IAEA activities related to the Proliferation Resistance features of Fast Reactors

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International Atomic Energy Agency

IAEA National training course on Heavy Liquid Metal Cooled Fast Reactors: Benefits and Challenges

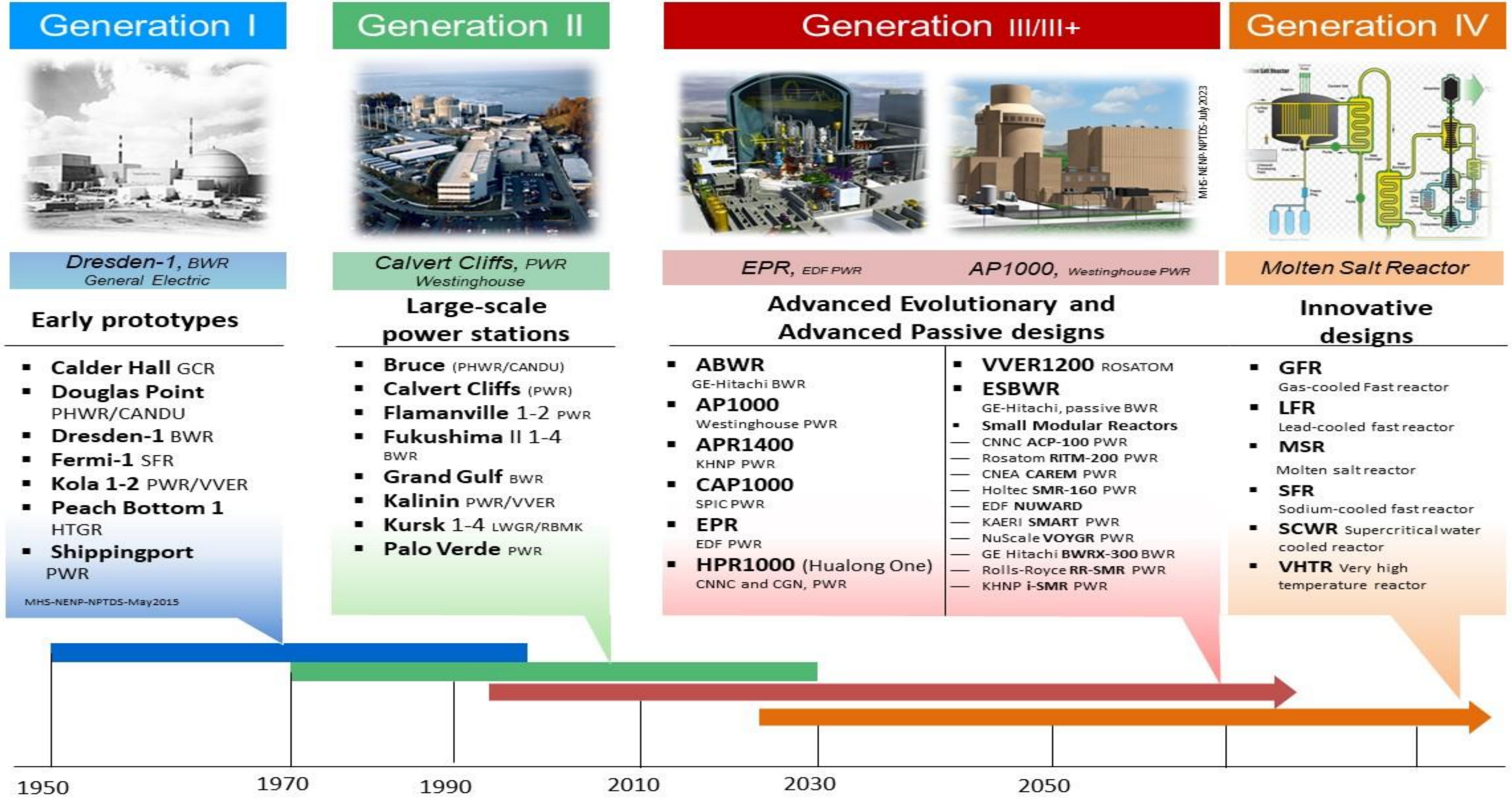
February 16-20, 2026

Pitesti, Romania

Outline

- Introduction
- Introduction to Proliferation Resistance (PR)
- PR: Basic Principle and Framework
- IAEA Activities

Evolution of Nuclear Power Reactor Technology



Innovative Reactors (Gen-IV)

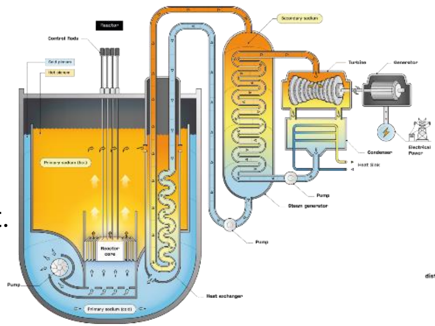
GEN IV International Forum
Expertise | Collaboration | Excellence

