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Developing a Long-Term Nuclear Energy Strategy: the INPRO Methodology for Nuclear Energy System Assessment

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IAEA Nuclear Energy Policy Management School

Developing a Long-Term Nuclear Energy Strategy: the INPRO Methodology for Nuclear Energy System Assessment

IAEA/INPRO Group

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Outline of presentation

- History of INPRO methodology
- Holistic nature of NESA using INPRO methodology
- Concept of sustainable development and NESA
- Using NESA to support development of a long-term nuclear energy strategy
- Practical approach to performing NESA
- Conclusion

History

- **2000 : Launching of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) based on IAEA General Conference resolution (GC(44)/RES/21)**
- **2001 – 2006 : Development of the Methodology as a tool for Nuclear Energy System Assessment (NESA)**
- **2004 – 2008 : Six national and one multinational NESA leading to several collaborative projects (CPs)**
- **2010 – 2011 : NESA in Belarus**
- **2011 – : NESA in Ukraine, Indonesia**

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History

- Effort to develop INPRO methodology between 2001 to 2005:
  - Contribution by ~ 150 experts from ~ 30 countries:
    - ~ 10 person years
  - Contribution by ~ 50 IAEA staff from several IAEA departments:
    - ~ 30 person years (mainly CFE).
  - Total effort for development:
    - ~ 40 person years

History

INPRO Objectives:

- To help ensure that sustainable nuclear energy is available to contribute to the energy needs of the 21st century.

- To bring together technology suppliers and users to jointly consider national and international actions to achieve innovations in nuclear reactors, fuel cycles and related institutions.

History

6 key issues influence the acceptability and sustainability of nuclear power:

1. Cost
2. Nuclear waste
3. Proliferation
4. NM security and protection from sabotage
5. Impact on resources and the environment
6. Safety

Improved stakeholder/public communication and continuous technical improvements necessary for progress on these key issues

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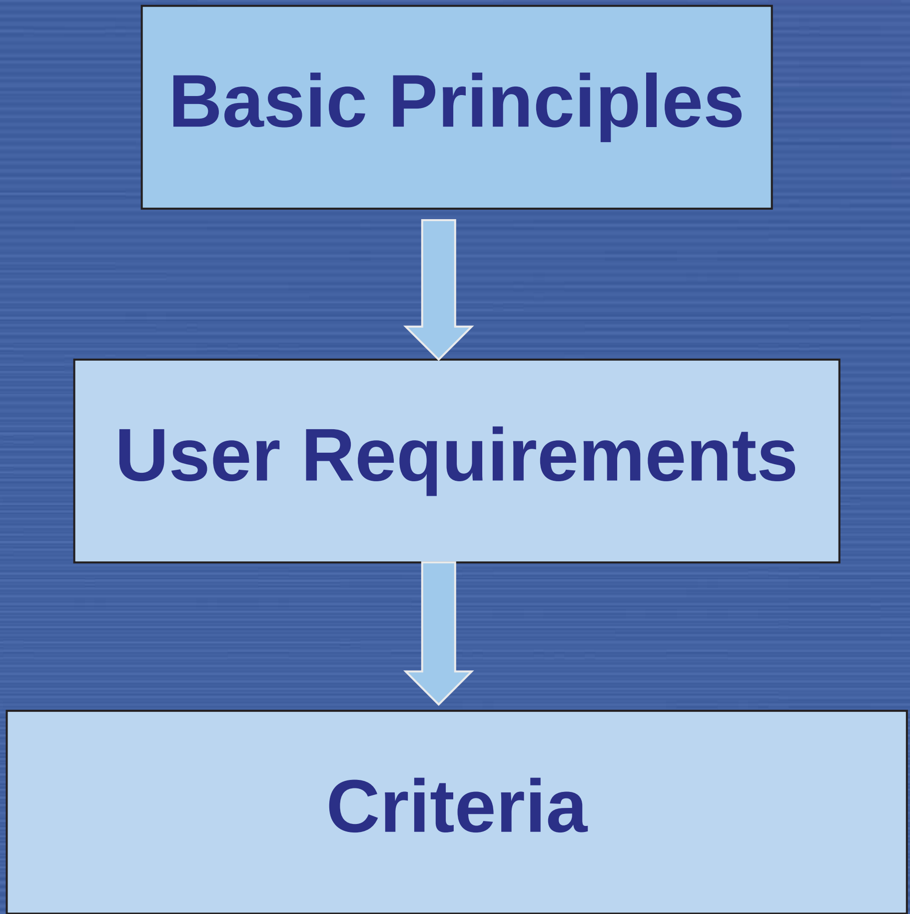
History

