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IAEA INPRO Project: Overview

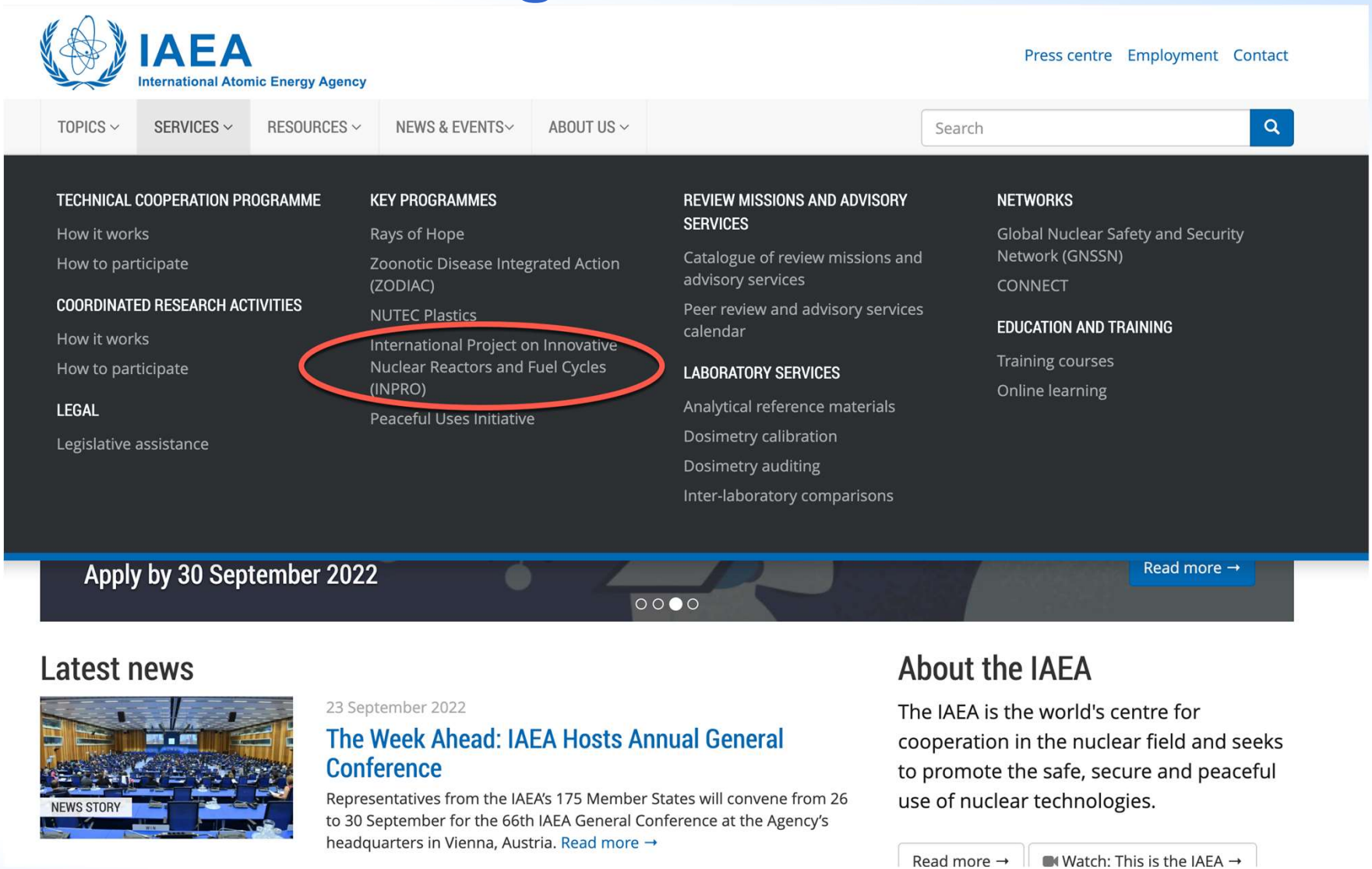
Alexander Bychkov, IAEA / INPRO

Joint IAEA-ICTP Workshop on Physics and Technology of Innovative Nuclear Energy Systems

12-16 December 2022, ICTP, Trieste, Italy

IAEA
INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles

INPRO is one of the Key IAEA Programmes



What is INPRO?

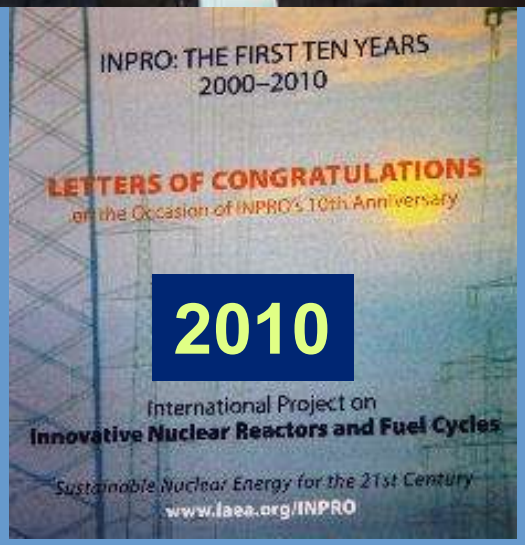
➢ International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)

- INPRO is a key forward looking IAEA activity assessing nuclear energy systems integrated with the “One House” of the IAEA
- The INPRO members are key drivers of projects and tasks in INPRO

INPRO is a part of the realization process of Russia's President Initiative, presented at the United Nations Millennium Summit in September 2000

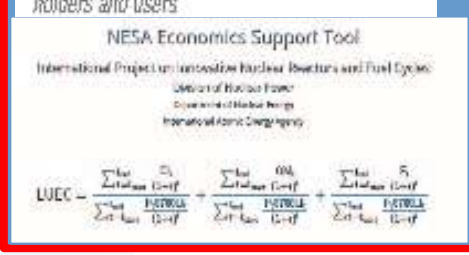
2000

ROSATOM



INTERNATIONAL PROJECT ON INNOVATIVE NUCLEAR REACTORS AND FUEL CYCLES

- *Developing sustainable nuclear energy scenarios*
- *Investigating institutional and technical innovations*
- *Assessing the sustainability of nuclear energy systems*
- *Facilitating dialogue between technology holders and users*

