INPRO Dialogue Forum 8: Toward Nuclear Energy System Sustainability: Economics, Resource Availability and Institutional Arrangements

Overview of the INPRO Methodology in the area of Environment: Impact from Depletion of Resources

Presented by Vladimir KUZNETSOV
NENP/INPRO Section

IAEA
International Atomic Energy Agency

Content

INPRO Objectives

INPRO International Project on Innovative Nuclear Reactors and Fuel Cycles

- INPRO cooperates with Member States to ensure that sustainable nuclear energy is available to help meet the energy needs of the 21st century in accordance with UN concept of sustainability.

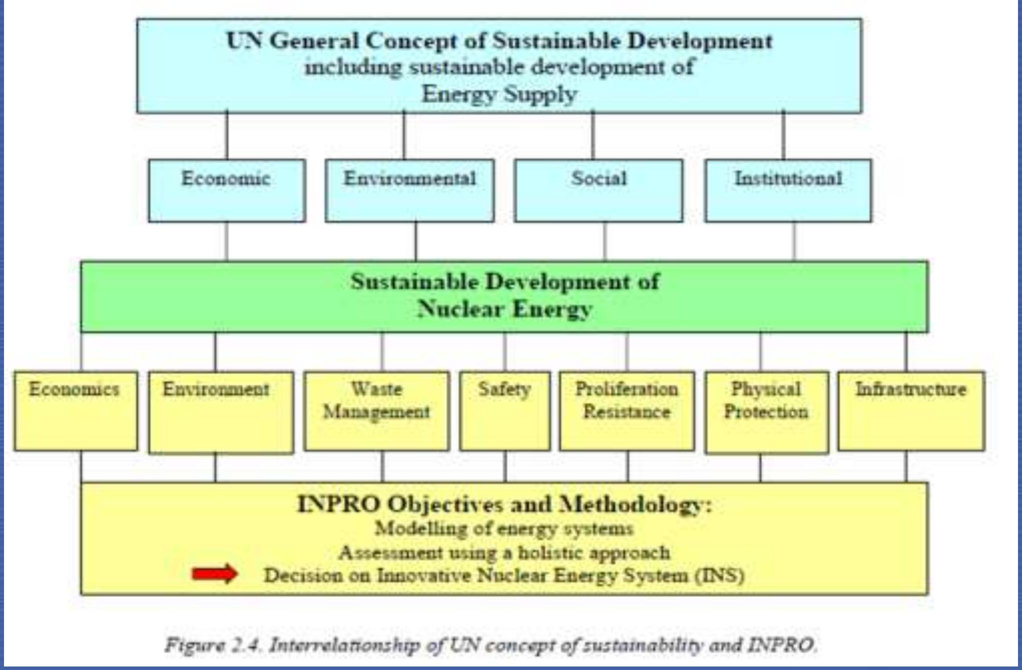
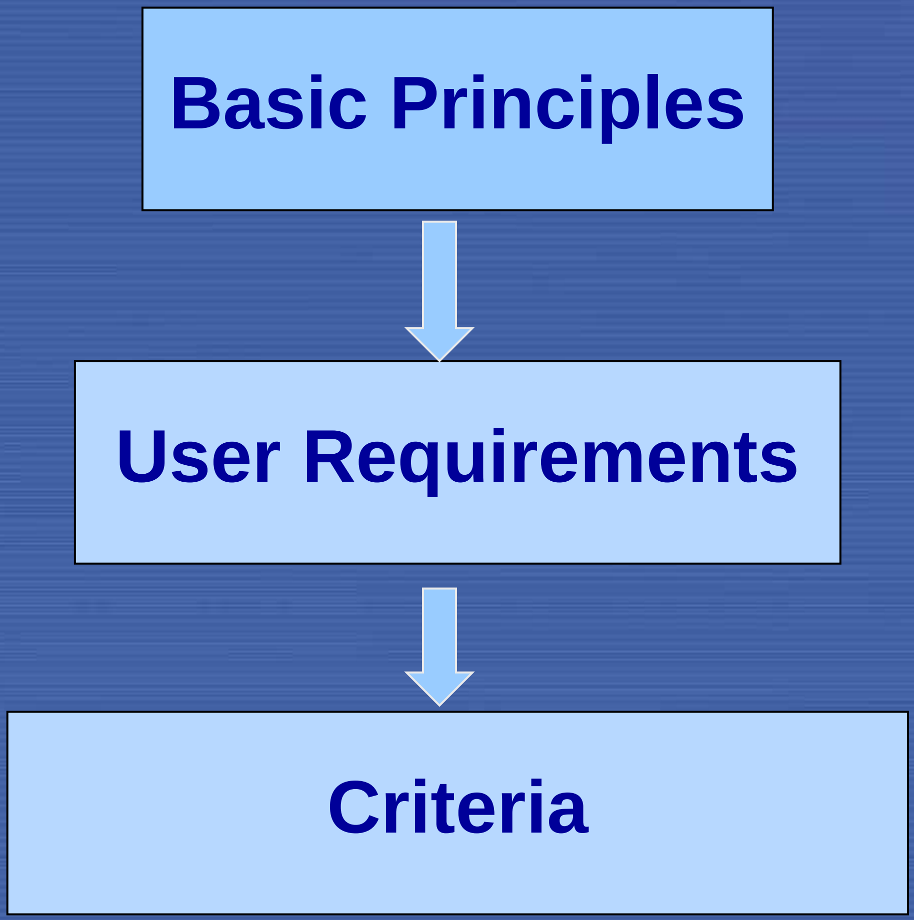