- Six assessment areas to address these six key issues in the INPRO methodology:
    1. Economics
    2. Waste management
    3. Proliferation resistance
    4. Physical protection
    5. Environment (impact of stressors, availability of resources)
    6. Safety of reactors and fuel cycle facilities
- One additional area called Infrastructure (legal frame work and institutional measures)

Architecture of INPRO requirements



Basic Principles:

goals for development of sustainable NES

User Requirements:

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

Criteria:

Assessor’s tools to check whether a User Requirement has been met

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Architecture of INPRO requirements

Holistic Nature of NESA

Nuclear Energy System Assessment (NESA) using the INPRO methodology:

- **Covers innovative and evolutionary designs of all reactor types and Nuclear Fuel Cycle facilities**
- **Covers all components (or facilities) of a Nuclear Energy System (no matter where located)**
- **All phases of a Nuclear Energy System, i.e. cradle to grave**

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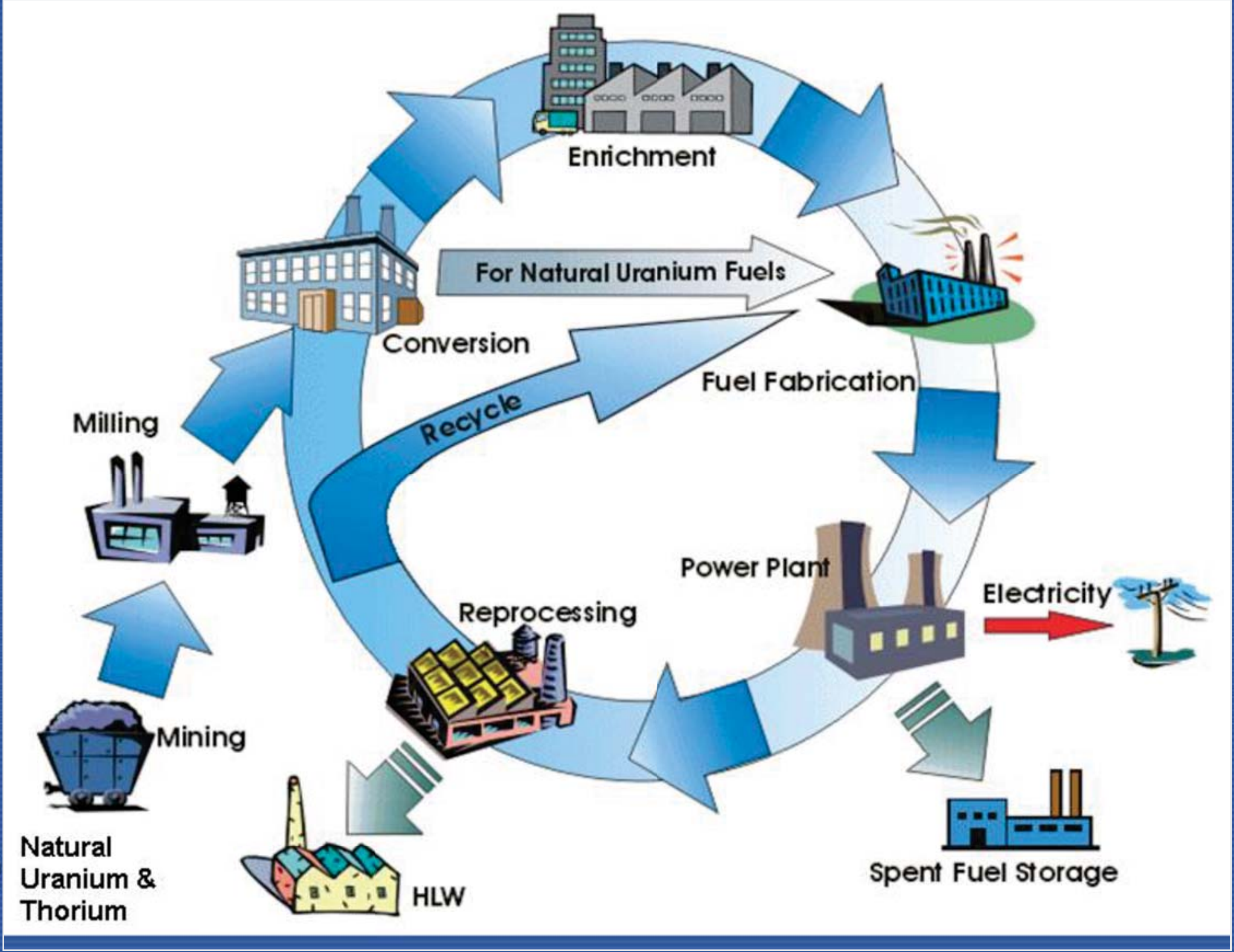
Holistic Nature of NESA