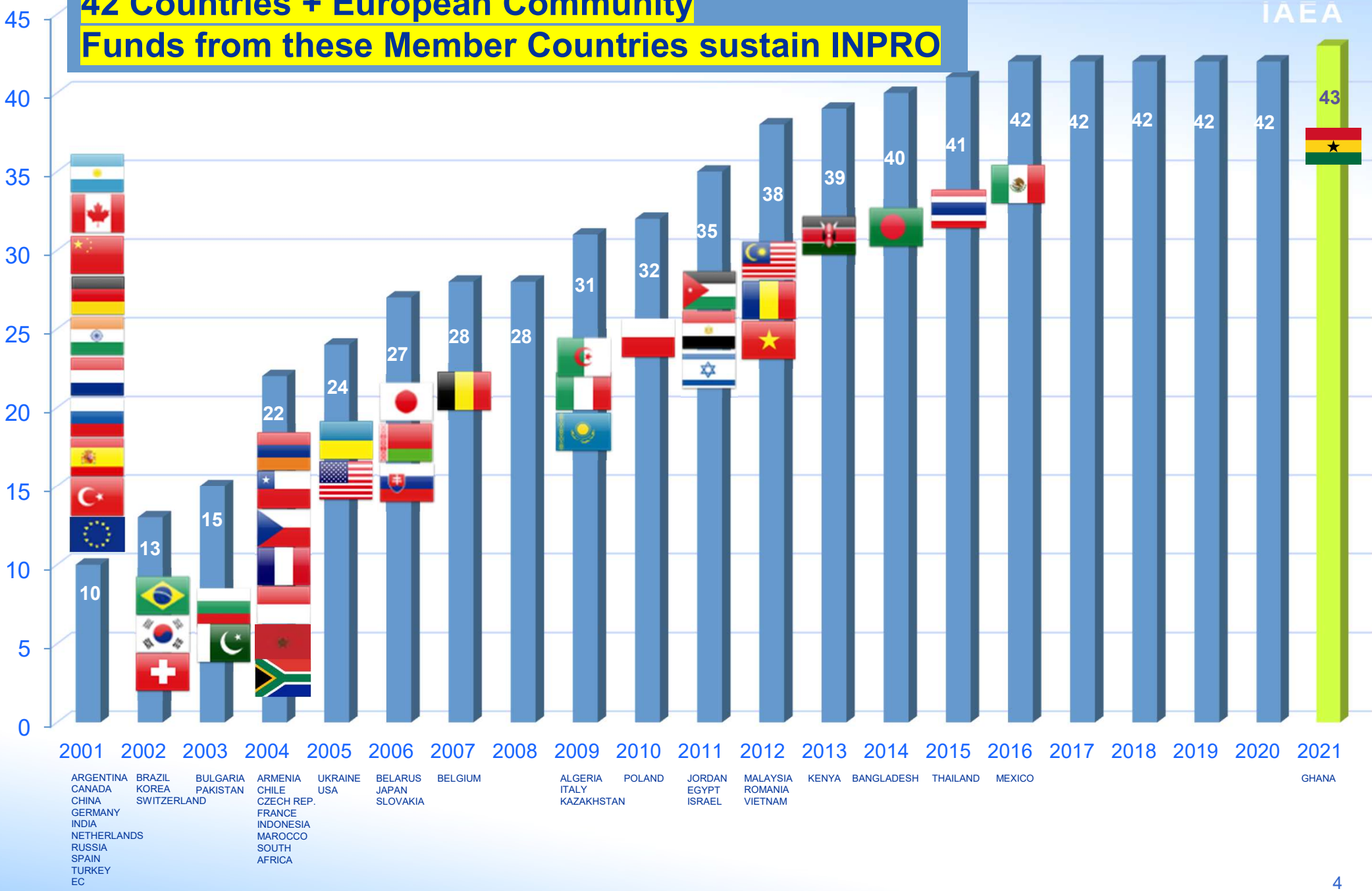


2020

Assessment Areas

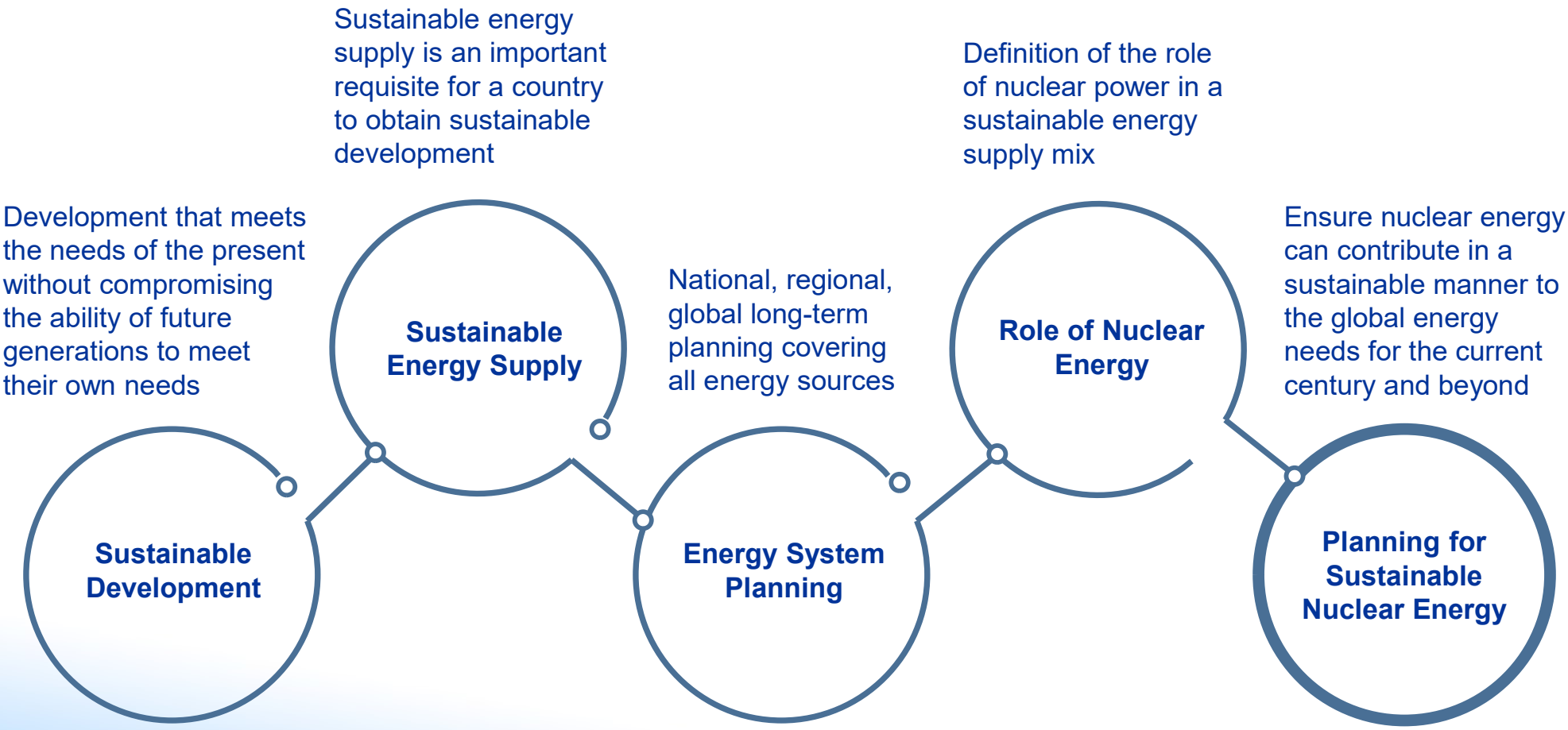
INPRO Membership Based Project

42 Countries + European Community
Funds from these Member Countries sustain INPRO



INPRO Objective

Ensure nuclear energy is available to contribute, in a sustainable manner, to the growing energy needs of the current century and beyond

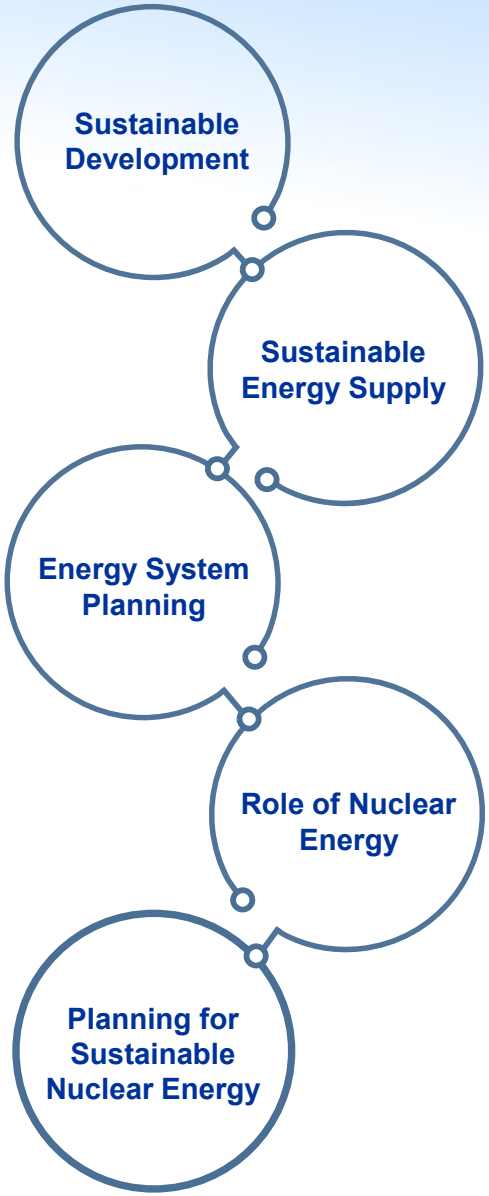


INPRO Vision Statement

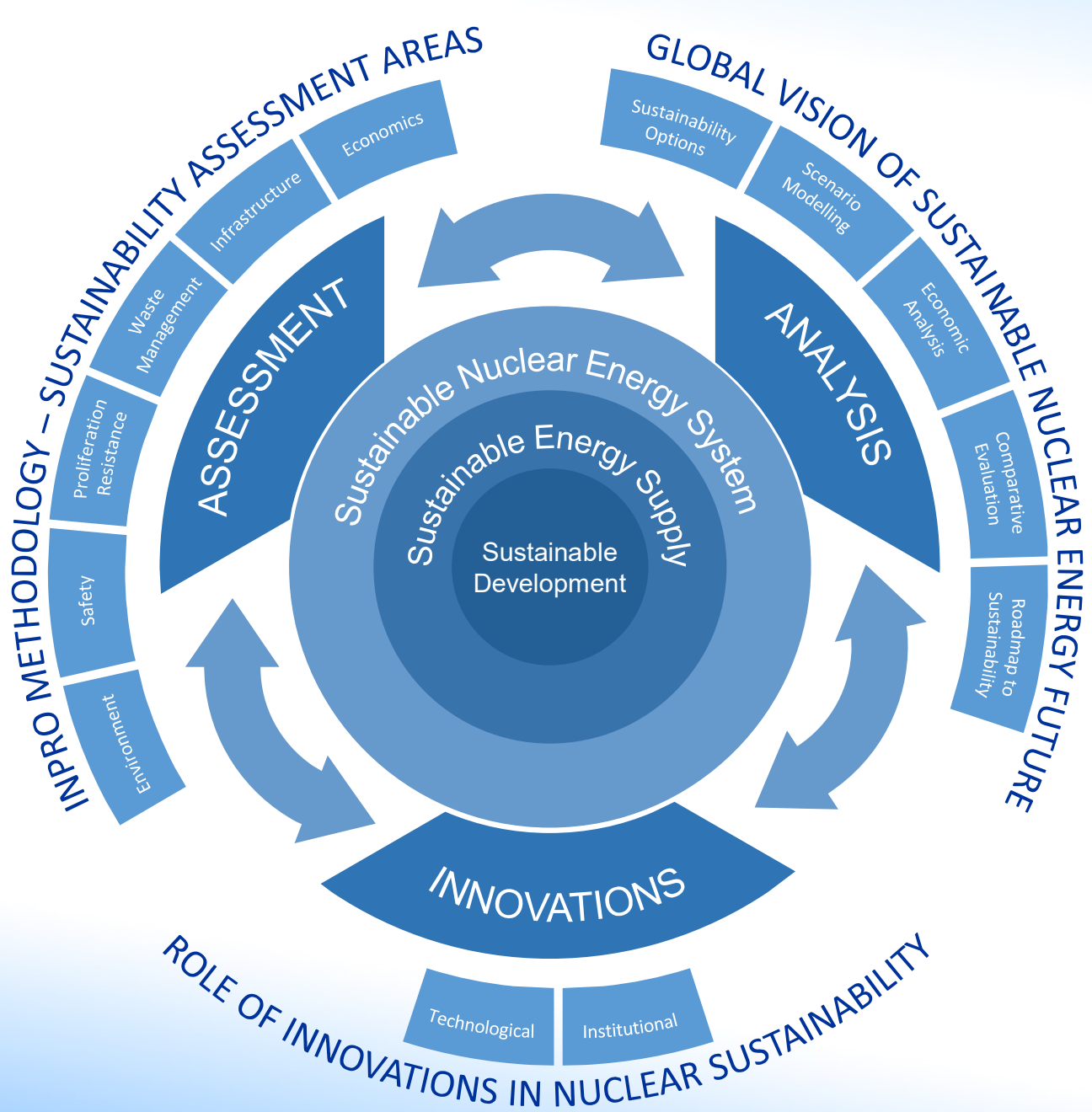
Support Member States in their long-term strategic planning for deploying sustainable nuclear energy

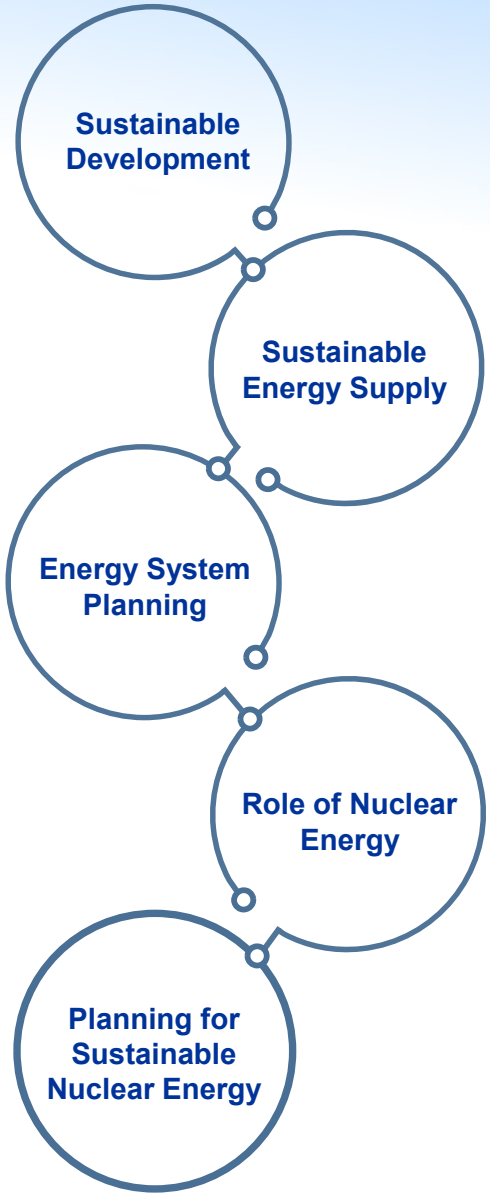
Advanced and innovative nuclear energy system scenario modelling, analysis, and sustainability assessment using the INPRO Methodology

Dialogue, cooperation and collaboration among Member States in their respective roles as nuclear energy technology developers, suppliers and customers



INPRO Activities





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Current activity of INPRO – Tasks structure

INPRO Task Structure

Task 1: Global Scenarios

Task 2: Innovations

Task 3: Sustainability Assessment and Strategies

Task 4: Dialogue & Outreach

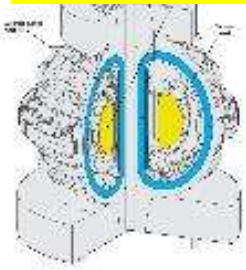
TOOLS / SERVICES

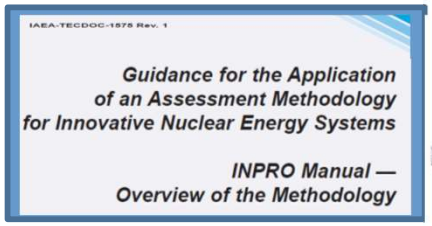
ASENES

Scenario modelling and analysis	Economic analysis and evaluation of Nuclear Energy System (NES)	Comparative evaluation of NESs and scenario options	Road mapping towards enhanced NE sustainability
MESSAGE-NES	NEST	KIND-ET	ROADMAPS-ET

