classified to facilitate waste management in all parts of the INS.*	**IN4.1.1:** Classification scheme.	**AL4.1.1:** The scheme permits unambiguous, practical segregation and measurement of waste arisings.
	UR4.2 Pre-disposal Waste Management: *Intermediate steps between generation of the waste and the end state should be taken as early as reasonably practicable. The design of the steps should ensure that all-important technical issues (e.g., heat removal, criticality control, confinement of radioactive material) are addressed. The processes should not inhibit or complicate the achievement of the end state.*	**IN4.2.1:** Time to produce the waste form specified for the end state.	**AL4.2.1:** As short as reasonably practicable.
		IN4.2.2: Technical indicators, e.g., - Criticality compliance. - Heat removal provisions. - Radioactive emission control measures. - Radiation protection; measures (shielding etc.). - Volume / activity reduction measures. - Waste forms.	**AL4.2.2:** Criteria as prescribed by regulatory bodies of specific Member States.
		IN4.2.3: Process descriptions that encompass the entire waste life cycle.	**AL4.2.3:** Complete chain of processes from generation to final end state and sufficiently detailed to make evident the feasibility of all steps.

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<tr><td colspan="4">Volume 5 : Area of Proliferation Resistance</td></tr>
<tr><td rowspan="5">Proliferation resistance</td><td colspan="3">Proliferation resistance basic principle (BP)
Proliferation resistance intrinsic features and extrinsic 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 program. Both intrinsic features and extrinsic measures are essential, and neither shall be considered sufficient by itself.</td></tr>
<tr><td rowspan="2">User requirement (UR)</td><td colspan="2">Criteria (CR)</td></tr>
<tr><td>Indicators (IN)</td><td>Acceptance Limits (AL)</td></tr>
<tr><td rowspan="2">UR1 State commitments:
States' commitments, obligations and policies regarding non-proliferation and its implementation should be adequate to fulfill international standards in the non proliferation regime.</td><td>IN1.1: States' commitments, obligations and policies regarding non-proliferation established?
• EP1.1.1: Party to international non-proliferation treaty NPT
• EP1.1.2: Party to regional non-proliferation regimes
• EP1.1.3: Comprehensive safeguards agreements in force
• EP1.1.4: Additional protocol in force
• EP1.1.5: INFCIRC/66-type safeguards agreement in force.
• EP1.1.6: Export control policies of NM and nuclear technology
• EP1.1.7: SSAC or RSAC in force
• EP1.1.8: Regulatory body, designated in national legislation for implementing and applying safeguards agreements</td><td>AL1.1: Yes, in accordance with international standards.</td></tr>
<tr><td>IN1.2: Institutional structural arrangements in support of PR have been considered accordingly?</td><td>AL1.2: Yes, based on expert judgment.</td></tr>
</table>

	UR2 Attractiveness of NM and technology: *The attractiveness of nuclear material (NM) and nuclear technology in an INS for a nuclear weapons program should be low. This includes the attractiveness of undeclared nuclear material that could credibly be produced or processed in the INS.*	**IN2.1:** **-** Technical indicators: - Material quality. **-** Material quantity. **-** Material form.	**AL2.1:** Attractiveness of NM considered in design of INS and found acceptable low based on expert judgment.
		IN2.2: Nuclear technology.	**AL2.2:** Attractiveness of technology considered in design of INS and found acceptable low based on expert judgment.
	UR3 Difficulty and detectability of diversion: *The diversion of nuclear material (NM) should be reasonably difficult and detectable. Diversion includes the use of an INS facility for the production or processing of undeclared material.*	**IN3.1:** Accountability.	**AL3.1:** Based on expert judgment equal or better than existing designs, meeting international state of practice.
		IN3.2: Amenability	**AL3.2:** Based on expert judgment equal or better than existing designs, meeting international best practice.
		IN3.3: Detectability of NM.	**AL3.3:** Based on expert judgment equal or better than existing facilities.
		IN3.4: Difficulty to: - modify process; - modify facility design; - misuse technology or facilities.	**AL3.4:** Based on expert judgment equal or better than existing designs, meeting international best practice.
	UR4 multiple features: *Innovative nuclear energy systems should incorporate multiple proliferation resistance features and measures.*	**IN4.1:** The extent by which the INS is covered by multiple intrinsic features and extrinsic measures.	**AL4.1:** All plausible acquisition paths are (can be) covered by extrinsic measures on the facility or State level and by intrinsic features which are compatible with other design requirements.
		IN4.2: Robustness of barriers covering each acquisition path.	**AL4.2:** Robustness is sufficient based on expert judgment.