NES includes all components (Facilities)



Concept of Sustainable Development

Concept of Sustainable Development
Societal, economical, environmental, institutional aspects

↓

Need for sustainable **Energy Supply**

History

1987: Brundtland report defines Sustainable Development: "***development that meets the needs of the present without compromising the ability of future generations to meet their own needs".***

1992: Agenda 21, how to achieve development in the 21st century that is socially, environmentally, and economically sustainable.

1997: Kyoto protocol, reduction of GHG (limited use of NP).

1998: World Energy Assessment report deals with issues of sustainable energy supply.

2002: World summit on sustainable development (WSSD). Role of energy supply in fighting poverty.

2009: Copenhagen conference

2010: Cancun conference

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Concept of sustainable development and energy system planning

Concept of Sustainable Development

Societal, economical, environmental, institutional aspects

Performance of energy system planning

On a national, regional, global level, covering all energy sources

Need for sustainable Energy Supply

Definition of the **role of nuclear power** in sustainable energy system

IAEA tools for energy system planning (PESS assistance, e.g. MESSAGE, MAED, etc.)

- **Reference energy demand scenarios:**
  - Expected population growth.
  - GDP per capita.
  - Electricity intensity per GDP.
- **Evaluation of supply options:**
  - Driving forces (e.g. cost of electricity).
  - Constraints (e.g. availability of domestic fuels).
- **Role of nuclear power** in energy supply mix.

Concept of sustainable development, energy system planning and NESA

Concept of sustainable development

societal, economical, environmental, institutional aspects

→

Performance of energy system planning

On a national, regional, global level, covering all energy sources

→

Nuclear Energy System Assessment (NESA)
using the holistic INPRO Methodology

(INPRO assistance)

↓

Need for **Sustainable Energy Supply**

Definition of the **role of nuclear power** in sustainable energy supply mix

Follow up actions to achieve **sustainable nuclear energy system**

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NESA to Support Long-Term Strategy

- Long-term nuclear energy strategy is important. Characteristic timescale of drivers and implications are long-term:
  - Environmental and resource impacts (~100 yrs +)
  - Technology lifecycles (50 to 100 yrs)
  - Waste management (100 yrs to indefinite)
  - Integration of ‘embarking countries’ into the ‘nuclear family’ of nations (~10 yrs, often more)
  - Large investment volume, high financial risk (~$5B/unit)
  - Development of competent authorities, institutions – particularly institutional innovations in the future

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Generalized INPRO requirements

Main messages in each area of the INPRO Methodology:

1. Economics: Nuclear energy products must be competitive with alternative energy sources available in the country, and serve as a complementary part of the energy mix

2. Waste management: Nuclear waste must be managed so that human health and environment are protected and undue burdens on future generations are avoided

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Generalized INPRO requirements

Main messages in each area of the INPRO Methodology:

3. Proliferation resistance: Future NES must remain unattractive for a nuclear weapon program through a combination of intrinsic features and extrinsic measures

4. Physical protection: Best practice defence in depth regime implemented for whole life cycle of NES

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Generalized INPRO requirements

Main messages in each area of the INPRO Methodology:

5. Environment: Impact of stressors from future NES must be within performance envelope of current NES or better. Resources must be available to run NES until end of 21st century or longer.