Innovative Reactor:

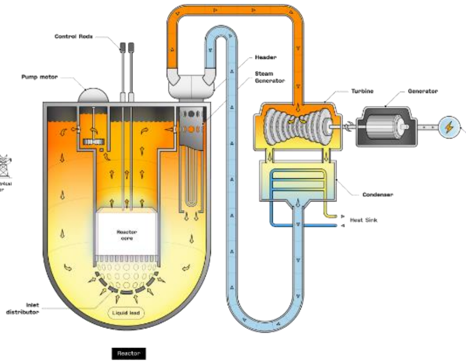
Advanced design which incorporates conceptual changes in design approaches or system configuration in comparison with existing practice. Substantial R&D, feasibility tests, and possibly a prototype or demonstration reactor are required prior to deployment.

- **Early Prototypes and Demonstration Plants Gen-I**
- **Current Fleet Gen-II/III**
- **Advanced Nuclear Reactors**
  - *Evolutionary designs*
    Gen-III and Gen-III+
  - *Innovative designs*
    Gen-IV
  - SMRs can be either *evolutionary* or *innovative*
  - *Innovative SMR*
    Advanced Modular Reactor (AMR)

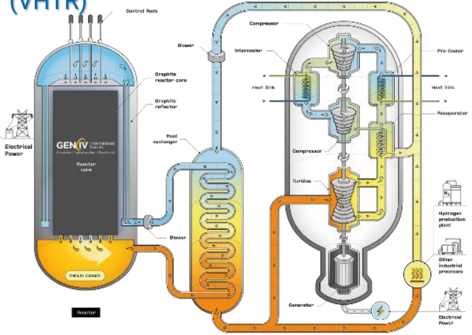
Sodium cooled Fast Reactor (SFR)

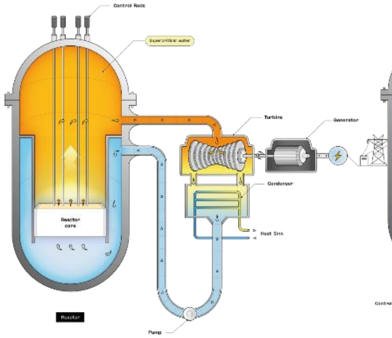


Lead cooled Fast Reactor (LFR)

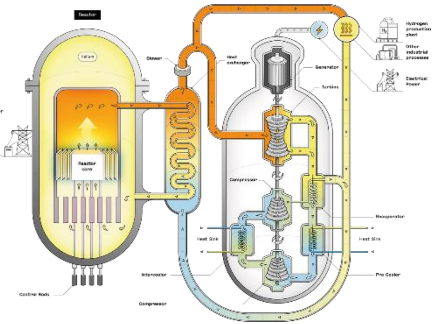


Very-High-Temperature Reactor (VHTR)

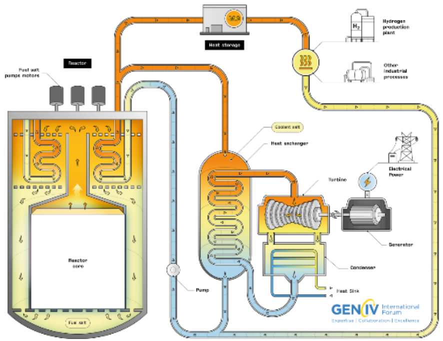




Supercritical Water cooled Reactor (SCWR)