	UR5 Optimization of design: 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.	**IN5.1:** PR has been taken into account as early as possible in the design and development of the INS.	**AL5.1:** Yes
		IN5.2: Cost of incorporating into an INS those intrinsic features and extrinsic measures, which are required to provide or improve proliferation resistance.	**AL5.2:** Minimal total cost of the intrinsic features and extrinsic measures over the life cycle of the INS implemented to increase PR.
		IN5.3: Verification approach with a level of extrinsic measures agreed to between the State and verification authority (e.g., IAEA, regional SG organization, etc.)?	**AL5.3:** Yes.

Volume 6: Area of Physical Protection			
Physical protection	**Physical protection basic principle (BP)** *A Physical Protection Regime shall be effectively and efficiently implemented for the full lifecycle of an INS.*		
	User Requirements (UR)	**Criteria (CR)**	
		Indicators (IN)	**Acceptance Limits (AL)**
	UR1 legislative and regulatory framework *:* *Prior to the deployment of the INS the legislative and regulatory framework to govern PP should be established.*	**IN1.1:** Have the competent authorities (such as regulatory authorities, response force authorities, etc.) been designated, empowered and responsibilities defined (or planned)?	**AL1.1:** Yes.
		IN1.2: Has the legislative and regulatory framework related to physical protection been developed (or is it under development)?	**AL1.2:** Yes, in accordance with international standards.
		IN1.3: Have the physical protection responsibilities and authorities of the facility operator been clearly defined?	**AL1.3:** Yes, in accordance with State physical protection regulations and laws.
	UR2 Integration of PP throughout PRO *Physical Protection should be integrated into all INPRO areas and throughout all phases.*	**IN2.1:** Have synergies and divergences between PP, safety, PR, and operations been addressed?	**AL2.1:** Yes, through the review of a joint expert panel.
		IN2.2: Is there evidence that assessments in all areas of INPRO have accounted for PP?	**AL2.2:** Yes, as appropriate.
		IN2.3: Is there evidence of forethought into the issues of PP as the INS is shut-down and decommissioned?	**AL2.3:** Yes.

	UR3 Trustworthiness: *A program to determine trustworthiness should be defined and implemented.*	**IN3.1:** Is there a trustworthiness program with established acceptance criteria?	**AL3.1:** Yes.
	UR4 Confidentiality: *Sensitive information developed for all areas of INPRO should be protected in accordance with its security significance.*	**IN4.1:** Has a program been developed for protecting sensitive information?	**AL4.1:** Yes.
		IN4.2: Have procedures been developed and implemented at all levels to identify and protect sensitive information?	**AL4.2:** Yes.
	UR5 Threat: *The physical protection systems should be based on the State's current evaluation of the threats.*	**IN5.1:** Is there evidence that a DBT or other appropriate threat statement has been developed?	**AL5.1:** Yes.
		IN5.2: Are there provisions for periodic review of threat by the State?	**AL5.2:** Yes.
		IN5.3: Is there evidence that the concept of DBT or other appropriate threat statement has been used to establish the PP systems?	**AL5.3:** Yes.
		IN5.4: Has the designer introduced flexibility in PPS design to cope with the dynamic nature of threat?	**AL5.4:** Yes.
	UR6 Graded approach: *Physical protection requirements should be based on a graded approach.*	**IN6.1:** Has the state defined limits for consequences of malicious acts directed against nuclear materials and facilities (including transports)?	**AL6.1:** Yes.
		IN6.2: Has the concept of a graded approach been used by the State when specifying PP requirements and by the user to define PPS?	**AL6.2:** Yes.