6. Safety: Contemplated NES facilities should have equal or better safety performance than recent, comparable installations.

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Generalized INPRO requirements

Main messages in each area of the INPRO Methodology:

7. Infrastructure: Assure adequate infrastructure and reduce effort to create and maintain it

    - Legal and institutional frame work
    - Industrial and economic infrastructure
    - Socio-political infrastructure (public acceptance, human resources)

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Characteristics of INPRO Requirements

- INPRO User Requirements are directed at:
  - Designer or developer of nuclear facilities
  - State (government institutions)
  - Operator of nuclear facilities
  - National industry (involved in nuclear power program)

- Input data needed for evaluation of INPRO User Requirements to be provided by responsible organization

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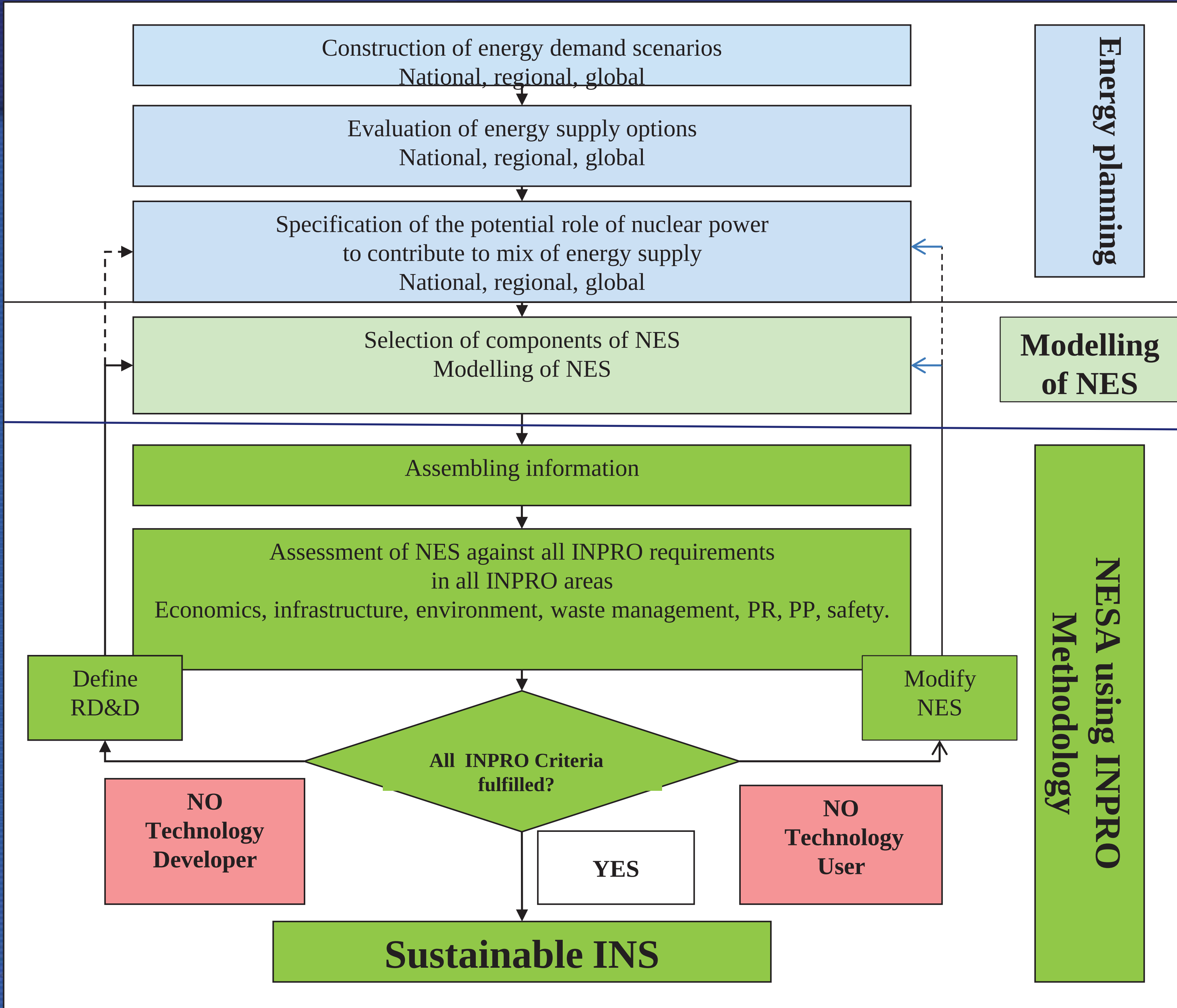
Energy system planning, Modelling, NESA