Figure 2.4. Interrelationship of UN concept of sustainability and INPRO.

✓*Brundtland definition of sustainability*: Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

IAEA

Architecture of INPRO Methodology: NES Sustainability Assessment – NESA



Basic Principles :

goals for development of sustainable NES (14).

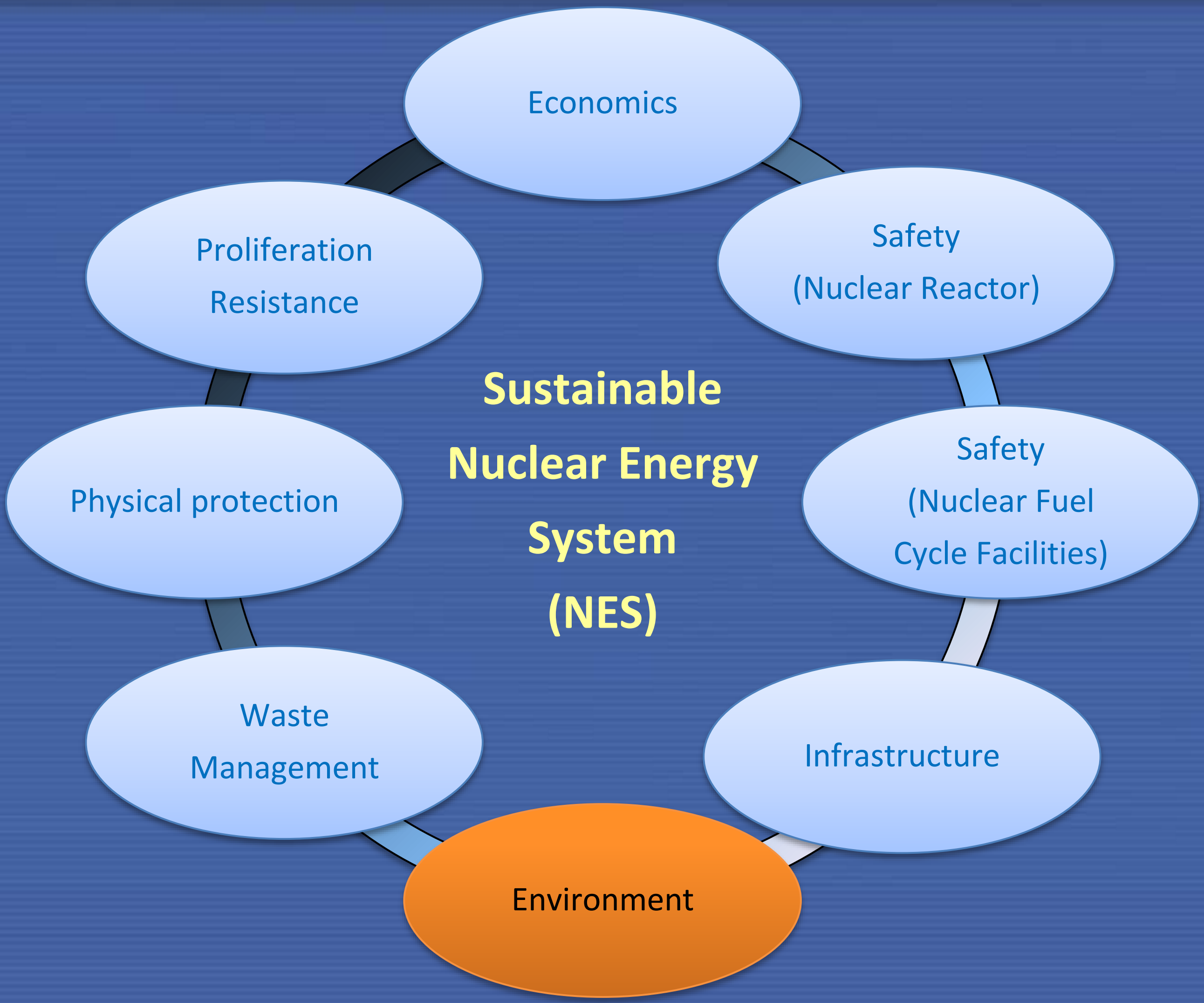
User Requirements:

what should be done by designer, operator, industry and/or State to meet goal defined in Basic Principles (52).

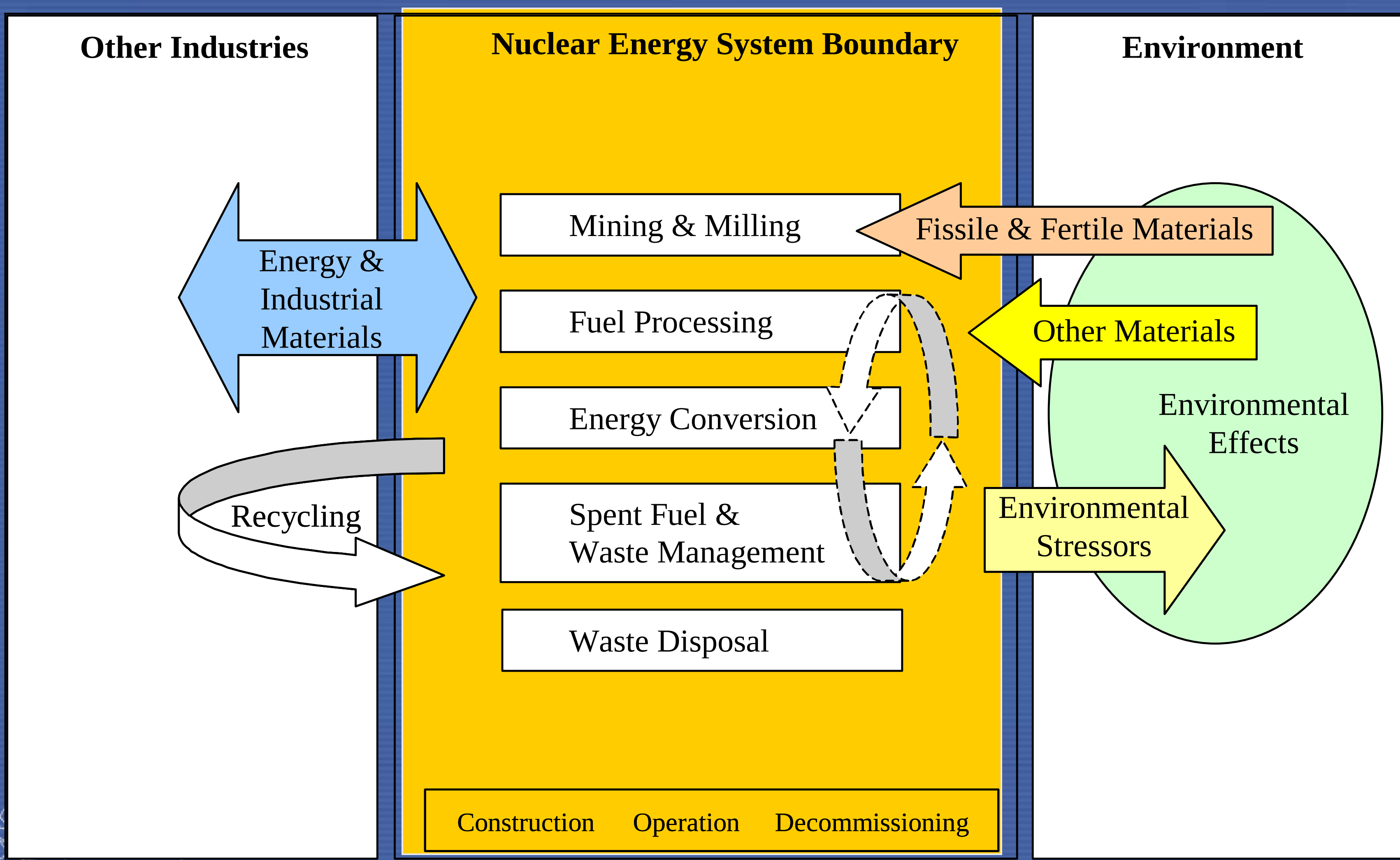
Criteria-Indicators & Acceptance Limits:

Metrics to check whether a User Requirement has been met (125).

Areas assessed in the framework of a NESA



Interfaces of a nuclear energy system and environment



Definitions (1)

"**Environment**" definition includes :

- Human beings.
- Non-human biota.
- Abiotic components, including soil, water and air.
- Natural resources and landscape.
- Interactions among these components.

Definitions (2)

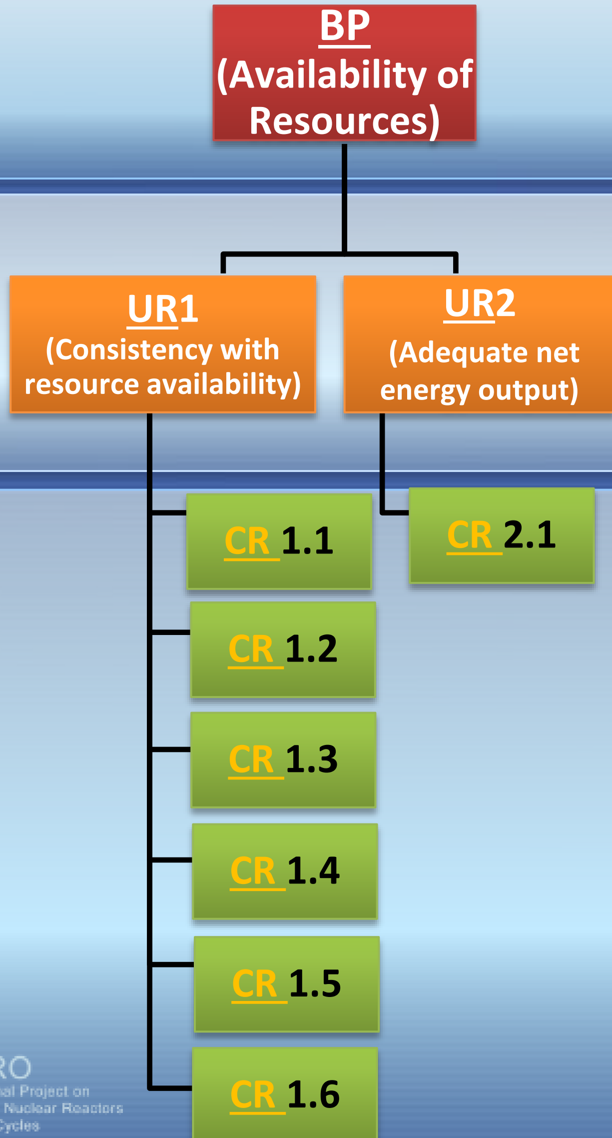
- "**Environmental effect**" definition includes detrimental change caused by:
  - Physical, chemical or biological change.
  - Health effects on people, plants and animals.
  - Effects on quality of life.
  - Depletion of resources.

Revised INPRO manual on Environment is divided in two volumes

I. INPRO Methodology for Sustainability Assessment of Nuclear Energy Systems: Environmental Impact of Stressors

II. INPRO Methodology for Sustainability Assessment of Nuclear Energy Systems: Environmental Impact from Depletion of Resources (Nuclear Energy Series NG-T-3.13)

Structure of the Area of Environment – Depletion of Resources (1)



Basic Principles BP:
goals for development of sustainable NES.