UR7 Quality assurance: *Quality assurance policy and programs for all activities important to PP should be established and implemented.*	**IN7.1:** Is there a QA policy defined and implemented for all activities important to PP?	**AL7.1:** Presence of periodic review mechanism.
UR8 Security culture: *All organizations involved in implementing physical protection should give due priority to development, maintenance and effective implementation of the security culture in the entire organization.*	**IN8.1:** Has a security culture program been developed and implemented for all organizations and personnel involved in the INS?	**AL8.1:** Yes.
UR9 PP considerations in siting: *The PP should be considered when siting INS components.*	**IN9.1:** Has the terrain, topography and geography been assessed to preclude potential benefit to adversaries (high ground to observe, approach, and attack, air approaches, cover and concealment, etc)?	**AL9.1:** Yes
	IN9.2: Has feasibility/flexibility, vulnerability, and efficiency of transportation and offsite response routes been assessed (air, sea, land)?	**AL9.2:** Yes
	IN9.3: Has future development/ encroachment by public been considered?	**AL9.3:** Yes

	UR10 INS layout and design: *INS component layout and design should be developed to minimize susceptibility and opportunities for malicious action.*	**IN10.1:** Is there evidence that consideration has been given to physical protection in the design of the INS components?	**AL10.1:** Yes
		IN10.2: Is there evidence that consideration has been given to physical protection in the layout of the INS components?	**AL10.2:** Yes
	UR11 Design of PPS: *The physical protection system of all INS components should be developed in uniform layers of protection using a systematic approach.*	**IN11.1:** Has deterrence, detection, assessment, delay, and response been integrated to achieve timely interruption of malicious act?	**AL11.1:** Yes.
		IN11.2: Has the PPS been designed with consideration of insider adversaries exploiting capabilities such as access, knowledge, and authority?	**AL11.2:** Yes.
		IN11.3: Has the PPS been developed with several uniform layers and methods of protection?	**AL11.3:** Yes.
	UR12 Contingency plans: *Contingency plans to respond to unauthorized removal of nuclear material or sabotage of nuclear facilities/transport or of nuclear material, or attempts thereof, should be prepared and appropriately exercised by all license holders and authorities concerned.*	**IN12.1:** Have responsibilities for execution of the emergency plans been identified?	**AL12.1:** Yes.
		IN12.2: Have capabilities of the PP regime been established to prevent and mitigate radiological consequences of sabotage?	**AL12.2:** Yes.
		IN12.3: Have capabilities of PP regime been established to recover stolen nuclear material or recapture facilities before the adversary can achieve its objective?	**AL12.3:** Yes.

Volume 7: Area of Environment			
Environmental	**Environmental Basic Principle (BP1) (Acceptability of expected adverse environmental effects)** *The expected (best estimate) adverse environmental effects of the innovative nuclear energy system shall be well within the performance envelope of current nuclear energy systems delivering similar energy products.*		
	User Requirements (UR)	**Criteria (CR)**	
		Indicators (IN)	**Acceptance Limits (AL)**
	UR1.1 controllability of environmental stressors: *The environmental stressors from each part of the INS over the complete life cycle should be controllable to levels meeting or superior to current standards.*	**IN1.1.1:** L_{St-i}, = level of stressor i.	**AL1.1.1:** $L_{St-i} < S_i$, where S_i is the standard for stressor i.
	UR1.2 adverse effects as low as reasonable practicable: *The likely adverse environmental effects attributable to the INS should be as low as reasonably practicable, social and economic factors taken into account.*	**IN1.2.1:** Does the INS reflect application of ALARP to limit environmental effects?	**AL1.2.1:** Yes.