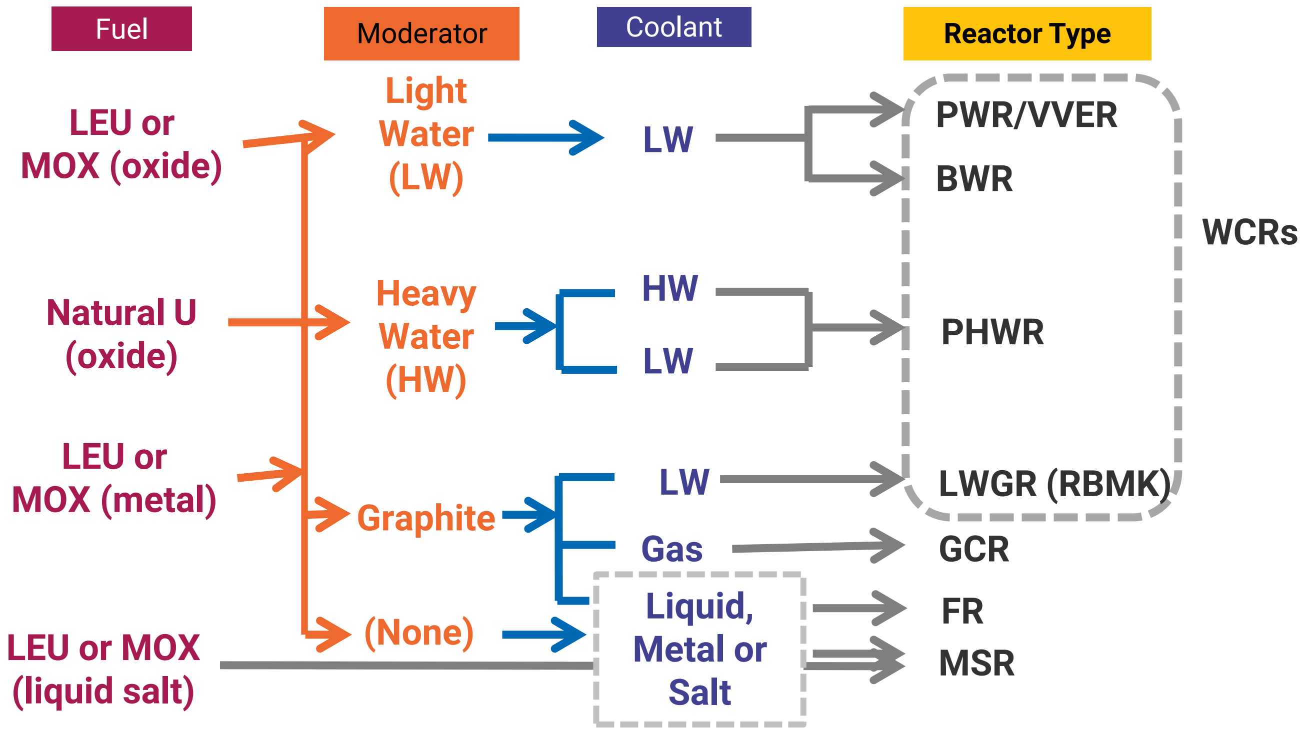
Gas cooled Fast Reactor (GFR)



Molten Salt Reactor (MSR)

Source: GIF homepage (www.gen-4.org)

Nuclear Power Reactor Classifications



MOX: mixed-oxide containing any combination of U, Pu and Th

GIF: Goals for Gen-IV Nuclear Energy Systems

Sustainability-1	Generation IV nuclear energy systems will provide sustainable energy generation that meets clean air objectives and provides long-term availability of systems and effective fuel utilisation for worldwide energy production.
Sustainability-2	Generation IV nuclear energy systems will minimise and manage their nuclear waste and notably reduce the long-term stewardship burden, thereby improving protection for the public health and the environment.
Economics-1	Generation IV nuclear energy systems will have a clear life-cycle cost advantage over other energy sources.
Economics-2	Generation IV nuclear energy systems will have a level of financial risk comparable to other energy projects.
Safety and Reliability-1	Generation IV nuclear energy systems operations will excel in safety and reliability.
Safety and Reliability-2	Generation IV nuclear energy systems will have a very low likelihood and degree of reactor core damage.
Safety and Reliability-3	Generation IV nuclear energy systems will eliminate the need for offsite emergency response.
Proliferation Resistance and Physical Protection	Generation IV nuclear energy systems will increase the assurance that they are very unattractive and the least desirable route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism.

See at: www.gen-4.org

Nuclear Non-Proliferation Treaty (NPT)

Landmark international treaty that **aims** to

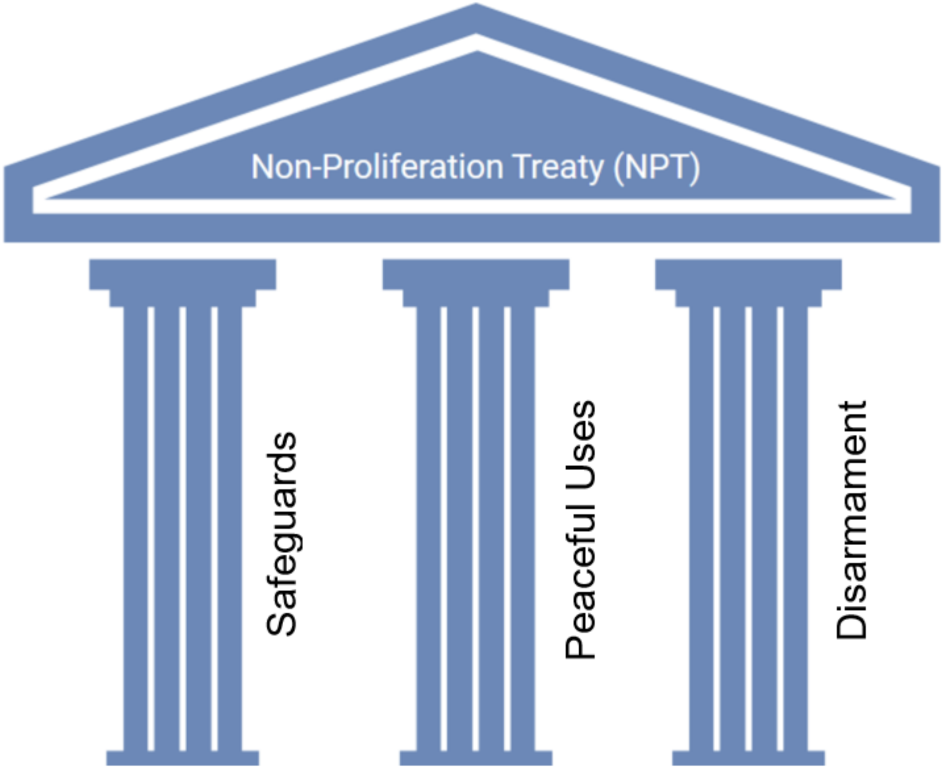
- **prevent** the spread of nuclear weapons and other nuclear explosive devices,
- **promote cooperation** in the peaceful uses of nuclear energy, and
- **further the goal** of nuclear disarmament