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

Criteria CR:
Assessor’s tools to check whether a User Requirement has been met .

Structure of the Area of Environment – Depletion of Resources (2)

Basic Principle BP (Availability of resources):

A nuclear energy system (NES) shall be capable of contributing to the energy needs in the 21st century while making efficient use of non-renewable resources.

Two User Requirements:

- **UR2.1:** Consistency with resource availability**:**

  All needed material resources are available and efficiently used

- **UR2.2:** Adequate net energy output.

  Energy output surpasses energy input in reasonable short time

Structure of the Area of Environment – Depletion of Resources (3)

	Criteria	Indicators (IN) and Acceptance Limits (AL)
UR1 Consistency with resource availability: *The NES 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 NES. In addition, the NES should make efficient use of non-renewable resources.*	**CR1.1** fissile/ fertile material	**IN1.1:** quantity, $F_j(t)$, of fissile/fertile material type j available for use in the NES at time t. **AL1.1:** $F_j(t) > D_j(t)$, quantity available for NES should be bigger than quantity needed for any $t < 100$ years.
	CR1.2 non-renewable material	**IN1.2:** quantity, $Q_i(t)$, of material type i available for use in the NES at time t. **AL1.1:** $Q_j(t) > D_j(t)$, quantity available for NES, $Q_j(t)$, should be bigger than quantity needed, $D_j(t)$, for any $t < 100$ years.
	CR1.3 power supply to NES	**IN1.3:** P(t): power available (from both internal and external sources) for use in the NES at time t. **AL1.3:** $P(t) \geq P_{NES}(t)$, for any $t < 100$ years, where $P_{NES}(t)$ is the power required by the NES at time t.
	CR1.4 end use of uranium	**IN1.4:** U_{eu} = end use (net) energy delivered by the NES per Mg of uranium mined. **AL1.4:** $U_{eu} > U_0$ U_0 = maximum achievable end use for an existing NES with a once through (open) fuel cycle.
	CR1.5 end use of thorium	**IN1.5:** Th_{eu} = end use (net) energy delivered by a NES per Mg of thorium mined. **AL1.5:** $Th_{eu} > Th_0$ Th_0 = maximum achievable end use for a current operating thorium cycle.
	CR1.6 end use of non-renewable resources	**IN1.6:** C_i = end use (net) energy delivered by the NES per Mg of limited non-renewable resource i consumed. **AL1.6:** $C_i > C_0$ C_0 to be determined on a case specific basis.

Structure of the Area of Environment – Depletion of Resources (4)

UR2 Adequate net energy output: *The energy output of the NES should exceed the energy required to implement, operate and decommission the NES within an acceptably short period.*	**CR2.1** amortization time	**IN2.1:** T_{EQ} = time required to match the total energy input into the NES with energy output (years). **AL2.1:** $T_{EQ} << T_L$ T_L = intended life time of NES.

Changes against IAEA TECDOC-1575, vol. 7 (1)

(1) Manual on Environment is split in two manuals, one dedicated to depletion of resources, another one – to stressors

(2) Background material updated, for example, Red Book 2009 changed to Red Book 2011

(3) Extended summary on results of the completed collaborative project on Global architecture of innovative NES with thermal and fast reactors and a closed nuclear fuel cycle (GAINS) IAEA Nuclear Energy Series No. NP-T-1.14 is included as Appendix 3

(4) INS changed to NES

(5) Numbering of BP, UR, CR, IN and AL changed to exclude ‘2.’ at the left

(6) No changes to indicators (IN)

Changes against IAEA TECDOC-1575, vol. 7 (2)

Changes to Criteria (CR)

New:	Old:
CR1.1: Fissile/fertile material *(no changes in the indicator)*	**CR2.1.1:** Fissile material
CR1.2: Non-renewable material	**CR2.1.2:** Non-renewable material
CR1.3: Power supply to NES *(no change in the indicator)*	**CR2.1.3:** Power
CR1.4: End use of uranium	**CR2.1.4:** End use of uranium
CR1.5: End use of uranium	**CR1.5:** End use of uranium
CR.1.6: End use of non-renewable resources	**CR.1.6:** End use of non-renewable resources