Environmental	**Environmental basic principle BP2 (Fitness for Purpose)** *The INS shall be capable of contributing to the energy needs in the 21st century while making efficient use of non-renewable resources.*		
	User Requirements (UR)	**Criteria (CR)**	
		Indicators (IN)	**Acceptance Limits (AL)**
	UR2.1 Consistency with resource availability: *The INS should be able to contribute to the world's energy needs during the 21st century without running out of fissile/fertile material and other non-renewable materials, with account taken of reasonably expected uses of these materials external to the INS. In addition, the INS should make efficient use of non-renewable resources.*	**IN2.1.1:** F_j (t) = quantity of fissile/fertile material j available for use in the INS at time t.	**AL2.1.1:** F_j (t) > 0 for all t < 100 years
		IN2.1.2: Q_j(t) = quantity of material i available for use in the INS at time t.	**AL2.1.2:** Q_j (t) > 0 for all t < 100 years
		IN2.1.3: P(t) = power available (from both internal and external sources) for use in the INS at time t.	**AL2.1.3:** $P(t) \geq P_{INS}(t)$ for all t < 100 years, where $P_{INS}(t)$ is the power required by the INS at time t.
		IN2.1.4: U = end use (net) energy delivered by the INS per Mg of uranium mined.	**AL2.1.4:** $U > U_0$,U_0 : maximum achievable for a once-through PWR.
		IN2.1.5: T = end use (net) energy delivered by the INS per Mg of thorium mined.	**AL2.1.5:** $T > T_0$,T_0 : maximum T achievable with a current operating thorium cycle.
		IN2.1.6: C_i = end use (net) energy delivered per Mg of limited non-renewable resource i consumed	**AL2.1.6:** $C_i > C_0$,C_0 to be determined on a case specific basis.
	UR2.2 Adequate net energy output: *The energy output of the INS should exceed the energy required to implement and operate the INS within an acceptably short period.*	**IN2.2.1:** T_{EQ} = time required to match the total energy input with energy output (yrs).	**AL2.2.1:** $T_{EQ} < k*T_L$ T_L = intended life of INS. K < 1

Volume 8&9 : Area of Safety

	User Requirements (UR)	Criteria (CR)	
		Indicators (IN)	Acceptance Limits (AL)
Safety	**Safety basic principle (BP1) (defence in depth)** *Installations of an Innovative Nuclear Energy System shall incorporate enhanced defence-in-depth as a part of their fundamental safety approach and ensure that the levels of protection in defence-in-depth shall be more independent from each other than in existing installations.*		
Safety	**UR1.1 Robustness:** *Installations of an INS should be more robust relative to existing designs regarding system and component failures as well as operation.*	**IN1.1.1**: Robustness of design (simplicity, margins). • **EP1.1.1.1**: Margins of design • **EP1.1.1.2**: Simplicity of design • **EP1.1.1.3**: Quality of manufacture and construction • **EP1.1.1.4**: Quality of materials **EP1.1.1.5**: Redundancy of systems	**AL1.1.1:** Superior to existing designs in at least some of the aspects discussed in the text.
		IN1.1.2: High quality of operation. • **EP1.1.2.1:** margins of operation. • **EP1.1.2.2:** reliability of control systems. • **EP1.1.2.3:** impact from incorrect human intervention. • **EP1.1.2.4:** quality of documentation. • **EP1.1.2.5:** quality of training. • **EP1.1.2.6:** organization of plant. • **EP1.1.2.7:** availability/capability of plant. • **EP1.1.2.8:** use of world wide operating experience.	**AL1.1.2:** Superior to existing designs in at least some of the aspects discussed in the text.

		IN1.1.3: Capability to inspect.	**AL1.1.3:** Superior to existing designs in at least some of the aspects discussed in the text.
		IN1.1.4: Expected frequency of failures and disturbances.	**AL1.1.4:** Superior to existing designs in at least some of the aspects discussed in the text.
	UR1.2 Detection and interception: *Installations of an INS should detect and intercept deviations from normal operational states in order to prevent anticipated operational occurrences from escalating to accident conditions.*	**IN1.2.1:** Capability of control and instrumentation system and/or inherent characteristics to detect and intercept and/or compensate deviations from normal operational states. • **EP1.2.1.1:** continuous monitoring of plant health. • **EP1.2.1.2:** dynamic plant analysis.	**AL1.2.1:** Key system variables relevant to safety (e.g. flow, pressure, temperature, radiation levels) do not exceed limits acceptable for continue d operation (no event reporting necessary).
		IN1.2.2: Grace period until human actions are required.	**AL1.2.2:** Superior to existing designs in at least some of the aspects discussed in the text.
		IN1.2.3: Inertia to cope with transients.	**AL1.2.3:** Superior to existing designs in at least some of the aspects discussed in the text
	UR1.3 Design basis accidents: *The frequency of occurrence of accidents should be reduced, consistent with the overall safety objectives. If an accident occurs, engineered safety features should be able to restore an installation of an INS to a controlled state, and subsequently (where relevant) to a safe shutdown state, and ensure the confinement of radioactive material. Reliance on human intervention should be minimal, and should only be required*	**IN1.3.1:** Calculated frequency of occurrence of design basis accidents.	**AL1.3.1:** Reduced frequency of accidents that can cause plant damage relative to existing facilities
		IN1.3.2: Grace period until human intervention is necessary.	**AL1.3.2:** Increased relative to existing facilities.
		IN1.3.3: Reliability of engineered safety features.	**AL1.3.3:** Equal or superior to existing designs.
		IN1.3.4: Number of confinement barriers maintained.	**AL1.3.4:** At least one.
		IN1.3.5: Capability of the engineered safety features to restore the INS to a controlled state (without operator actions).	**AL1.3.5:** Sufficient to reach a controlled state.