opened for signature in 1968 and entered into force in 1970

cornerstone of the global nuclear non-proliferation regime

Most widely signed treaty

3 Pillars of NPT



Non-proliferation Treaty

1. Facilitate the application of IAEA Safeguards
2. Promote peaceful use of nuclear energy
3. Move towards nuclear disarmament

IAEA Safeguards

Safeguards are a set of **technical measures** applied by the IAEA to **independently verify** States' undertakings under their safeguards agreements

States **accept these measures** through the conclusion of safeguards agreements – CSA required under the Nuclear Non-Proliferation Treaty

190 States have SG agreements in force

Proliferation Resistance

- **Proliferation Resistance**

  is

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

INTERNATIONAL ATOMIC ENERGY AGENCY — STR-332
DEPARTMENT OF SAFEGUARDS

Proliferation Resistance Fundamentals for Future Nuclear Energy Systems

2002

- **Degree of Proliferation Resistance**

  results

from **a combination** of, *inter alia,*

- technical design features,
- operational modalities,
- institutional arrangements,
- safeguards measures

Proliferator

State seeking to acquire a nuclear weapon or other nuclear explosive device.

What are the requirements for Proliferator State to be successful?

1. Nuclear material
2. Technology
3. Skills & knowledge
4. Time

Considerations

Proliferator needs

- Nuclear materials
- Technologies
- Skills & knowledge
- Time

Fast reactors and associated fuel cycle facilities may contribute

- ➢ Variety of attractive nuclear materials and forms
- ➢ Capabilities: reprocessing, isotope separation, etc.
- ➢ Development of skills & knowledge

Intrinsic features: design

Extrinsic measures: State's commitments (i.e., AP), and IAEA safeguards

Proliferation Resistance

- Proliferation barriers:
  - **Intrinsic Features** inherent to a particular fuel cycle system /nuclear energy system (i.e., technology and design features);
  - **Extrinsic Measures**, involving administratively-added measures (physical protection and international safeguards).

- **Dynamic relation** between extrinsic and intrinsic barriers. The proliferation resistance is achieved by a combination of them.

- To satisfy international standards for adequacy of protection against the diversion of nuclear material, **external barriers** can be added to compensate for weaknesses in intrinsic barriers.

Nonproliferation assessment:

- identifies the barriers to proliferation;
- evaluates their effectiveness.

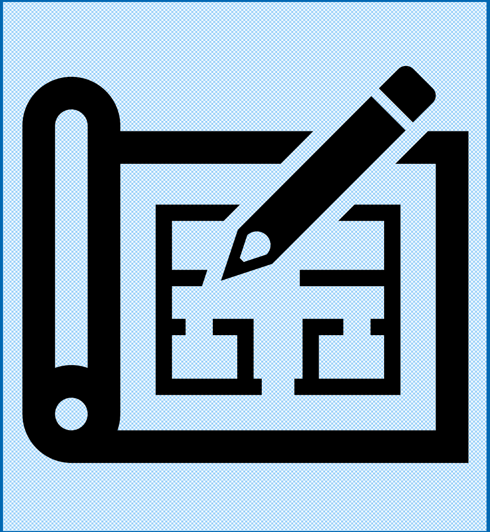
Presented by M. Nitoi (RATEN, Romania) at the IAEA Technical Meeting on Proliferation Resistance Features of Fast Reactors and Associated Fuel Cycles (18-21 August 2025)

Intrinsic Features

Technical barriers or design characteristics of NFC that make it difficult to gain access to materials or misuse facilities to obtain material for nuclear weapons or other explosives

- **<u>Misuse</u> includes replication or modification of facilities, processes and technology to support weapons development**

- **<u>Attractiveness</u> of nuclear material and facilities must also bo considered**