Potential Users of a NESA

Benefit for 3 potential users of INPRO Methodology in a NESA:

- **Technology developers/suppliers:**
  ➔ Assistance for planning/executing RD&D
- **Technology users:**
  ➔ Assistance for decision making when considering initial/additional deployment of NES components
- **Prospective first time users:**
  ➔ Assistance with becoming knowledgeable technology consumers/owners

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Types of NESA

- **Different** levels of **depth and scope in a NESA**:
  - **NESA as learning tool**: Increase of awareness of long term nuclear issues (newcomer).
  - **NESA with limited scope**: Selected areas of INPRO methodology and/or selected components of NES (developer).
  - **Full scope NESA**: All areas of INPRO methodology, full depth of assessment, complete NES. → Long term sustainability

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Benefits of NESA

- Main **benefits to developer** from applying holistic INPRO methodology in a NESA:
  - **Identification of critical issues**, i.e. gaps.
    - Ensure that development will close identified "gaps".
  - **Balanced design**, i.e. avoidance of undesirable consequences in one area caused by development in another area.
  - Assistance in selection of preferred option.
  - Increased assurance that proposed NES (component) will be deployed once developed.

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Benefits of NESA

- Main **benefits to experienced user** from applying holistic INPRO methodology in a NESA:
  - Identification of issues ("gaps") at early stage of deployment of additional units.
  - Follow up actions to close "gaps" to move NES towards sustainability.
  - Identification of potential advantages of different NES options.

Benefits of NESA

- Main **benefits** to **newcomer** from applying a "graded approach" to holistic INPRO Methodology in a NESA:
  - **Increase of awareness** of all nuclear issues, i.e. educational tool.
  - Development of cadre of **knowledgeable individuals**.
  - Assistance in **planning** and decision making process.

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Steps in a NESA

- **Prerequisites**:
  - Energy system planning study performed (e.g., PESS' energy system planning assistance).
  - NESA team established (e.g., TSOs, National Academies, etc.)
  - Scope and purpose of NESA defined
  - Nuclear Energy System (NES) specified

Steps in a NESA

- **Step 1:** Familiarization with the INPRO Methodology:
  - Study of INPRO documentation and relevant references.
  - Training by IAEA/INPRO experts.

- **Step 2:** Identification of sources of **input** needed for a NESA:
  - Designer and/or operator of facilities of NES
  - National industry involved in nuclear power program
  - Government agencies
  - IAEA organizations and data bases
  - INPRO NESA support package: Input tables (Waste Management, Economics, Infrastructure, on CD-ROM)

Steps in a NESA

- **Step 3:** Performance of assessment with the goal to identify “gaps”, i.e. issues that need follow up actions:
  - Work in different areas of the INPRO methodology can be performed in parallel
  - Keep continuous contact within the NESA team
  - Maintain contact to IAEA/INPRO group to answer questions

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Steps in a NESA

- **Step 4:** Documentation of assessment results:
  - Objective and scope of NESA
  - Reference energy plan and role of NP
  - NES selected for assessment
  - Sources of information *
  - Result of the assessment, i.e. judgment on potential of NES to fulfil the criteria and rationale for judgement *
  - Summary and conclusion of the assessment *
  - Follow up actions *
  - Feedback on INPRO methodology *

* in each area of INPRO methodology

Steps in a NESA

- **Step 5** (recommendation): Peer review of the NESA by the IAEA/INPRO secretariat
  - Use of internal and (if needed) external experts