Transportable NPP Akademik Lomonosov

Fusion Studies





SMR NESA

CAREM

SMART

2021
18th and 19th Dialogue Forum

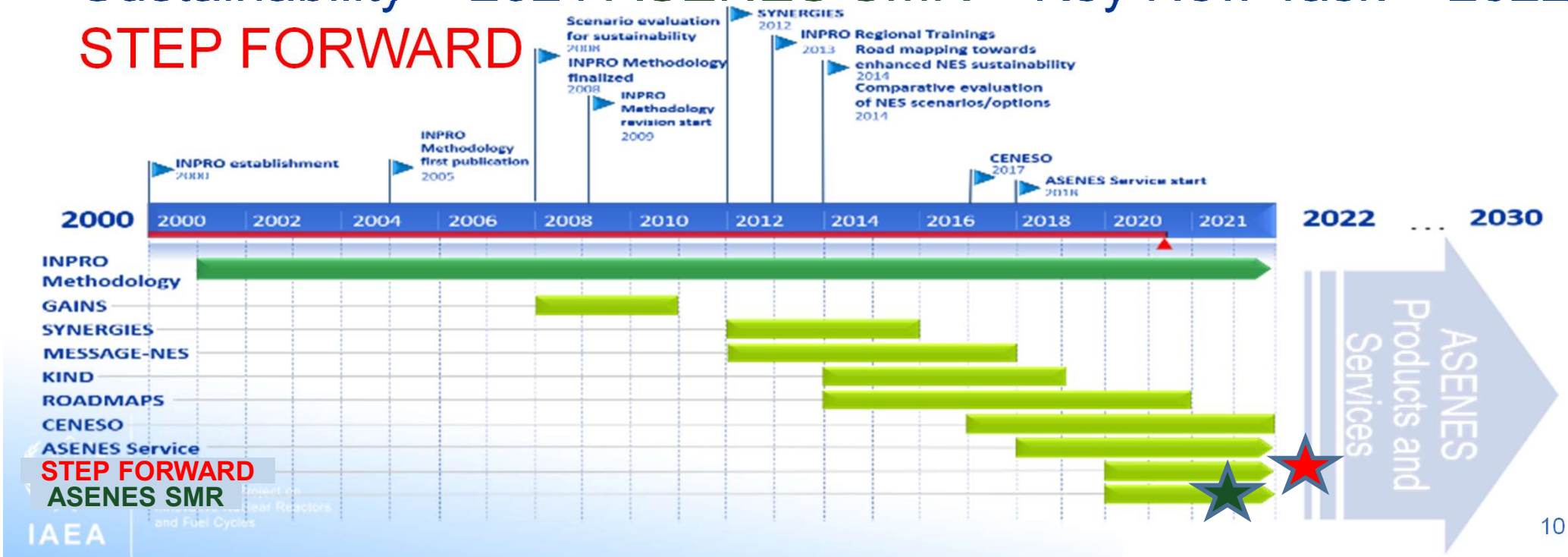
2023
20th Dialogue Forum
USA March 2023

RITM-200M

INPRO Task 1:Global Scenarios

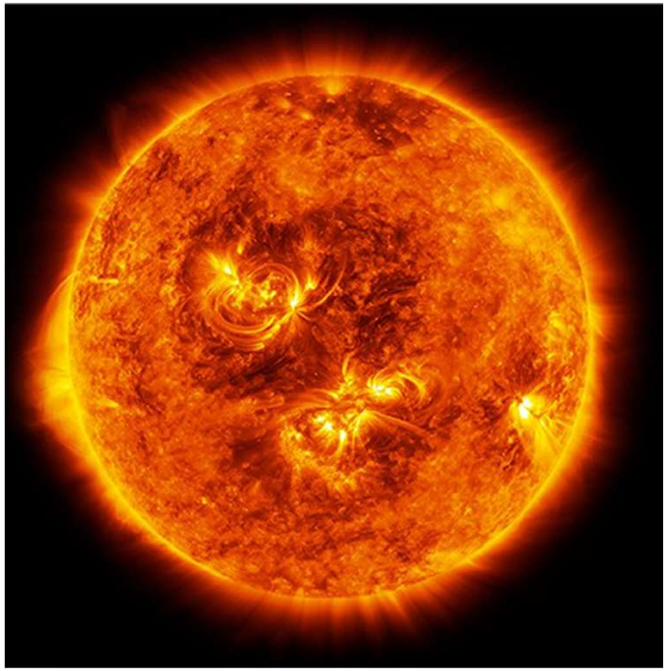
- Develop global and regional nuclear energy scenarios
- Use developed scientific-technical analysis tools
- Provide a global vision of sustainable nuclear energy development in the current century and beyond
- Forge innovative new partnerships
- Analysis Support for Enhanced Nuclear Energy Sustainability – 2021 ASENES SMR – Key New Task – 2022

STEP FORWARD



INPRO Task 2: Innovation

- **Innovations in nuclear energy technology and institutions**
  - Case studies for the Deployment of Factory Fuelled SMRs
  - Review of Innovative Reactor Concepts For Prevention of Severe Accidents And Mitigation of Their Consequences (RISC)
  - WIRAF – Waste arisings from innovative reactors and fuel cycles
  - Back-end fuel cycle activities
  - INPRO study on Legal and Institutional Issues of prospective deployment of Thermonuclear (Fusion) facilities



INPRO Task 3: Sustainability Assessments and Strategies

Nuclear Energy system Sustainability Assessments (NESA) and INPRO Methodology

- BN-1200 NESA Report
- Draft summaries of NESA completed by Ukraine
- Complete update of INPRO Methodology
- Streamlined and useful revision of Proliferation Resistance Manual
- SMR NESA studies
  - Argentina – May 2021
  - Russia – May 2021
  - ROK – July 2021
- FRAMES Energy System Modelling

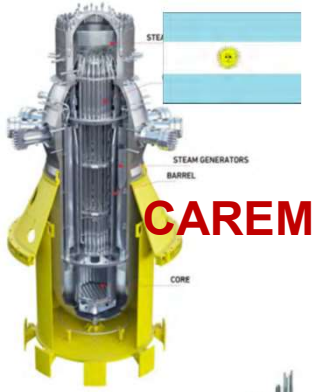
BN-1200

Nuclear Energy System Assessment

NESA

Assessment areas of Economics, Safety, Infrastructure, Environment, Proliferation Resistance and Waste Management

NESA support package



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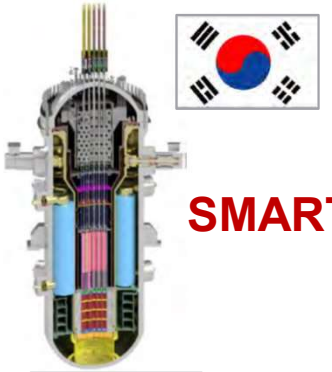

SMART

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INPRO Task 4: Dialogue and Outreach

➢ Dialogue Forums

- 18th DF and 19th DF = virtual successes in 2021
- 20th DF - The Nuclear Supply Chain: From Research to Deployment - USA
- 21st DF Deployment of Small Modular Reactor Projects and Technologies to Support the Sustainable Development Goals - Russia

➢ Educational Outreach

- INPRO Schools
- Higher educational outreach to include courses in degree programmes

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INPRO Methodology and Nuclear Energy System Assessment (NESA)

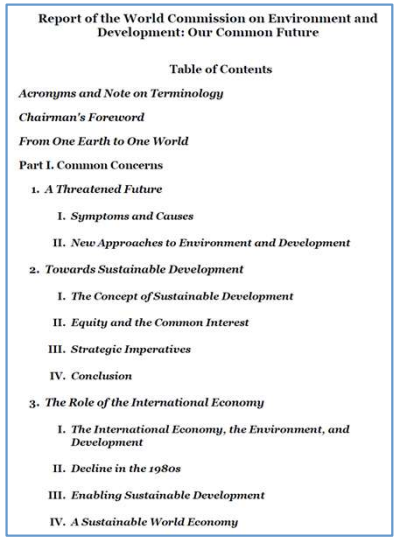
INPRO Methodology – Brief History

- IAEA tool for assessing the sustainability of nuclear energy systems (NES)
- First published in 2003
- Major update of assessment manuals in 2008
- Major revisions 2014-2022
- Several assessments performed and published as IAEA TECDOCs
- Contribution from 300+ national and international experts

UN Concept of Sustainable Development

"development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

- Concept of needs - in particular the essential needs of the world's poor, to which overriding priority should be given
- Idea of limitations - imposed by the state of technology and social organization on the environment's ability to meet present and future needs



Report of the World Commission on Environment and Development: Our Common Future

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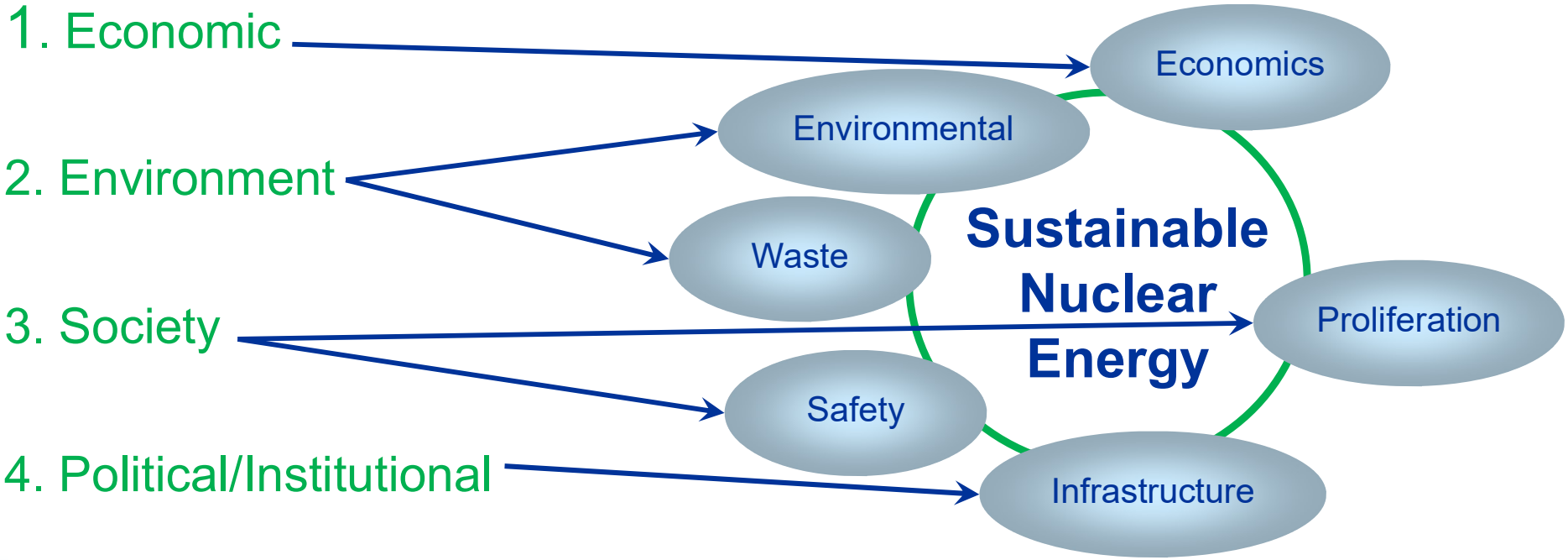
**"Report of the World Commission on Environment and Development: Our Common Future", Oxford University Press, Oxford (1987)*