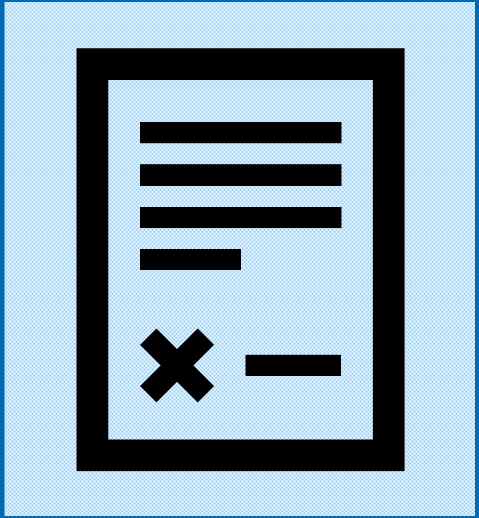
Extrinsic Measures

Related to State’s commitments, obligations, and policies regarding nuclear non-proliferation

Bilateral agreements between export/import States

Commercial, legal or institutional arrangements that control access to nuclear material and energy systems

Verification activities: Arrangements to address violations of nuclear non-proliferation and safeguards undertakings



IAEA

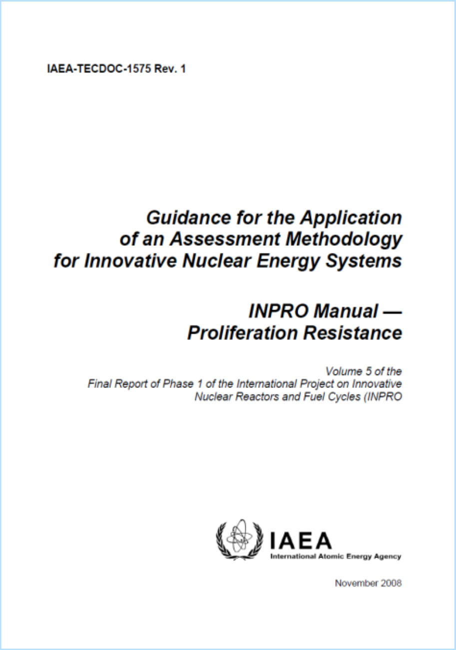
INPRO Methodology

For assessing the sustainability of innovative nuclear energy systems (NES)

INPRO Methodology

Proliferation Resistance

- Major revision to INPRO PR Manual
- 9 Consultancy Meetings
- ~40 international experts
- Improved and streamlined assessment
- Good for comparing options
- Preprint should be ready soon!


IAEA-TECDOC-1575 Rev. 1

Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems

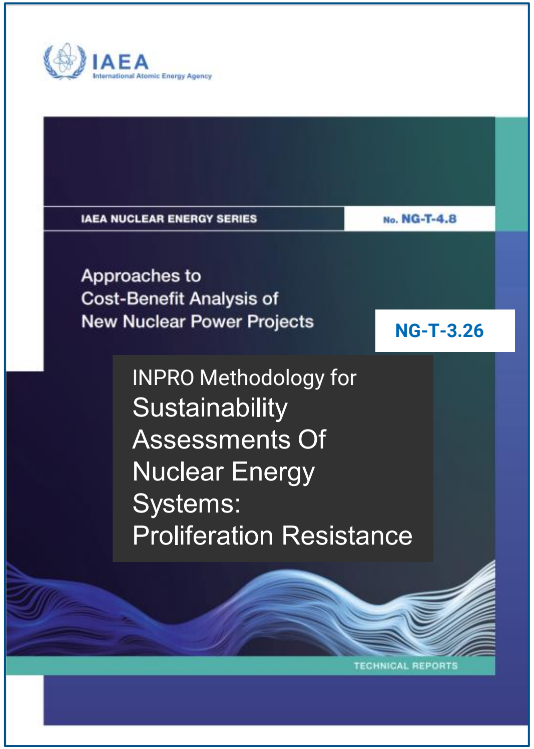
INPRO Manual — Proliferation Resistance

Volume 5 of the Final Report of Phase 1 of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO

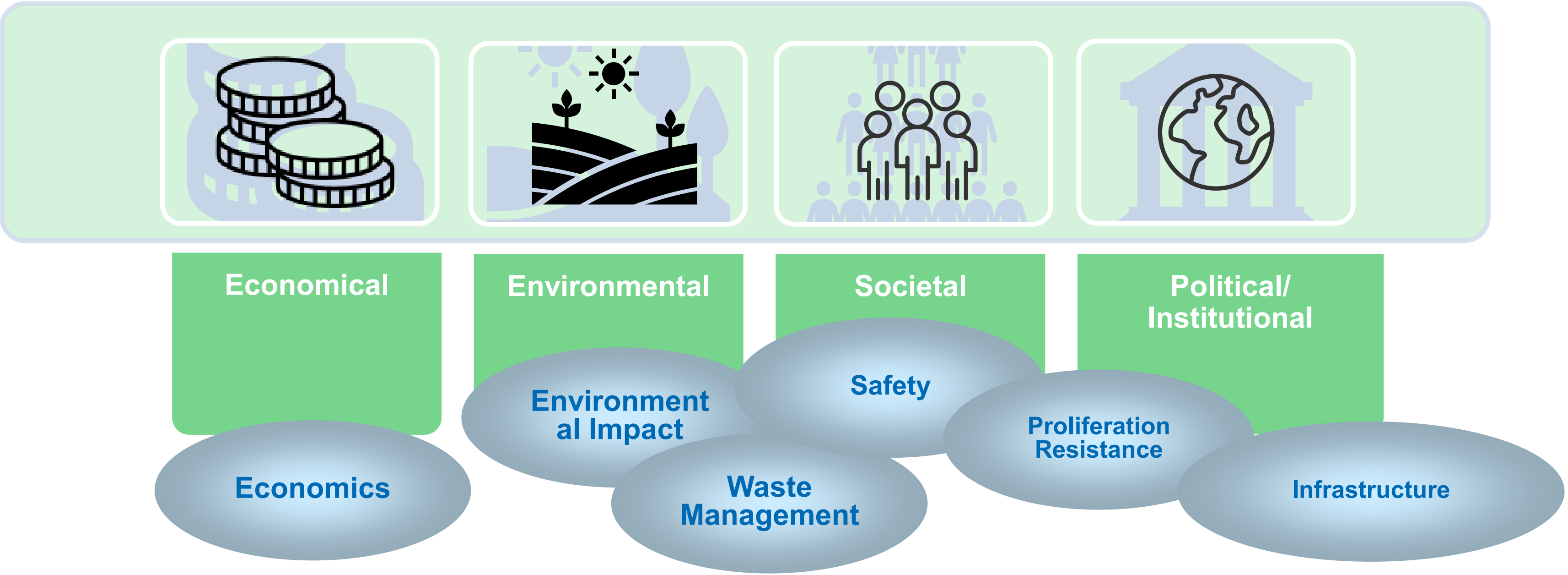
IAEA
International Atomic Energy Agency

November 2008

TECDOC-1575-Rev. 1 Vol. 5 (2008)