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Main Output of NESA

- Confirmation of sustainability of NES, or identification of gaps*
- Definition of follow up actions to close gaps*
- Note: Even if gaps are found, NES may be a good interim solution, if path to sustainable system has been defined

* "Gap" = INPRO Methodology Criterion not met

Organization of NESA

- Options for organization of national NESA performed by **Technology User (TU)**:
  - **OPTION 1** : TU performs NESA “alone”
  - **OPTION 2** : TU performs NESA with **support by technology holder** (i.e. supply of input data)
  - **OPTION 3** : TU performs NESA in close **cooperation with technology holder** (e.g., at the offices of technology holder)

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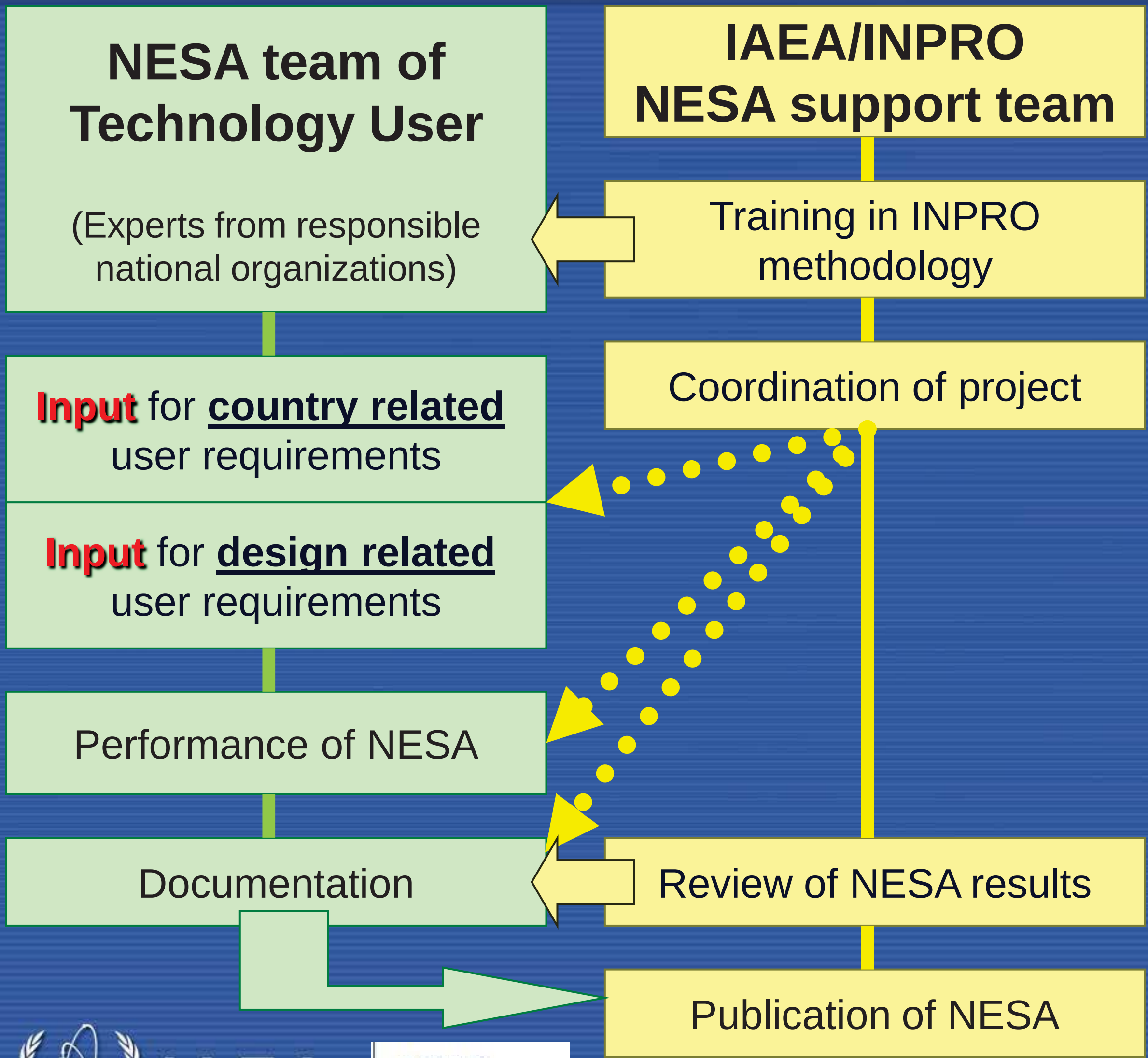
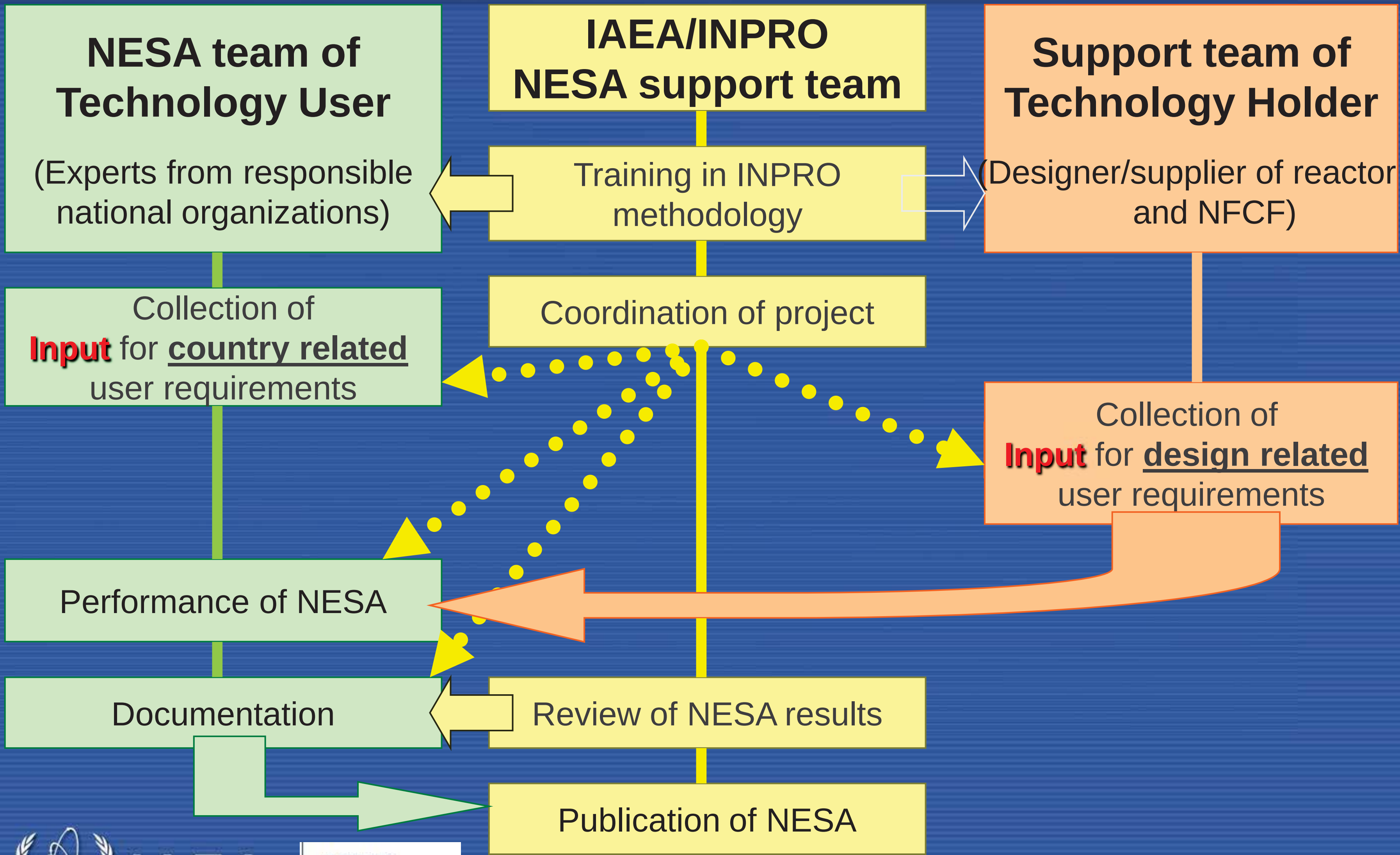
NESA by Technology User – OPTION-1