INPRO Aligned with UN Sustainable Development

UN concept for sustainable development of energy

INPRO methodology for sustainability assessment



INPRO Approach to Sustainability

- INPRO's approach is a *holistic* and *global* view of nuclear energy systems (NES) together with the pursuit of innovations in nuclear energy
- A nuclear energy system assessment of sustainability
  - Not analysis - except area of economics
  - Time frame – century (plus)
  - Longer time scales - waste management and decommissioning
- Nuclear Energy System Assessment = NESA

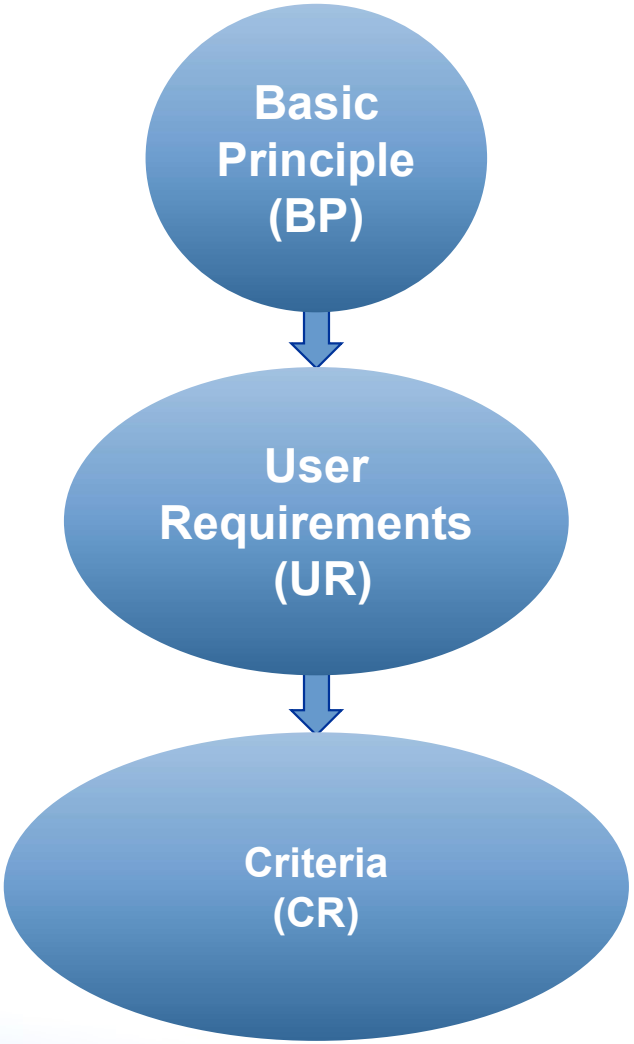
INPRO Assessment Areas and Goals

1. **Economics:** NES is economically attractive, and competitive with other energy sources
2. **Environmental Impact:**
   a) **Stressors:** no adverse impact on environment and human health
   b) **Depletion of resources:** sufficient resources for NES to run for a century (U and other materials)
3. **Waste management:** protect current and future generations and not pass undue burdens on

INPRO Assessment Areas and Goals

4. **Proliferation resistance:** unattractive means for nuclear weapons or explosive devices
5. **Safety:** planned NES safer than previous generations, reduced off-site releases and impact
   a) **Nuclear reactors**
   b) **Nuclear fuel cycle facilities (NFCF)**
6. **Infrastructure:** national and international measures to ensure NES is sustainable

INPRO Methodology

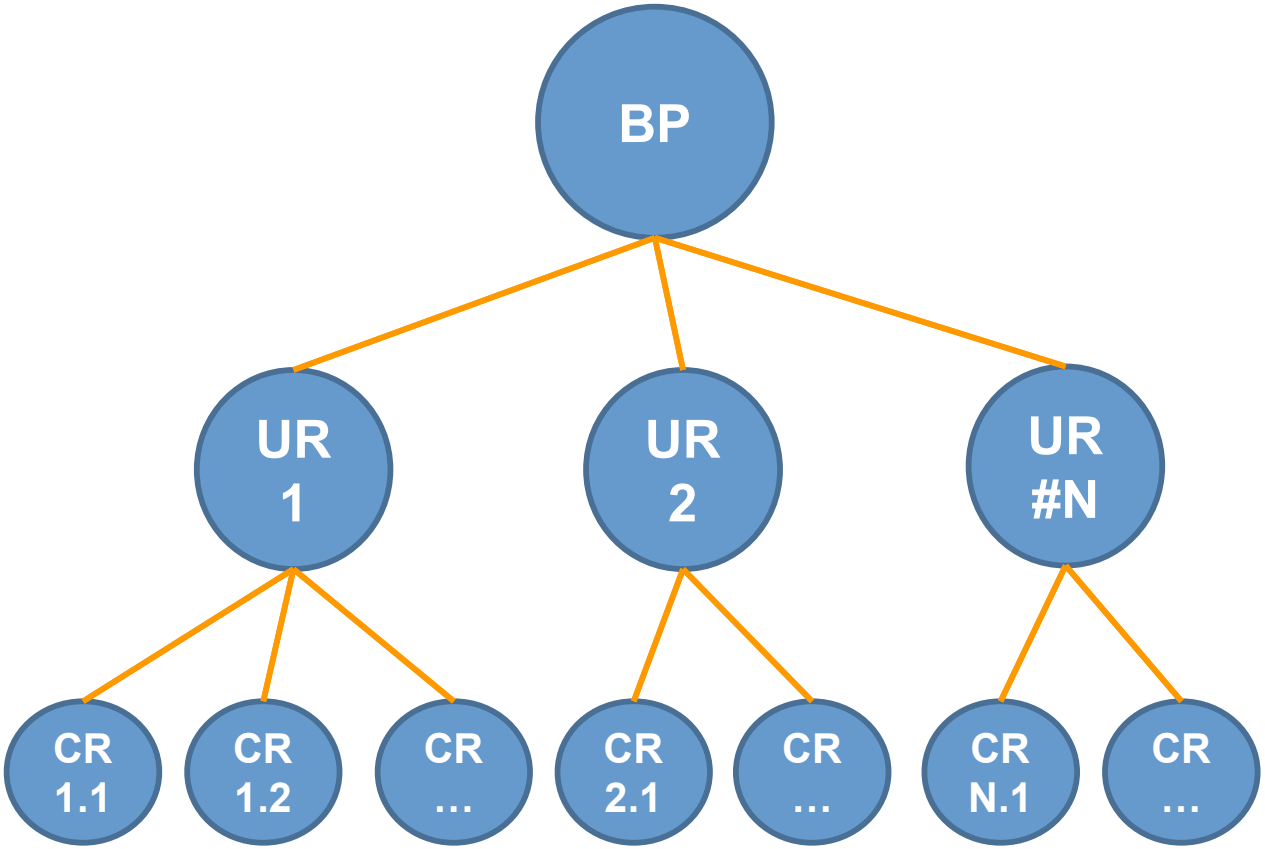


BP: Goals for the development of a sustainable Nuclear Energy System (NES)

UR: Requirements for designers, operators, industry and/or State to meet goal defined in Basic Principle (BP)

CR: Assessor's tool to check metrics for NES to support meeting User Requirements (URs)

INPRO Framework



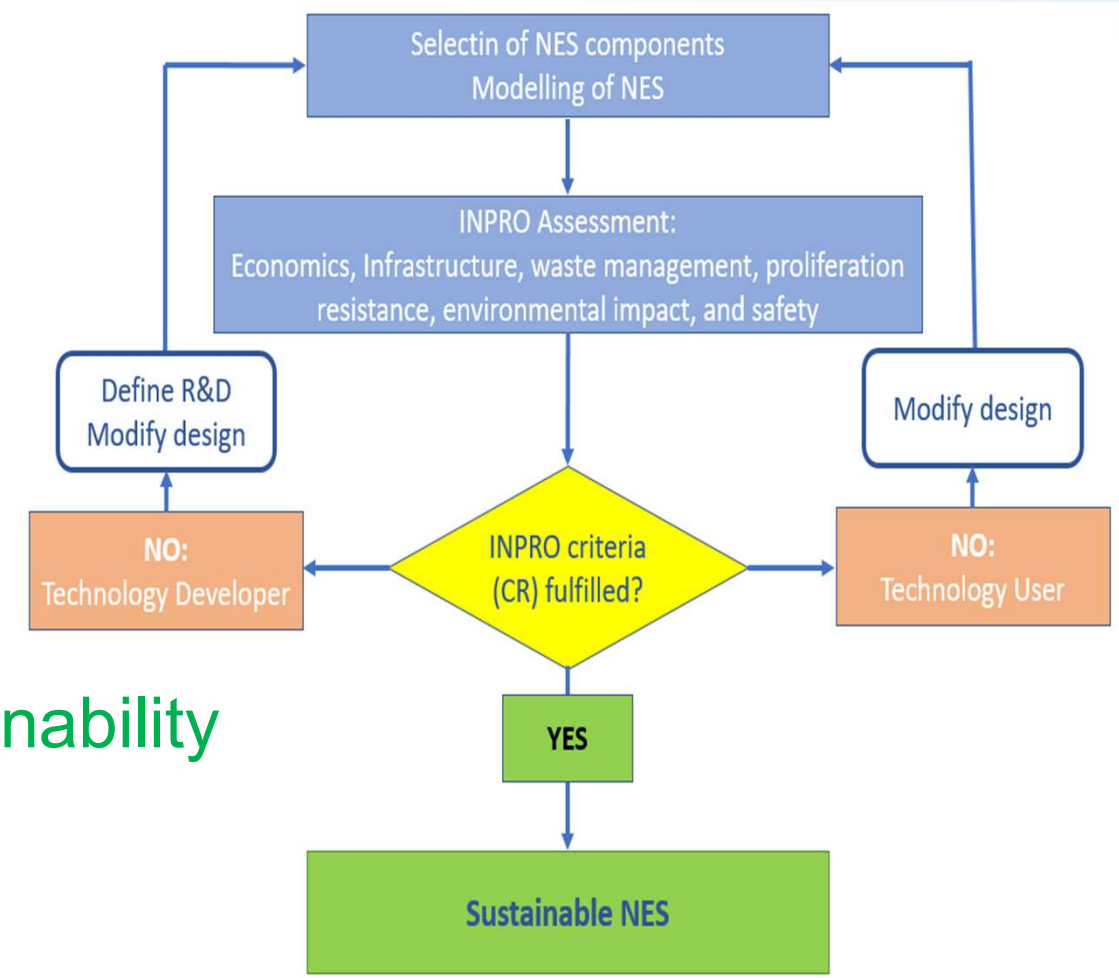
Basic Principle (BP):
One per INPRO manual –
8 BPs total

User Requirements (UR):
2-7 UR per BP

Criteria (CR):
1-6 CR per UR

Nuclear Energy System Assessment (NESA)