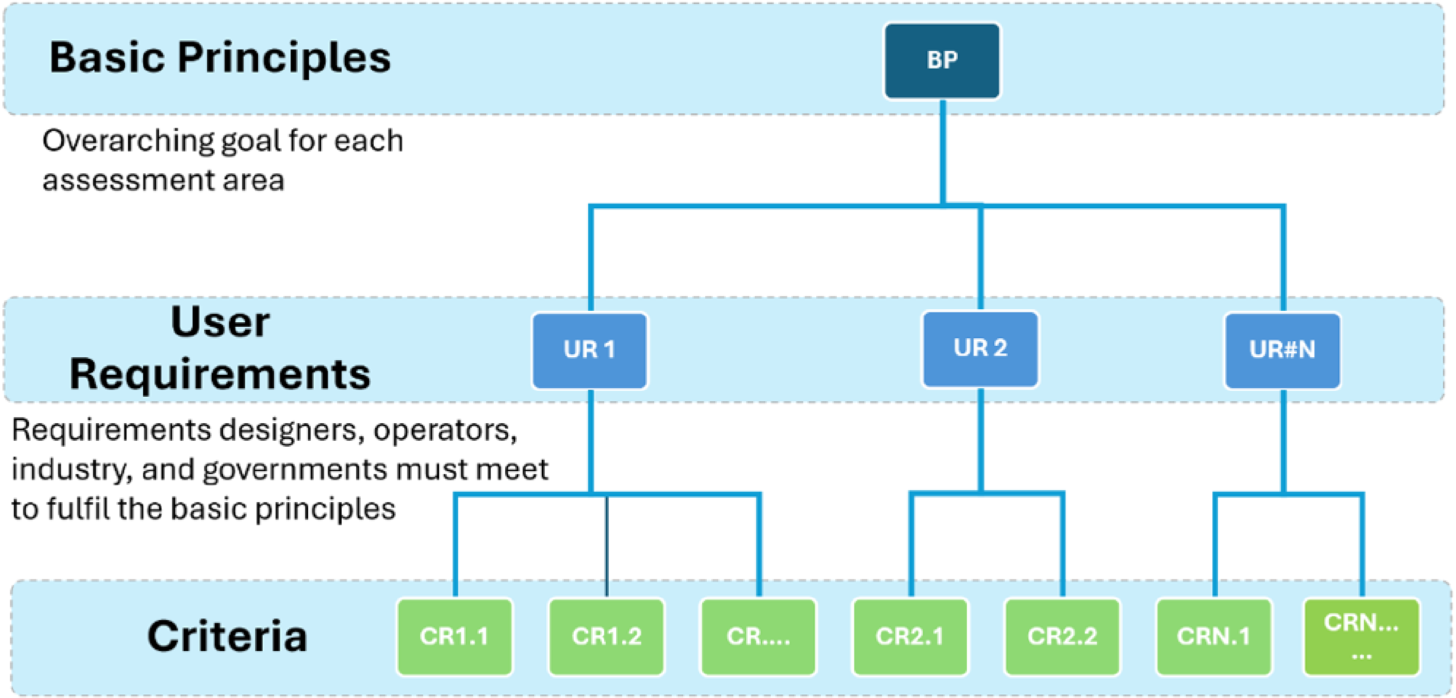


UN Concept of Sustainable Energy Development



INPRO Sustainable Nuclear Energy

INPRO Methodology Framework



Overarching goal for each assessment area

Requirements designers, operators, industry, and governments must meet to fulfil the basic principles

Quantitative or qualitative standards that assessors use to judge whether user requirements are satisfied

CR: Indicators (IN) + Acceptance Limits (AL)
Evaluation Parameters (EP) [Y/N]

Proliferation Resistance User Requirements

Proliferation Resistance BP:

Proliferation resistance intrinsic features and extrinsic measures should be implemented throughout the life cycle of a nuclear energy system (NES) to help ensure that the NES will continue to be an unattractive means to acquire nuclear material for a nuclear weapon or other nuclear explosive device; both intrinsic features and extrinsic measures are essential, and neither can be considered sufficient by itself.

- **UR1:** State's obligations and commitments
- **UR2:** Attractiveness of NES
- **UR3:** Facilitation of IAEA Safeguards
- **UR4:** Implementation of multiple measures
- **UR5:** Optimization of PR in NES Design

Proliferation Resistance Framework

BP: 1

Proliferation Resistance Basic Principle (BP):

Proliferation resistance intrinsic features and extrinsic measures should be **implemented** throughout the life cycle of a nuclear energy system (NES) to help ensure that the **NES** will continue to be an **unattractive** means to acquire nuclear material for a nuclear weapon or other nuclear explosive device; **both** intrinsic features and extrinsic measures are **essential**, and neither can be considered sufficient by itself.

UR: 5

CR: 11

- **UR1:** States' obligations and commitments
  - **CR1.1:** States' legal and policy framework
  - **CR1.2:** Institutional & structural arrangements
- **UR2:** Attractiveness of NES
  - **CR2.1:** Technology
  - **CR2.2:** Nuclear material
- **UR3:** Facilitation of IAEA Safeguards
  - **CR3.1:** Safeguards effectiveness
  - **CR3.2:** Efficient safeguards implementation
- **UR4:** Implementation of multiple measures
  - **CR4.1:** Defence in depth - intrinsic features
  - **CR4.2:** Defence in depth - extrinsic measures
- **UR5: Optimization of PR in NES**
  - **CR5.1:** PR included in all design phases
  - **CR5.2:** PR effective and efficient for operator
  - **CR5.3:** State approves PR measures

Concept of Attractiveness

How attractive is the nuclear technology and material to a proliferator?

Attractiveness Evaluation Scale to proliferator:

Very high, High, Moderate, Low, Very low

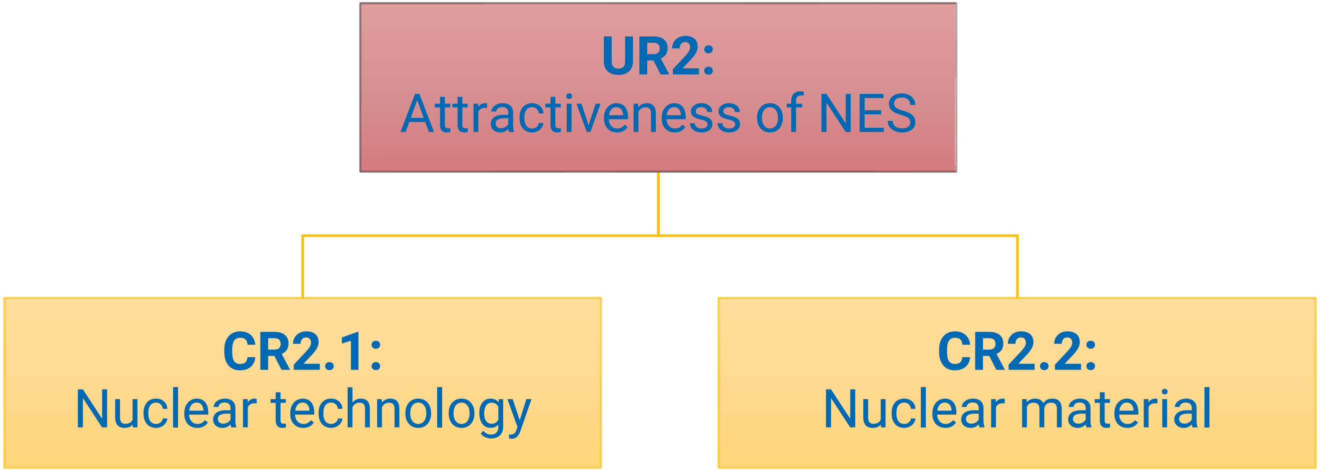
IN2.1: Attractiveness of nuclear technology