	after some grace period.	**IN1.3.6:** sub criticality margins	**AL1.3.6:** Sufficient to cover uncertainties and to allow adequate grace period.
	UR1.4 Release into containment: *The frequency of a major release of radioactivity into the containment / confinement of an INS due to internal events should be reduced. Should a release occur, the consequences should be mitigated.*	**IN1.4.1** Calculated frequency of major release of radioactive materials into the containment / confinement.	**AL1.4.1:** At least an order of magnitude less than for existing designs; even lower for installations at urban sites.
		IN1.4.2: Natural or engineered processes sufficient for controlling relevant system parameters and activity levels in containment/ confinement.	**AL1.4.2**: Existence of such processes.
		IN1.4.3: In-plant severe accident management.	**AL1.4.3:** Procedures, equipment and training sufficient to prevent large release outside containment / confinement and regain control of the facility.
	UR1.5 Release into the environment: *A major release of radioactivity from an installation of an INS should be prevented for all practical purposes, so that INS installations would not need relocation or evacuation measures outside the plant site, apart from those generic emergency measures developed for any industrial facility used for similar purpose.*	**IN1.5.1:** Calculated frequency of a major release of radioactive materials to the environment.	**AL1.5.1:** Calculated frequency $<10^{-6}$ per unit-year, or practically excluded by design.
		IN1.5.2: Calculated consequences of releases (e.g. dose).	**AL1.5.2:** Consequences sufficiently low to avoid necessity for evacuation. Appropriate off-site mitigation measures (e.g., temporary food restrictions) are available.
		IN1.5.3: Calculated individual and collective risk.	**AL1.5.3:** Comparable to facilities used for a similar purpose

	UR1.6 Independence of DID levels: *An assessment should be performed for an INS to demonstrate that the different levels of defence-in-depth are met and are more independent from each other than for existing systems.*	**IN1.6.1:** Independence of different levels of DID.	**AL1.6.1:** Adequate independence is demonstrated, e.g. through deterministic and probabilistic means, hazards analysis etc.
	UR1.7 Human machine interface: *Safe operation of installations of an INS should be supported by an improved Human Machine Interface resulting from systematic application of human factors requirements to the design, construction, operation, and decommissioning.*	**IN1.7.1:** Evidence that human factors (HF) are addressed systematically in the plant life cycle.	**AL1.7.1:** Satisfactory results from assessment.
		IN1.7.2: Application of formal human response models from other industries or development of nuclear.	**AL1.7.2:** -Reduced likelihood of human error relative to existing plants, as predicted by HF models. - Use of artificial intelligence for early diagnosis and real-time operator aids. - Less dependence on operator for normal operation and short-term accident management relative to existing plants.

Safety	Safety basic principle (BP2) (Inherent safety) *Installations of an INS shall excel in safety and reliability by incorporating into their designs, when appropriate, increased emphasis on inherently safe characteristics and passive systems as a part of their fundamental safety approach.*		
	User Requirements (UR)	**Criteria (CR)**	
		Indicators (IN)	**Acceptance Limits (AL)**
	UR2.1 Minimization of hazards: INS should strive for elimination or minimization of some hazards relative to existing plants by incorporating inherently safe characteristics and/or passive systems, when appropriate.	**IN2.1.1:** Sample indicators: stored energy, flammability, criticality, inventory of radioactive materials, available excess reactivity, and reactivity feedback. • **EP2.1.1.1:** Stored energy. • **EP2.1.1.2:** Flammability. • **EP2.1.1.3:** Inventory of radioactive materials. • **EP2.1.1.4:** Criticality. • **EP2.1.1.5:** Available excess reactivity. • **EP2.1.1.6:** Reactivity feed back.	**AL2.1.1:** Superior to existing designs.
		IN2.1.2: Expected frequency of abnormal operation and accidents.	**AL2.1.2:** Lower frequencies compared to existing facilities.
		IN2.1.3: Consequences of abnormal operation and accidents.	**AL2.1.3:** Lower consequences compared to existing facilities.
		IN2.1.4: Confidence in innovative components and approaches.	**AL2.1.4:** Validity established.