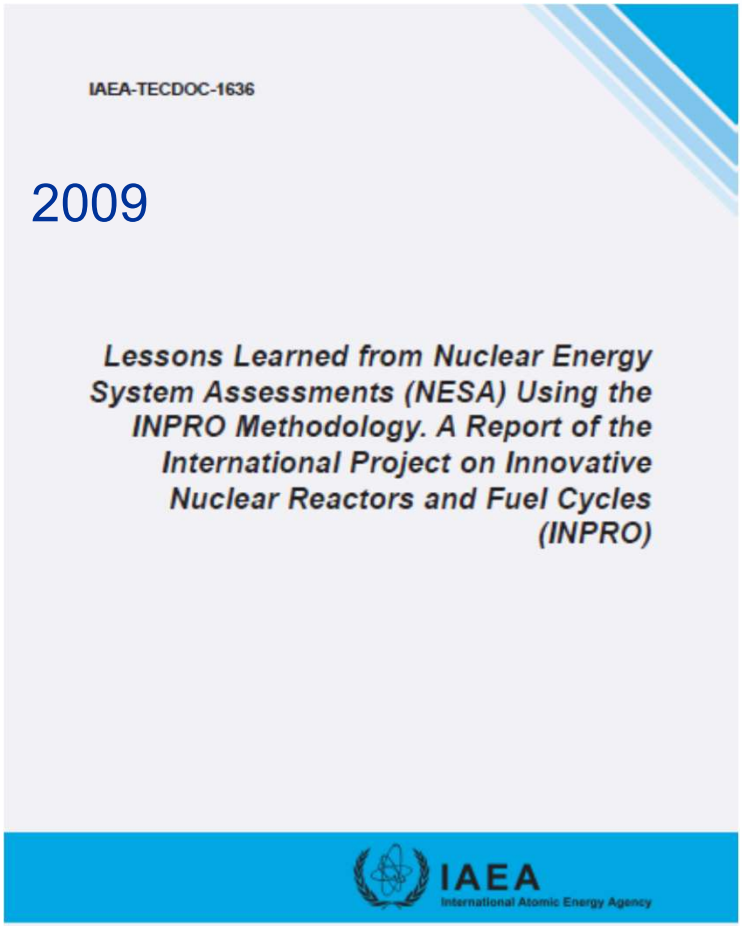
- Criteria Fulfilled?
- Yes - sustainable
- No
  - Identifies **gaps** and **improvement areas**
  - Modify design OR
  - Define areas for R&D
- Reassess
- Confirmation of NES Sustainability



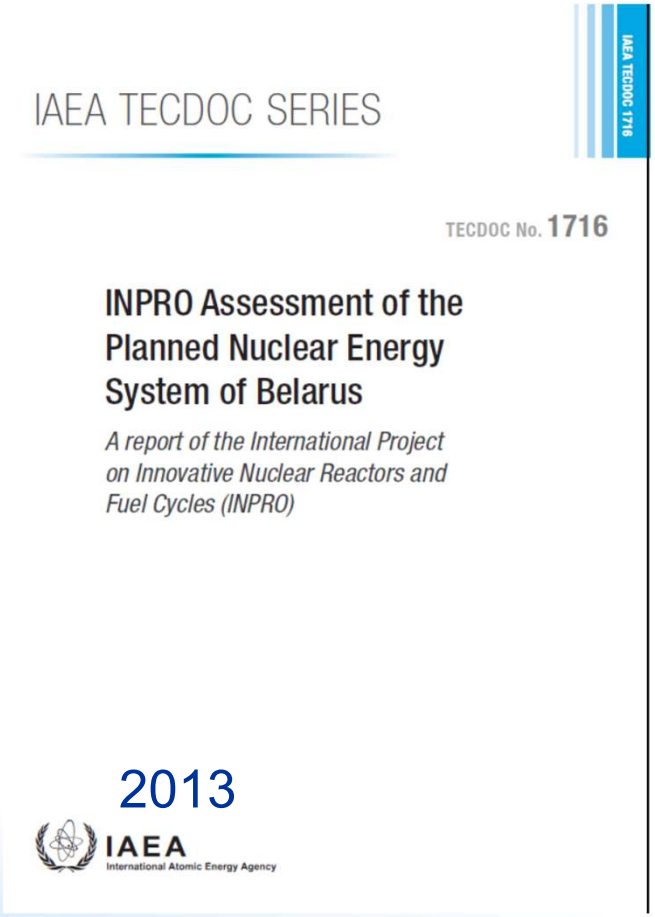
Sustainability Assessments Benefits

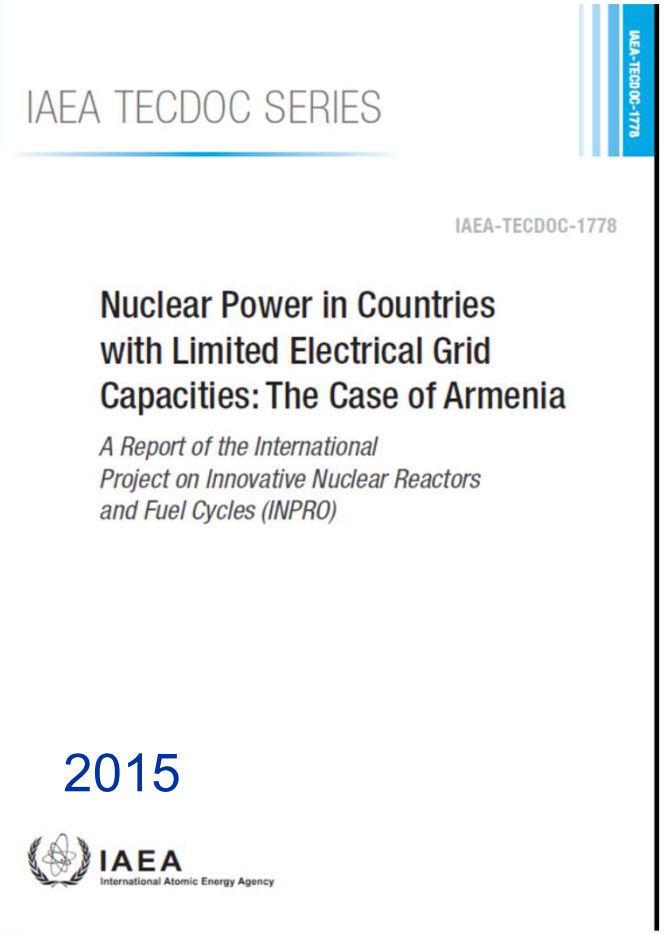
Newcomer Country	State / Government Institutions	National Industry	Designer / Technology Developer
• Limiting scope • Using a graded approach • Increasing awareness of long-term issues • Assisting with planning and decision making	• Maintaining or expanding NES • Comparing options • Identifying gaps • Identifying synergies amongst NES combinations	• Comparing options • Identifying improvements • Identifying areas for research and development	• Guiding development • Comparing options • Identifying options with advantages • Identify areas for R&D

Some NESAs results



Initial stage: Six national NESAs were fulfilled: Argentina, Brazil, India, Rep.Korea – as technology developer, Armenia, Ukraine – as technology users





NESAs were conducted by Belarus, Armenia, Kazakhstan, Indonesia etc.

Synergies with Milestone Approach

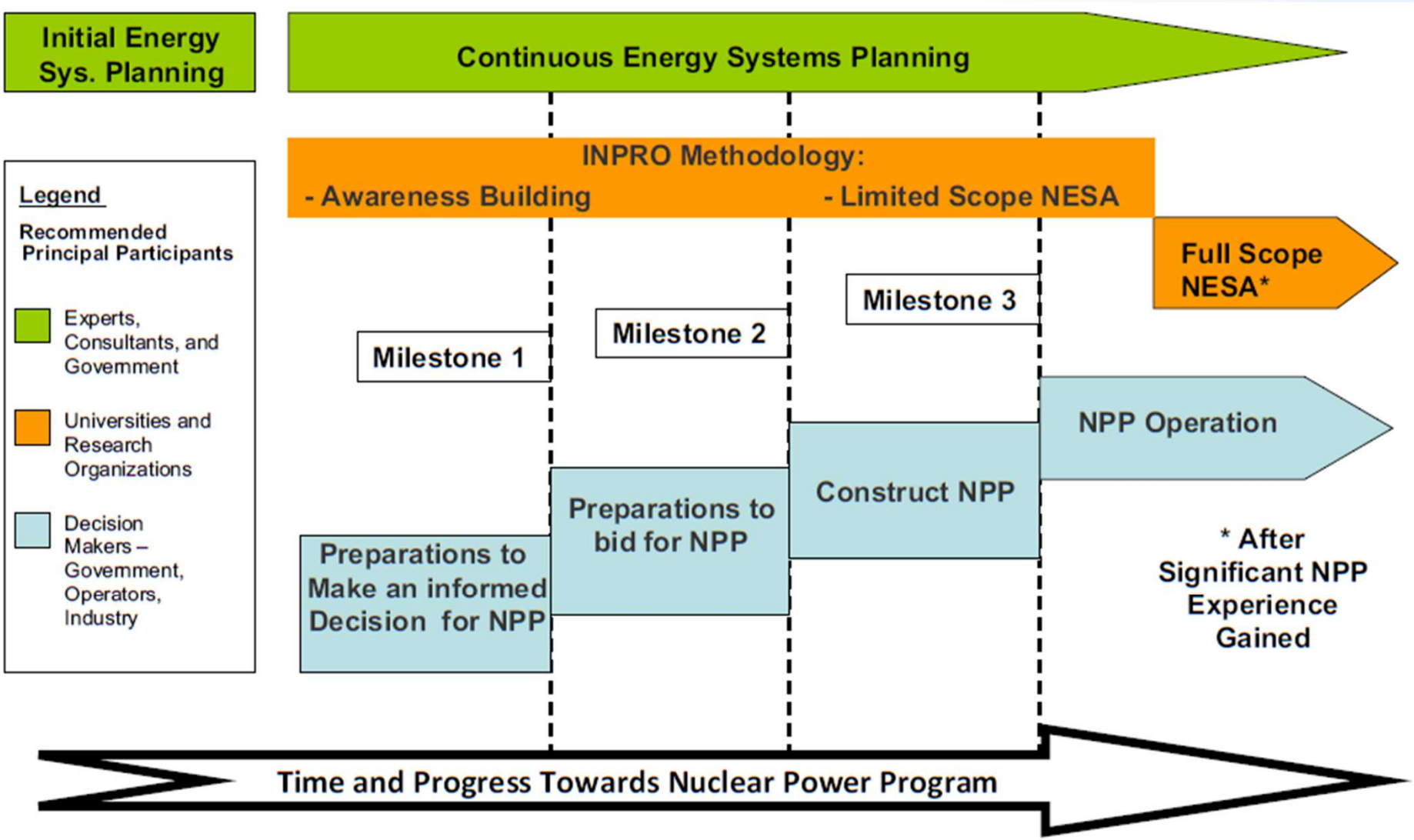


FIG. 4. Relationship among the tools for energy system planning, NESA and the Milestones approach for newcomer countries.

Steps in Performing a NESA

Familiarization with INPRO Methodology
- Briefing / training by the IAEA/INPRO (optional)
- Wiki INPRO INPRO Wiki (azure.com)

Select Team
- Cover all areas of NESA

Collect Data
- Technology developers, facilities operators, national industry involved in nuclear power program, government agencies, etc.

Perform Assessment
- Coordination among areas of assessment and communication with IAEA/INPRO to deal with questions

Document Results
- Reference energy plan, selected NES, role of nuclear, objective & scope, sources of data, results, feedback to INPRO, etc.