Changes to Acceptance Limits (AL)

New:	Old:
AL1.1: Fj(t) > Dj(t), quantity available for NES should be bigger than quantity needed for any t < 100 years (**AL1.1** applies to both **IN1.1** and **IN1.2**)	**AL2.1.1:** Fj(t) > 0 for any t < 100 years **AL2.1.2:** Fj(t) > 0 for any t < 100 years
AL2.1: TEQ << TL, TL = intended life time of NES	**AL2.2.1:** TEQ <k_*TL, TL = intended life time of NES. k<1

Resources: Definitions

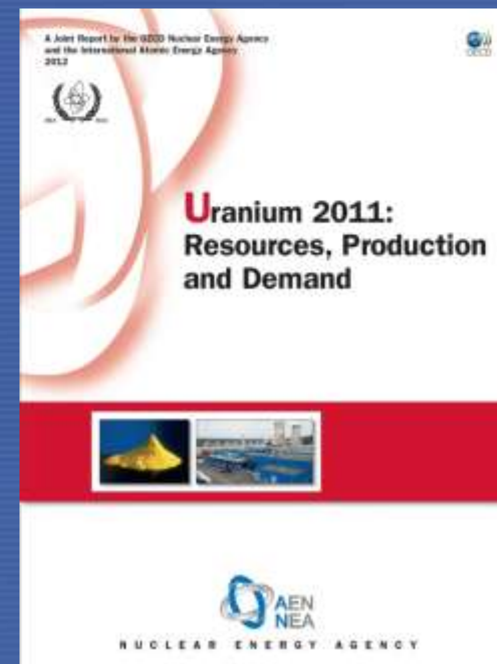
Definition of terms

- <u>Primary resources</u> for nuclear fuel:
  - Natural uranium (U_{nat})
  - Natural thorium (Th)
- <u>Secondary resources</u> for nuclear fuel:
  - Depleted uranium (DU)
  - High enriched uranium (HEU)
  - Spent nuclear fuel (SNF)
    - Reprocessed uranium (REPU)
    - Recycled plutonium (Pu)

Availability of resources (1)

Classification of U resources (Red Book 2011)

- **Conventional Resources:**
  - Reasonable Assured
  - Inferred
    } **~ 7 million tU**
  - Prognosticated
  - Speculative
    } **~ 11 million tU**
- **Unconventional Resources:**
  - Phosphates **~ 7 to 22 million tU**, Carbonatite, Lignite, Seawater **~ 4 billion tU**.



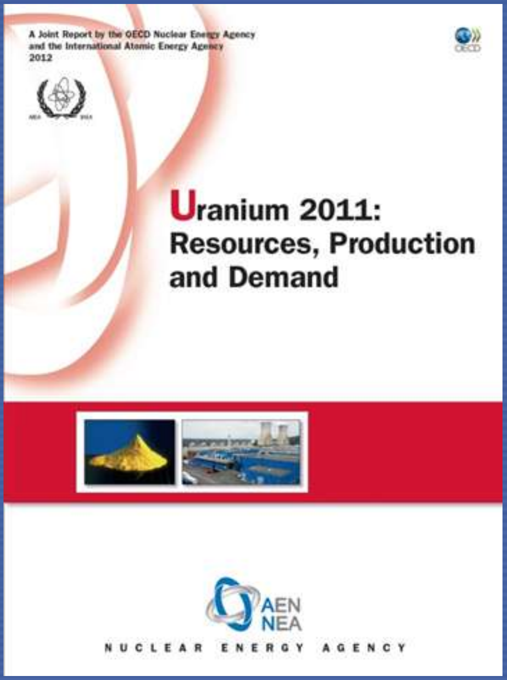
Availability of resources (2)

Cost categories of uranium resources

Costs to recover U $/kgU	Identified conventional U resources 1000 tU
< 260	7095
< 130	5362
< 80	3077
< 40	680

(Identified = reasonable assured + inferred)

Red Book 2011



Impact of natural U costs on Levelized Unit Electricity Cost (LUEC)

Structure of nuclear electricity generation cost (for large reactors) (OECD-NEA, 2011)

Discount rate	5%	10%
Total investment cost	58.6%	75.6%
O&M	25.2%	14.9%
Fuel costs	16.0%	9.5%
Carbon costs	0.0%	0.0%
Decommissioning	0.3%	0.0%

Natural U cost contribution to LUEC in the state-of-the-art LWRs is below 5%!