AL2.1: The attractiveness of all technology considered in the NES and within the State is addressed

Evaluation Parameter (EP)	Evaluation Scale (Attractiveness for proliferation)				
	Very High	High	Moderate	Low	Very Low
EP2.1.1: Reprocessing (extraction of fissile material)	Yes			No	
EP2.1.2: Enriching uranium	Yes			No	
EP2.1.3: Fabricating metal fuels	Yes			No	
EP2.1.4: Fabricating Pu-bearing non-metal fuel (MOX)		Yes		No	
EP2.1.5: Fabricating UOX fuel			Yes	No	
EP2.1.6: Fabricating other fuel (nitrides, carbides, TRISO, etc.)		Yes		No	
EP2.1.7: Irradiating fertile material		Yes		No	
EP2.1.8: Conditioning of spent fuel		Yes		No	
EP2.1.9: Producing medical isotopes		Yes		No	
EP2.1.10: Remote handling (hot cells, gloveboxes)		Yes		No	
EP2.1.11: Having dual-use equipment			Yes	No	

UR2: Attractiveness of NES

UR2: The attractiveness of nuclear technology and nuclear material in an NES should be low for acquiring a nuclear weapon or other nuclear explosive device.



TM on Proliferation Resistance of Fast Reactors and Associated Fuel Cycles

TM Topics:

- Evaluation of Proliferation Resistance (PR) of Fast Reactors and Associated Fuel Cycles: Methodologies, Definitions, Assessment and Metrics
- Reactor Design Features for Enhancing Proliferation Resistance
- Proliferation Resistance Considerations for Fast Reactor Fuel Cycles
- Safeguardability of Fast Reactors and Associated Fuel Cycles

Vienna, IAEA
18-25 August 2025

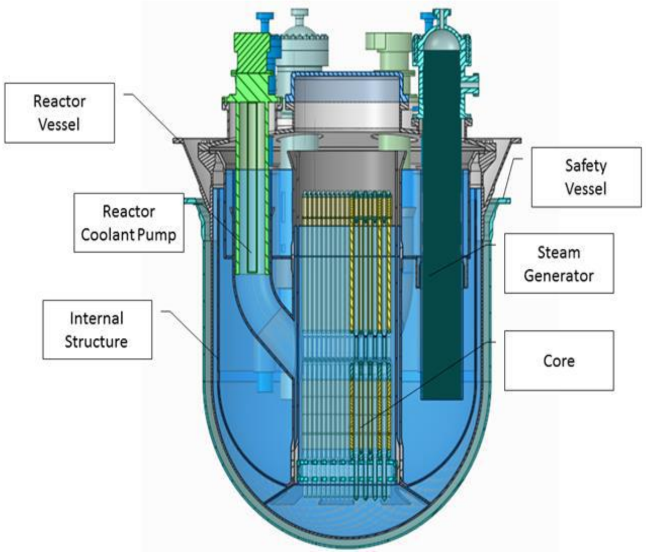
https://conferences.iaea.org/event/411/

Safeguards summary: Example of ALFRED

- **Design integrated safeguards**: The reactor incorporates features that facilitate safeguards, such as sealed fuel assemblies. The system provides for the installation of measurement instruments and surveillance equipment.

- **National safeguards framework**: Besides the general norms for the control of safeguards in the nuclear field, and the detailed list of materials, devices, equipment and information relevant to the proliferation, there were issued norms on authorization procedures for activities involving materials, devices and equipment, relevant to the proliferation of nuclear weapons and other nuclear explosive devices.

- **International safeguards**: ALFRED is developed to comply with IAEA safeguards, enabling effective verification and transparency of compliance with non-proliferation treaties.



Presented by M. Nitoi (RATEN, Romania) at the IAEA Technical Meeting on Proliferation Resistance Features of Fast Reactors and Associated Fuel Cycles (18-21 August 2025)

Conclusions

- **IAEA Safeguards by Design**:
  - SBD is the early consideration of safeguards technical measures in the design process of nuclear facilities.
  - Brings down barriers to future technology deployment.
  - Completely voluntary, driven by the designer

- Both the IAEA and the **technology designers** should take steps in the design phase to facilitate effective international safeguards.

- Technology designers are encouraged to reach out to the IAEA to engage on SBD

- Designers should conduct a review of the new reactor designs with reference to the efficient, well-established IAEA safeguards system for LWRs. Such a review should evaluate the possibility of turning the advanced reactor into an item facility, noting that the definition of an item may need to evolve in new and untraditional ways.

Thank you!

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