Peer Review
- Published NEsA on INPRO website
- Consult INPRO for support

NESA Economics Support Tool (NEST)

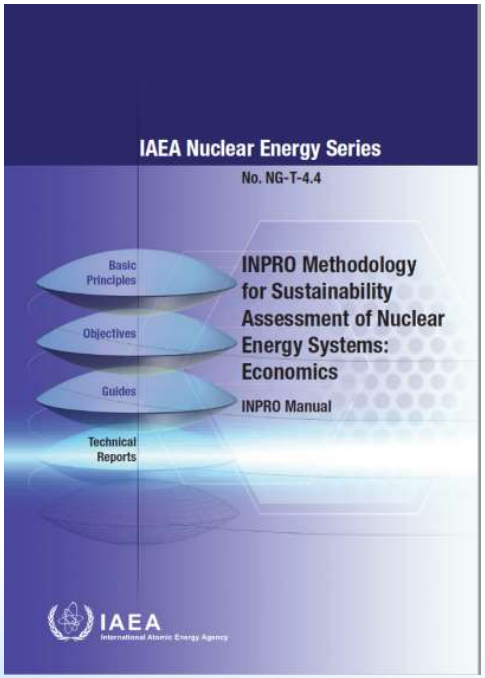
Inputs

Technical parameters:
reactor power output,
capacity / load factor,
lifetime, fuel burnup, etc.

Economic parameters:
Investment cost,
construction schedule,
NFC services cost,
O&M cost, discount rate etc.

Outputs

Energy cost (LUEC)
Figures of merit
(NPV, IRR, ROI)



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INPRO Service
Analysis Support for Enhanced Nuclear Energy Sustainability (ASENES)

“Analysis Support for Enhanced Nuclear Energy Sustainability: an INPRO Service to Member States” (ASENES)

Collaborative Projects → Methods, Tools And Project Publications → Service to MSs: ASENES

GAINS- Global Architecture of Innovative Nuclear Energy Systems with Thermal and Fast Reactors and a Closed Fuel Cycle

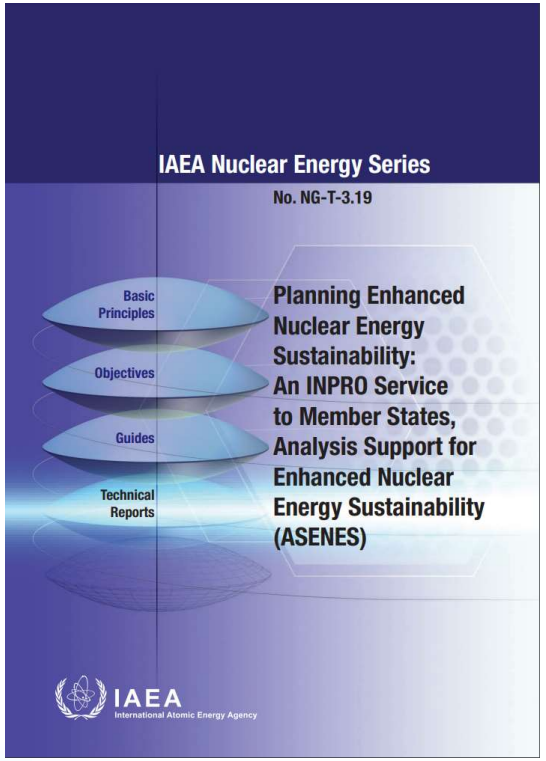
SYNERGIES - Synergistic Nuclear Energy Regional Group Interactions Evaluated for Sustainability

KIND/CENESO- Key Indicators for Innovative Nuclear Energy Systems

ROADMAPS- Roadmaps for a Transition to Globally Sustainable Nuclear Energy Systems

Project outputs include methods and software tools that could be further used by MSs for similar or alternative studies

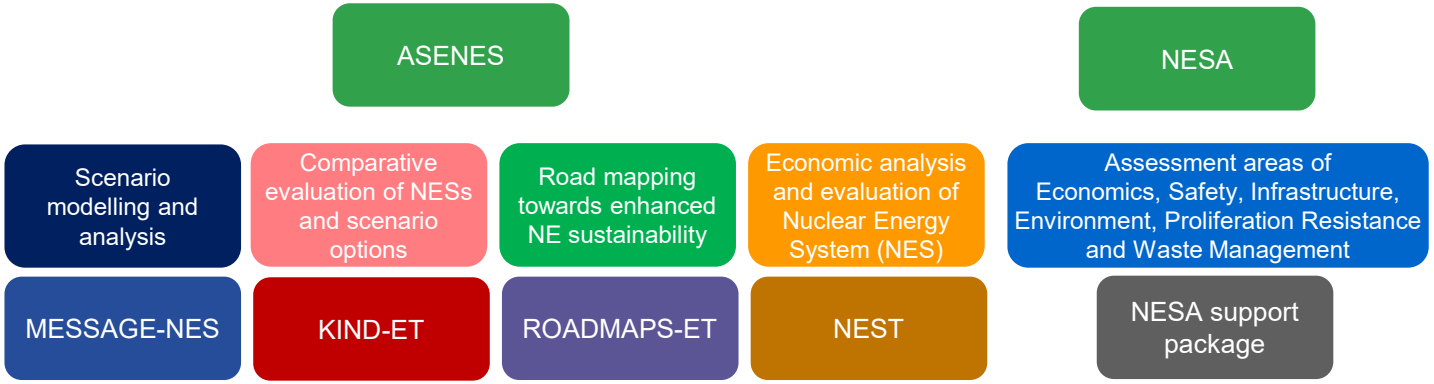
ASENES- Analysis Support for Enhanced Nuclear Energy Sustainability



INPRO integrated service to Member States

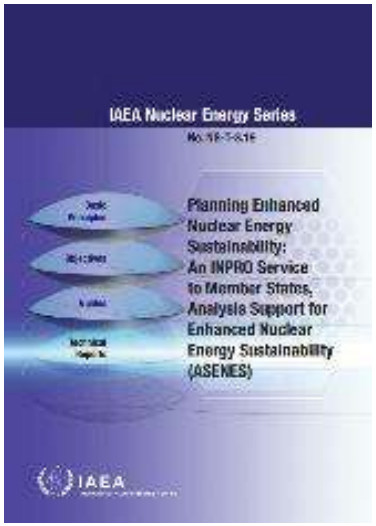
Analysis Support for Enhanced Nuclear Energy Sustainability

Nuclear Energy System Assessment



To support interested Member States in formulating national strategies for enhancing nuclear energy sustainability, INPRO has developed a service package titled **"Analysis Support for Enhanced Nuclear Energy Sustainability" (ASENES)**

The main purpose of this service is to facilitate capacity building in Member States aimed at strengthening the competence and skills of national experts for evaluation of alternative nuclear energy technologies and collaborative arrangements, and for formulation of strategic plans towards development and deployment of sustainable nuclear energy



ASENES Service: toolkit

ASENES

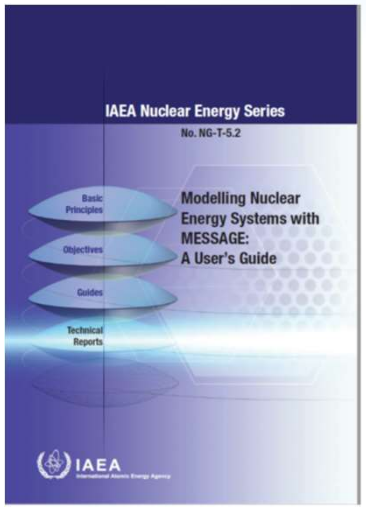
MESSAGE NES
Framework for nuclear energy scenario modelling

NEST
Nuclear energy economic analysis

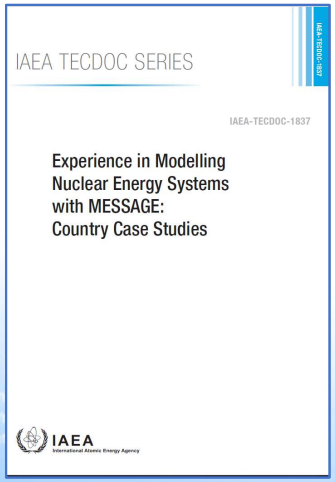
KIND-ET
Comparative evaluation of NES/scenario options

ROADMAPS-ET
Road mapping for enhanced nuclear energy sustainability

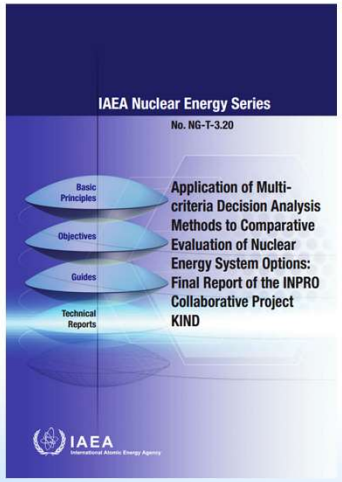
2016



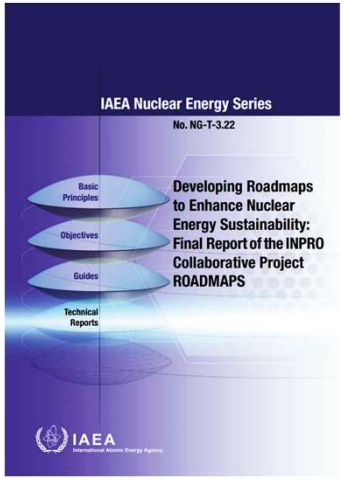
2018



2019



2021



For whom is the ASENES service intended?

- The target audience is national technical experts working in the areas of planning of a national nuclear power programme, innovative technology development for nuclear power and nuclear energy system analysis and assessment, and officers of ministries responsible for nuclear energy development programmes and international cooperation
- To obtain meaningful results with ASENES, user needs to have:
  - ✓ Access to information and data on the status, plans and prospects of nuclear energy in her(his) country including that on the status, plans and prospects of cooperation (nuclear trade) with other countries
  - ✓ In-depth knowledge of the discussion (debate) points regarding energy and/or nuclear energy system development in her(his) country
  - ✓ Connection and communication to decision makers

Benefits of using the ASENES tools

- Nuclear energy system evolution **scenario modelling** could help **better understand** the key issues of, and find plausible solutions for, enhanced **nuclear energy sustainability**
- **Comparative evaluation of nuclear energy system or scenario options** based on problem structuring and the state-of-the art judgement aggregation/uncertainty analysis methods can be used to support the multi-criteria selection of a preferred nuclear energy system through a substantive dialogue with decision makers
- Carrying out **road mapping for a national NES** could assist in strategic planning for national nuclear energy development. When road mapping is performed in cooperation among technology users and possible technology providers, additional benefits resulting thereof are strategic insights on international market of products and services for peaceful applications of nuclear energy.
- With this, providers could better plan expansions or cut-downs of their industrial capacities for certain products and services, while recipients would have a clearer picture of wherefrom the desired products and services could be procured and where could be the bottlenecks.
- **Economic evaluation of alternative nuclear energy systems allows to compare competitiveness of NES alternatives.**

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Examples of INPRO collaborative studies