<table>
<tr><td rowspan="5">Safety</td><td colspan="3">Safety basic principle (BP3) (risk of radiation)
Installations of an INS shall ensure that the risk from radiation exposures to workers, the public and the environment during construction, commissioning, operation, and decommissioning, are comparable to the risk from other industrial facilities used for similar purposes.</td></tr>
<tr><td rowspan="2">User Requirements (UR)</td><td colspan="2">Criteria (CR)</td></tr>
<tr><td>Indicators (IN)</td><td>Acceptance Limits (AL)</td></tr>
<tr><td>UR3.1 Dose to workers:
INS installations should ensure an efficient implementation of the concept of optimization of radiation protection for workers through the use of automation, remote maintenance and operational experience from existing designs.</td><td>IN3.1.1: Occupational dose values.</td><td>AL3.1.1: Less than limits defined by national laws or international standards and so that the health hazard to workers is comparable to that from an industry used for a similar purpose.</td></tr>
<tr><td>UR3.2 Dose to public:
Dose to an individual member of the public from an individual INS installation during normal operation should reflect an efficient implementation of the concept of optimization, and for increased flexibility in siting may be reduced below levels from existing facilities.</td><td>IN3.2.1: Public dose values.</td><td>AL3.2.1: Less than the limits defined by national laws or international standards and so that the health hazard to the public is comparable to that from an industry used for a similar purpose.</td></tr>
</table>

Safety	Safety Basic Principle (BP4) (RD&D) *The development of INS shall include associated research, development and demonstration work to bring the knowledge of plant characteristics and the capability of analytical methods used for design and safety assessment to at least the same confidence level as for existing plants.*		
	User Requirements (UR)	**Criteria (CR)**	
		Indicators (IN)	**Acceptance Limits (AL)**
	UR4.1 Safety basis: *The safety basis of INS installations should be confidently established prior to commercial deployment.*	**IN4.1.1:** Safety concept defined?	**AL4.1.1:** Yes.
		IN4.1.2: Clear process for addressing safety issues?	**AL4.1.2:** Yes.
	UR4.2 RD&D for understanding: *Research, Development and Demonstration on the reliability of components and systems, including passive systems and inherent safety characteristics, should be performed to achieve a thorough understanding of all relevant physical and engineering phenomena required to support the safety assessment.*	**IN4.2.1:** RD&D defined and performed and database developed?	**AL4.2.1:** Yes.
		IN4.2.2: Computer codes or analytical methods developed and validated?	**AL4.2.2:** Yes.
		IN4.2.3: Scaling understood and/or full scale tests performed?	**AL4.2.3:** Yes.

	UR4.3 Pilot plant: *A reduced-scale pilot plant or large-scale demonstration facility should be built for reactors and/or fuel cycle processes, which represent a major departure from existing operating experience.*	**IN4.3.1:** Degree of novelty of the process.	**AL4.3.1:** In case of *high degree of novelty:* Facility specified, built, operated, and lessons learned documented. In case of *low degree of novelty*: Rationale provided for bypassing pilot plant.
		IN4.3.2: Level of adequacy of the pilot facility.	**AL4.3.2:** Results sufficient to be extrapolated.
	UR4.4 Safety analysis: *For the safety analysis, both deterministic and probabilistic methods should be used, where feasible, to ensure that a thorough and sufficient safety assessment is made. As the technology matures, "Best Estimate (plus uncertainty analysis)" approaches are useful to determine the real hazard, especially for limiting severe accidents.*	**IN4.4.1:** Use of a risk informed approach?	**AL4.4.1:** Yes.
		IN4.4.2: Uncertainties and sensitivities identified and appropriately dealt with?	**AL4.4.2:** Yes.