Scope of assessment (UR1)

Confirmation of resource availability for:

- Fissile/ fertile material.
- Other non renewable material, e.g. Zr.
- External power supply.

Efficient use of uranium/ thorium and non renewable materials.

(1) Assessment approach (UR1)

- Regarding the availability of sufficient resources of fissile and fertile material, a global market for them exists, which necessitates a global assessment of such availability
- The result will be sensitive to whether the assessing country considers global resource market (implying trade) or domestic resource only – the results could be very different based on individual country’s trade policies and circumstances
- Recognizing that global assessment is beyond any reasonable capacity of an individual country, the report provides background materials and summarizes the results of some international global assessment studies that could be referred to and referenced in the corresponding national assessments

(2) Assessment approach (UR1)

- If a country performing NES assessment has large plans for its nuclear energy programme and foresees it could eventually become a major player in global nuclear energy markets, then it makes sense to consider joining the efforts with other countries to perform an updated global resource availability assessment.

- Such assessments are being periodically undertaken under the aegis or renowned international organizations, and one option to do so is to join the activities of the IAEA/INPRO task ‘Global scenarios: http://www.iaea.org/INPRO/activities/index.html

- Notwithstanding the existence of a global market for NES related non-renewable resources, national assessment also makes sense once the country considers benefitting in its national nuclear power programme from its own domestic resources.

- Regional assessment could be recommended in the case of existing or foreseen long term partnerships with particular neighbouring or non-neighbouring countries with which good relations and cooperation in the nuclear energy field exists. Such an assessment could foster further cooperation potentially resulting in a sustainable regional NES

Steps in assessment (UR1)

INPRO Methodolgy assessment of U resources:

1. Determine **availability** of global and national (and regional) resources of uranium until 2100.
   - Global resources: “Red Book” from OECD/NEA-IAEA.

2. Determine global and national (and regional) **demand** of uranium until 2100.
   - Global demand: e.g., from IAEA NES No. NP-T-1.14.

3. Confirm availability of uranium needed for global and national (and regional) Nuclear Energy System until 2100.

Scope of assessment (UR2)

Adequate net energy output:

- Time till total energy input equals output T_{EQ} << life time of NES.
- Example:
  - PWR with single recycling of Pu needs T_{EQ} of about 5 months.
  - Life time of PWR about 40+ years.

Sources reflecting upon global supply and demand in natural U

- ✓ OECD/ Nuclear Energy Agency (NEA), INTERNATIONAL ATOMIC ENERGY AGENCY, Uranium 2011: Resources, Production and Demand (‘Red Book’), OECD, Paris (2012).
- ✓ INTERNATIONAL ATOMIC ENERGY AGENCY, Framework for Assessing Dynamic Nuclear Energy Systems for Sustainability, Final Report of the INPRO Collaborative Project on Global Architectures of Innovative Nuclear Energy Systems with Thermal and Fast Reactors and a Closed Nuclear Fuel Cycle (GAINS), IAEA Nuclear Energy Series No. NP-T-1.14, IAEA, Vienna (2013).
- ✓ INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Energy Development in the 21st Century: Global Scenarios and Regional Trends, IAEA Nuclear Energy Series No. NP-T-1.8, IAEA, Vienna (2010).
- ✓ INTERNATIONAL ATOMIC ENERGY AGENCY, Role of Thorium to Supplement Fuel Cycles of Future Nuclear Energy Systems, IAEA Nuclear Energy Series No. NF-T-2.4, IAEA, Vienna (2012).
- ✓ OECD/NUCLEAR ENERGY AGENCY, A Preliminary Assessment of Raw Material Inputs that would be Required for Rapid Growth in Nuclear Generating Capacity, OECD/NEA, Paris (2011).