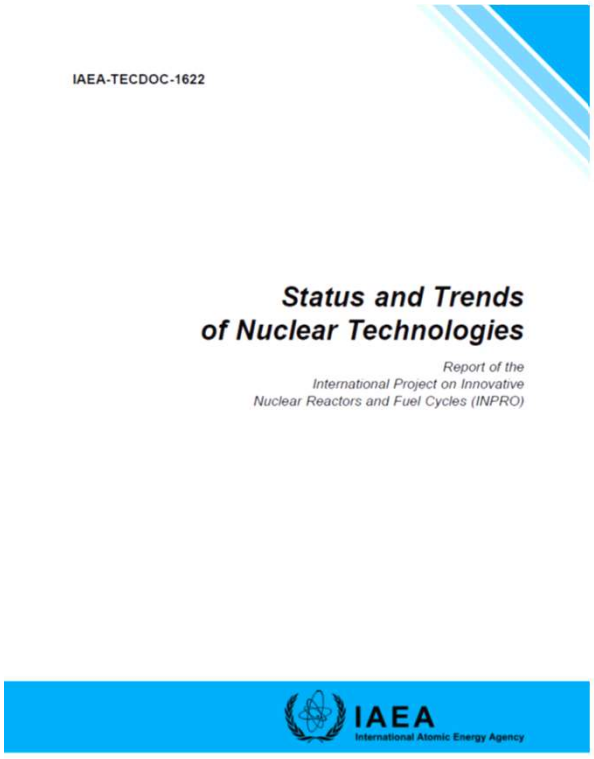
Innovative Multicomponent Nuclear Power systems in INPRO "history"

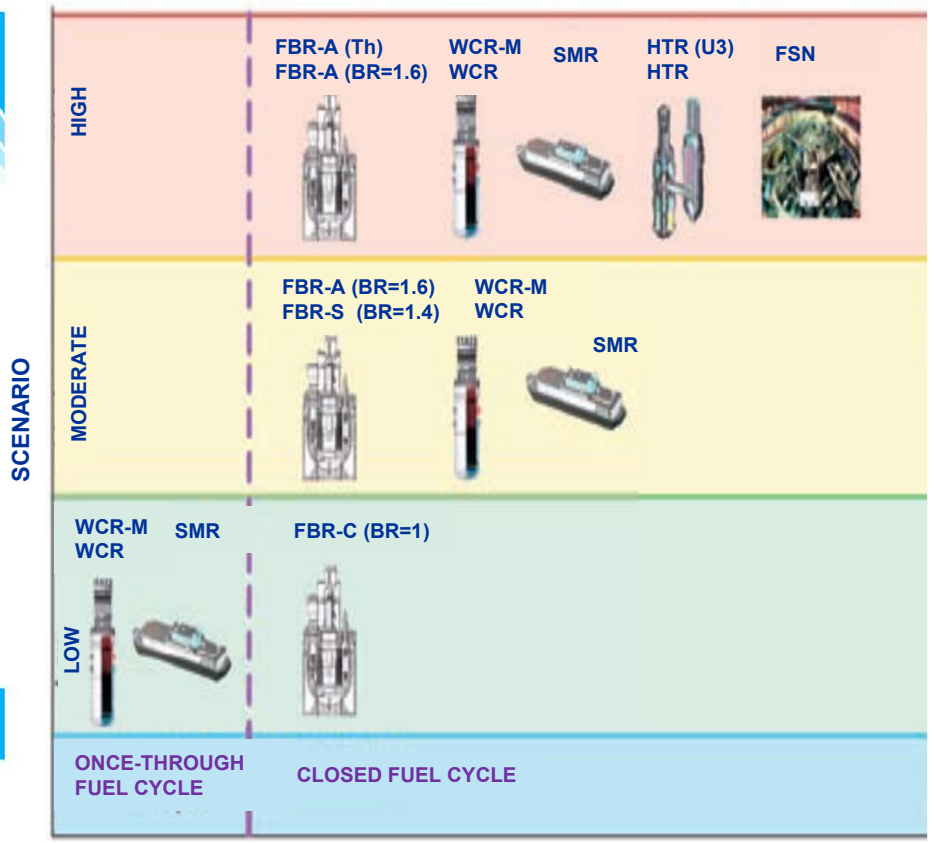
- **2000s: Evaluation and Assessment of nuclear reactor and fuel cycle innovative tendencies:**
  - **NESA for Closed Nuclear Fuel Cycle with Fast Reactors**
  - **Role of Thorium to Supplement Fuel Cycles of Future Nuclear Energy Systems**
    - **2010s: Strategic Studies and tools for consideration of international Nuclear Energy architecture and synergies (GAINS, SYNERGIES, ROADMAPS, KIND)**
      - **2020s: ASENES as full-scale Nuclear Power strategic service for MSs**
        - **New collaborative project: STEP FORWARD – ASENES for multicomponent NE systems with integrated fuel cycle**

INPRO's general overviews of innovative nuclear reactors and fuel cycle technologies in MSs

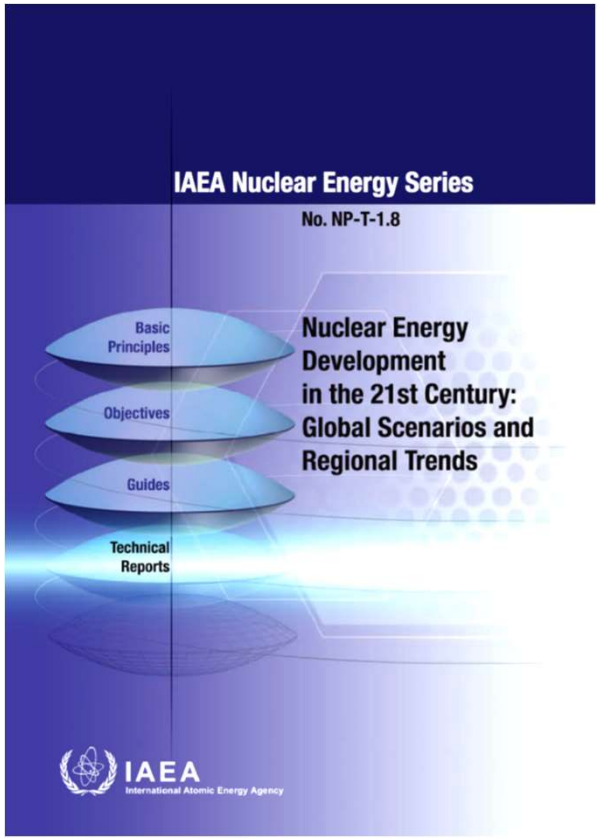
Consideration of Future Nuclear Energy

2009





2010



Assessment of NES based on a CNFC with FR – Joint Study

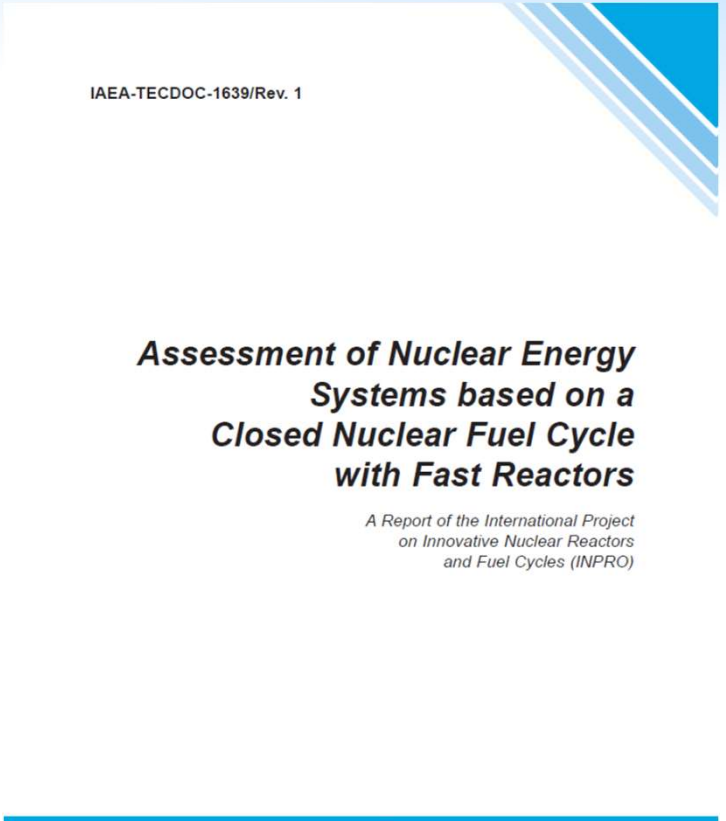
A Joint Study was started in 2005 and completed in 2007 within the INPRO.

Canada, China, France, India, Japan, the Republic of Korea, the Russian Federation, and Ukraine participated in this study.

The objectives were to assess a nuclear energy system based on a closed fuel cycle (CNFC) with fast reactors (FR) regarding - ***Sustainability, Determine milestones for the nuclear energy system deployment, and Establish frameworks for, and areas of, collaborative R&D work.***

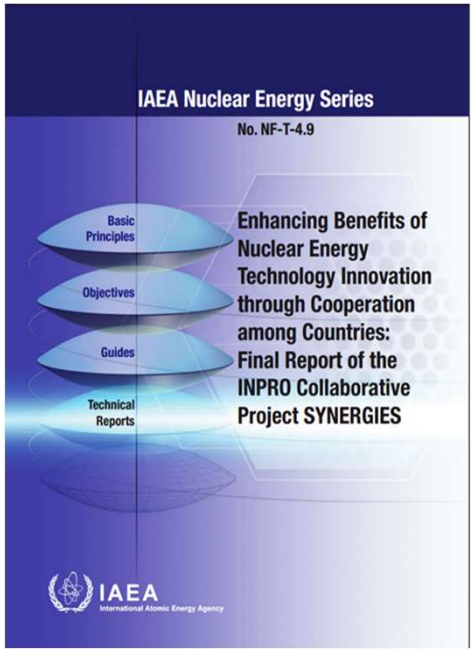
The assessment was carried out in accordance with requirements of INPRO methodology and guiding documents of the Joint Study developed and approved by the participating parties.

2012



INPRO Strategic Studies on Enhanced Nuclear Energy System

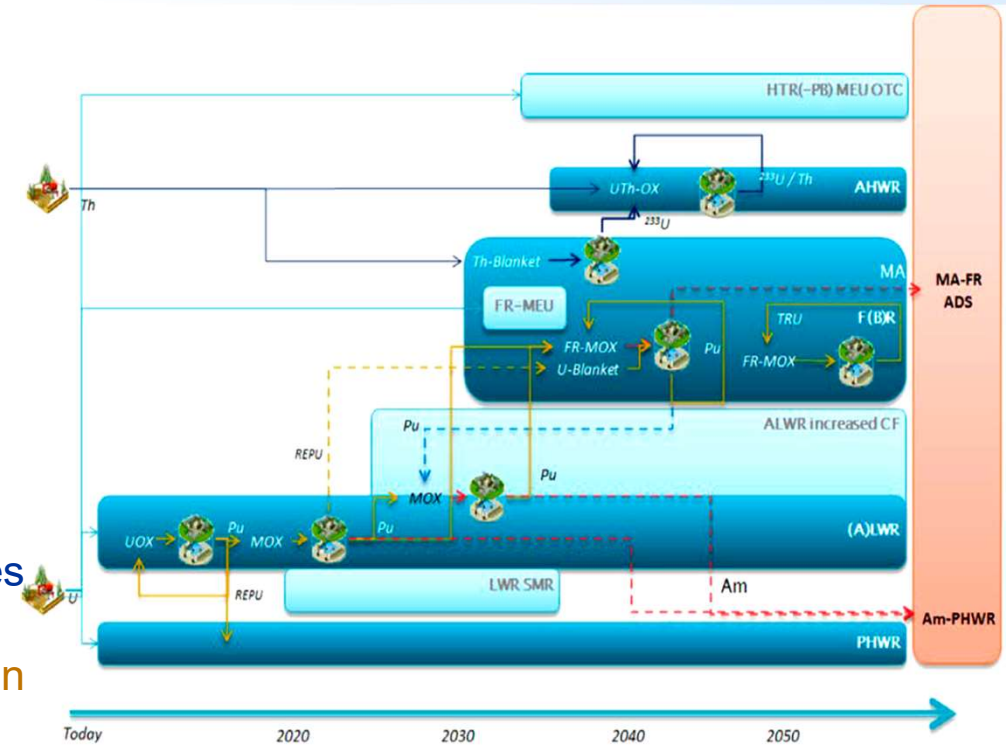
2018



The INPRO collaborative project "Synergistic Nuclear Energy Regional Group Interactions Evaluated for Sustainability" (SYNERGIES) has systematized options to enhance nuclear energy sustainability.

Enhanced sustainability may be achieved through:

- Innovations in technologies and/or changes in policies,
- Enhanced collaboration among countries



Technology related options may be structured along NFC types:

- Once-through
- Limited recycling of SNF
- MA or MA+FP transmutation
- Recycle with only physical processing
- Complete recycle of SNF
- Final geological disposal of all wastes

With advances in reactor technology sustainability can be enhanced within each NFC option

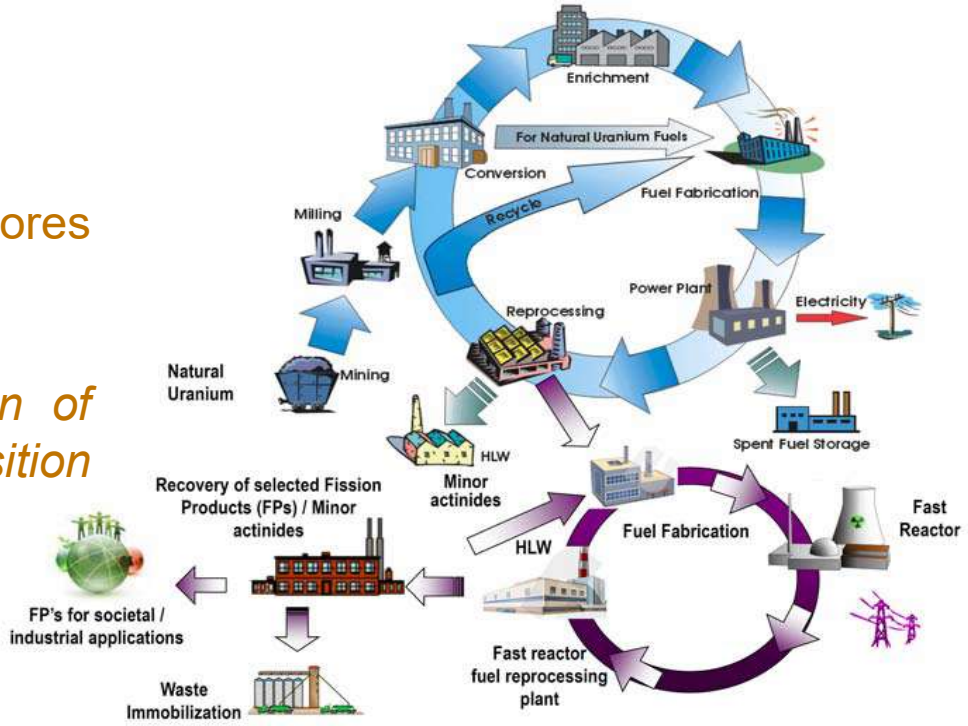
STEP FORWARD: new INPRO Pilot Study

Overall objective: to apply the ASENES package and national tools of relevance to evaluation of the nuclear energy systems and scenarios involving initially small number of innovative nuclear energy installations to enable multi-recycling of fuel in a complete nuclear energy system including also the operating and evolutionary reactors with thermal neutron spectrum.

The scope of innovative nuclear energy installations to be considered is open to include a variety of options, such as:

- ✓fast reactors with any types of coolant,
- ✓molten salt reactors,
- ✓accelerator driven subcritical systems,
- ✓thermal spectrum reactors with modified cores supporting fuel multi-recycling or even
- ✓fission-fusion hybrids.

Within studies on multi-recycling, *transmutation of radioactive waste and excess plutonium disposition* could also be topics for consideration.



Timeframe: 2022-2024

SMR and TNPP as institutional and technical innovations

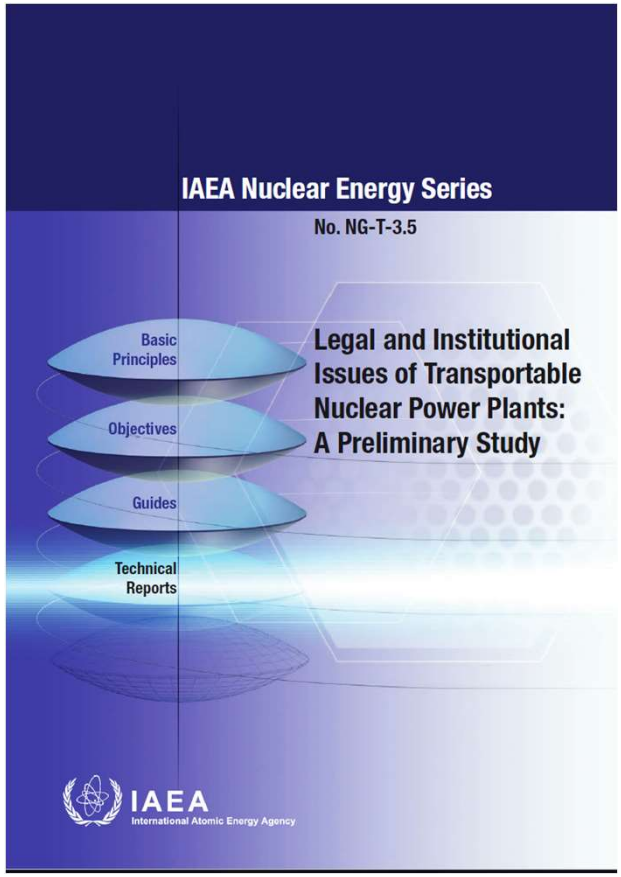
- **2000s-2010s – prospective role of SMRs. Overall considerations.**
  - **First studies of Transportable Nuclear Power Plants (TNPP) – finding of some legal gaps.**
  - **Request by MSs through GC resolutions to continue studies**
    - **2015- 2020 - Study of specific cases (TNPP 2)**
    - **Recommendation for further IAEA studies of the Legal aspects, Nuclear Safety and Security approaches and others**
      - **Current: Assessment and Strategy:**
      - **NESA for some SMRs designs**
      - **ASENES – SMR as new strategic service for MSs**

Studies on Transportable Nuclear Power Plants

- A preliminary study was performed in 2008-2013 and documented in the NE Energy Series Technical Report No. NG-T-3.5
- Following issues were considered: Infrastructure, safeguards, legal, nuclear safety and security, nuclear liability.

2013

- Collaborative Project: "INPRO Case study for the Deployment of a Factory Fuelled Small Modular Reactors (SMR)" – TNPP-2
- Three TNMPP have been selected for analysis:
  - (1) a submersible TNM(s);
  - (2) a floating TNM(s);
  - (3) a land-based TNM(s).
- TNM with reactors loaded with nuclear fuel in the Service Centre, tested and sealed in Supplier State for further relocation and operation a Host State.
- The study included a scenario of maximum outsourcing.



Current INPRO Projects on SMR

- **Case studies for the Deployment of Factory Fuelled SMRs (Transportable NPPs)**

- **Nuclear Energy system Sustainability Assessments (NESA) for** SMR initiated: Argentina (CAREM), Russia (RITM-200), ROK (SMART)

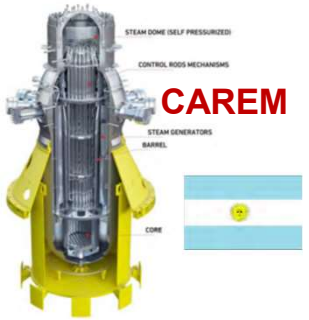
- **17th INPRO DF on Opportunities and Challenges in Small Modular Reactors /** 2–5 July 2019, Ulsan, Republic of Korea (143 participants from 22 Member States)

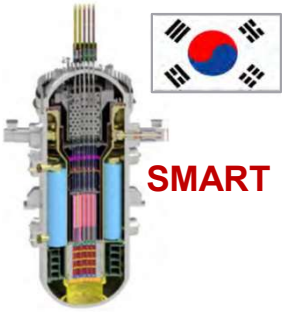
- **Collaborative project "Sustainable deployment scenarios for small modular reactors" (ASENES SMR)**

  Objective:

  - To provide the formulation and evaluation of promising scenarios and success factors for the deployment of sustainable NES with SMRs, including the prospective models of cooperation.

SMR NESA





ASENES Pilot Study on Sustainable Deployment of SMRs

- **Timeframe:** 2020-2024 (2025)
- **Participants and Observers:** Armenia, Bangladesh, Belarus, Bulgaria, Chile, China, Egypt, France, Germany, Indonesia, Israel, Mexico, Morocco, Romania, Russian Federation, South Africa, Thailand, Ukraine, USA, Viet Nam
- **10 Case Studies**:

1. Role of SMRs in **Armenia's** Nationally Determined Contributions (NDCs) target on GHG mitigation
2. Economic aspects of SMR deployment in countries with limited capabilities to finance nuclear energy projects
3. Feasibility of further expanding the nuclear power in **Belarus** with SMRs
4. Scenario analysis: deployment of SMRs, trend analysis of energy consumption in latest national plan of **China**
5. Analysis of SMR deployment scenarios in power system of the isolated region of Baja California Sur in **Mexico**
6. Scenario analysis on SMR deployment in the context of future energy market of **Romania**
7. Prospects of SMR deployment as effective supplement to existing NES with large reactors
8. Verification of previous SMR studies by using **NEST tool** and development of multi-aspect comparison of SMR projects using **KIND methodology**
9. Comparative study of SMR deployment and the current renewable energy power plants in **Thailand**, using KIND-ET
10. Identification of sustainable NES configuration based on large scale LWRs and SMRs

New INPRO Study: Legal and Institutional Issues of prospective deployment of Fusion facilities

- **Expected frame of the Study (started on 2022 followed by INPRO MSs recommendation):**
  - Discussion on the long-term sustainability issues for prospective deployment of fusion based facilities with a focus on non-technical aspects (jointly with other IAEA Departments and Sections)
  - Consideration of INPRO methodology and approaches application for long-term sustainability assessment of innovative energy systems with fusion based facilities
  - Review of legal and institutional issues, factors, and challenges, then identify gaps considering the current international instruments and national nuclear legislation and regulations.
  - Identification of main drivers and impediments for fusion based facilities implementation

Conclusions

INPRO methodology and INPRO tools are valid instruments for:

- Strategic planning of Nuclear power Systems for MSs with enhanced international and regional cooperation
- Systematic promotion of nuclear innovations and understanding of their roles in sustainable development

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Thank you!

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https://www.iaea.org/services/key-programmes/international-project-on-innovative-nuclear-reactors-and-fuel-cycles-inpro

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