GAINS analytical framework (example)

1. Models of the ‘nuclear world’ built & agreed

- homogeneous models
- heterogeneous models: groups can operate separately or synergistically

G1 - recycling strategy group;

G2 - direct disposal /reprocessing abroad

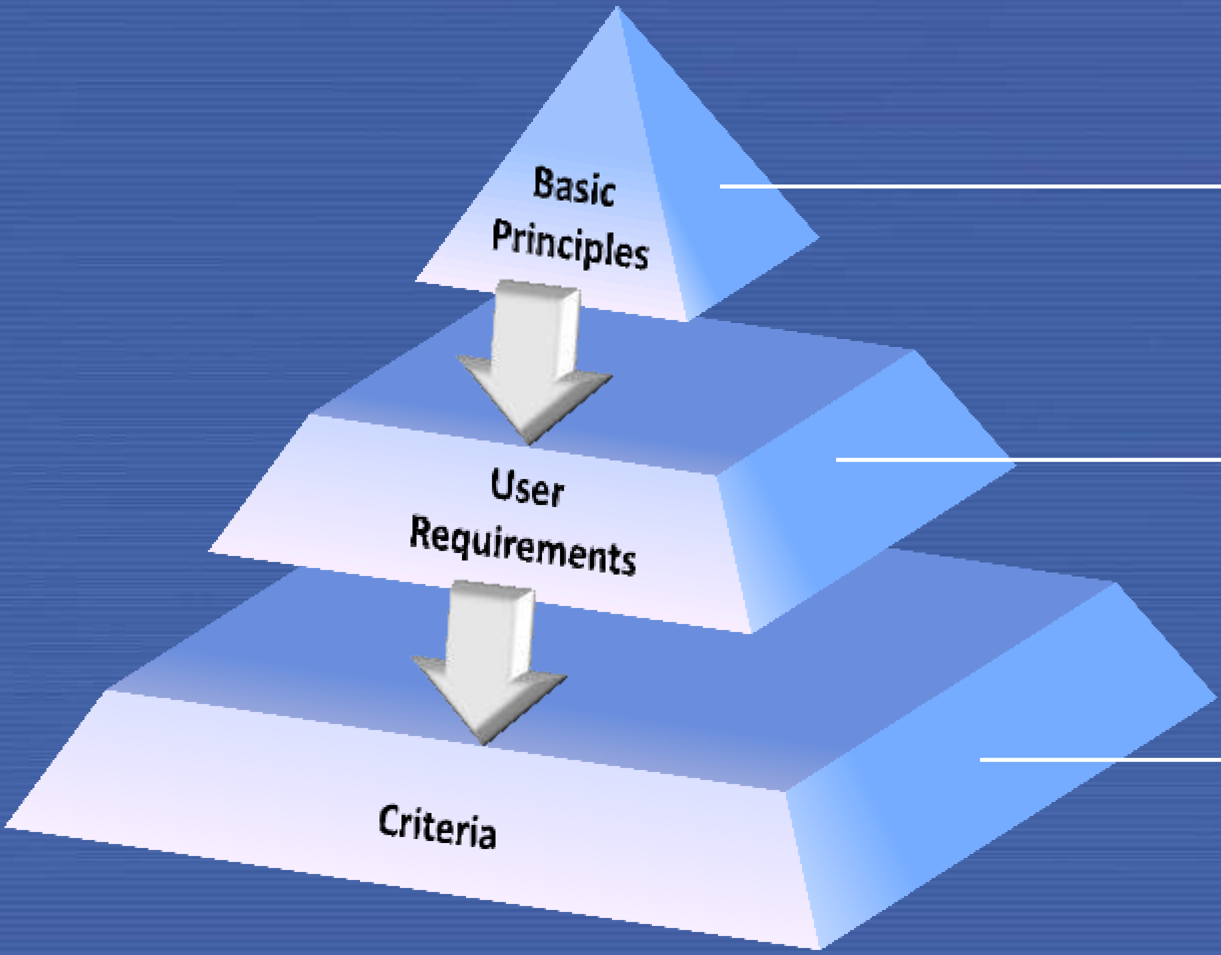
G3 - minimal infrastructure: disposal or reprocessing abroad

Homogeneous | Heterogeneous Separate | Heterogeneous Synergistic

Thank You!

For more information, please, visit:
http://www.iaea.org/INPRO/

INPRO Methodology



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Criteria CR:
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Definitions (3)

"Stressor" definition includes:

Entities that can induce an adverse response in the environment:

- Physical, or
- Chemical, or
- Biological effect.