NESA by Technology User – OPTION-2



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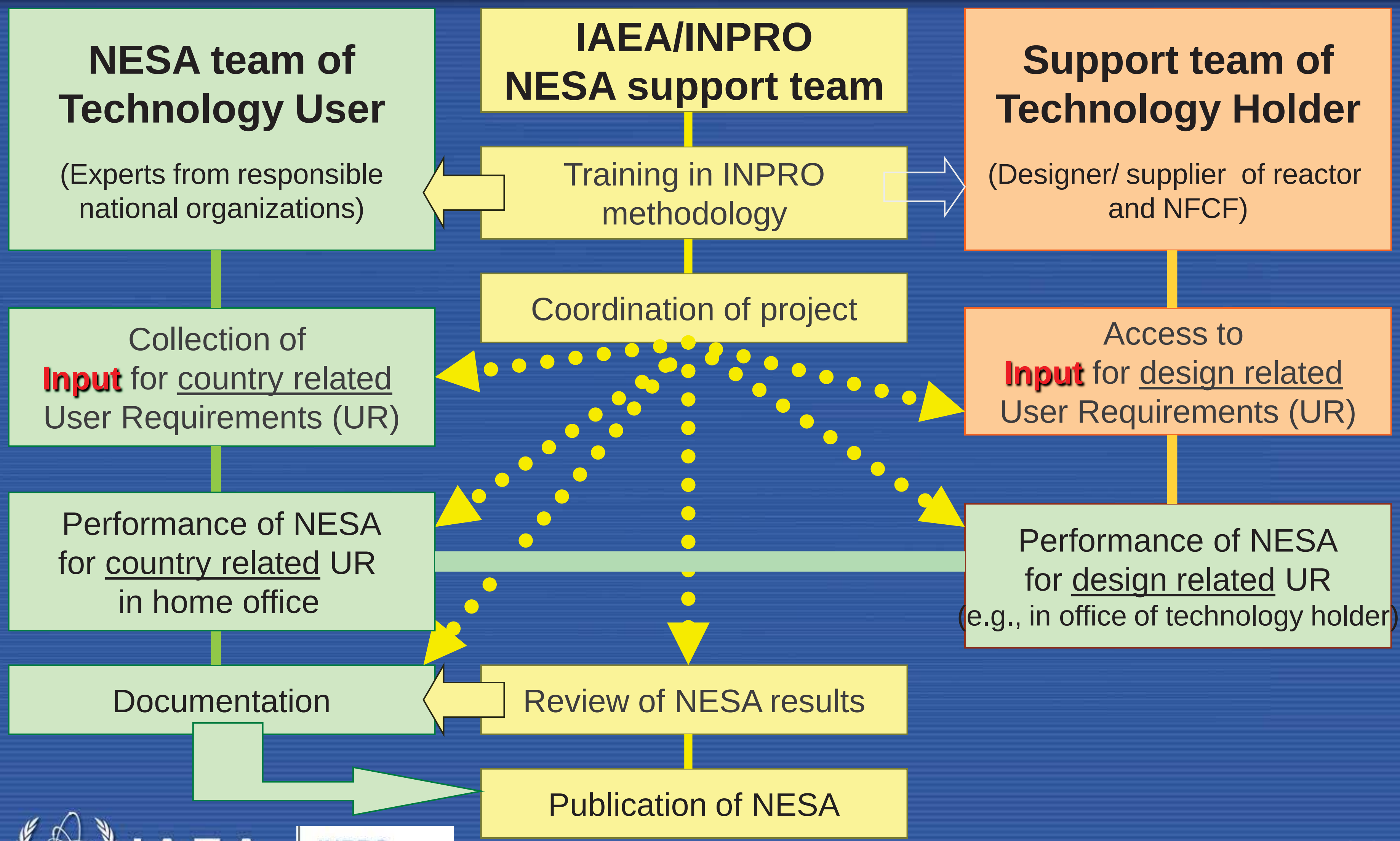
NESA by Technology User – OPTION-3



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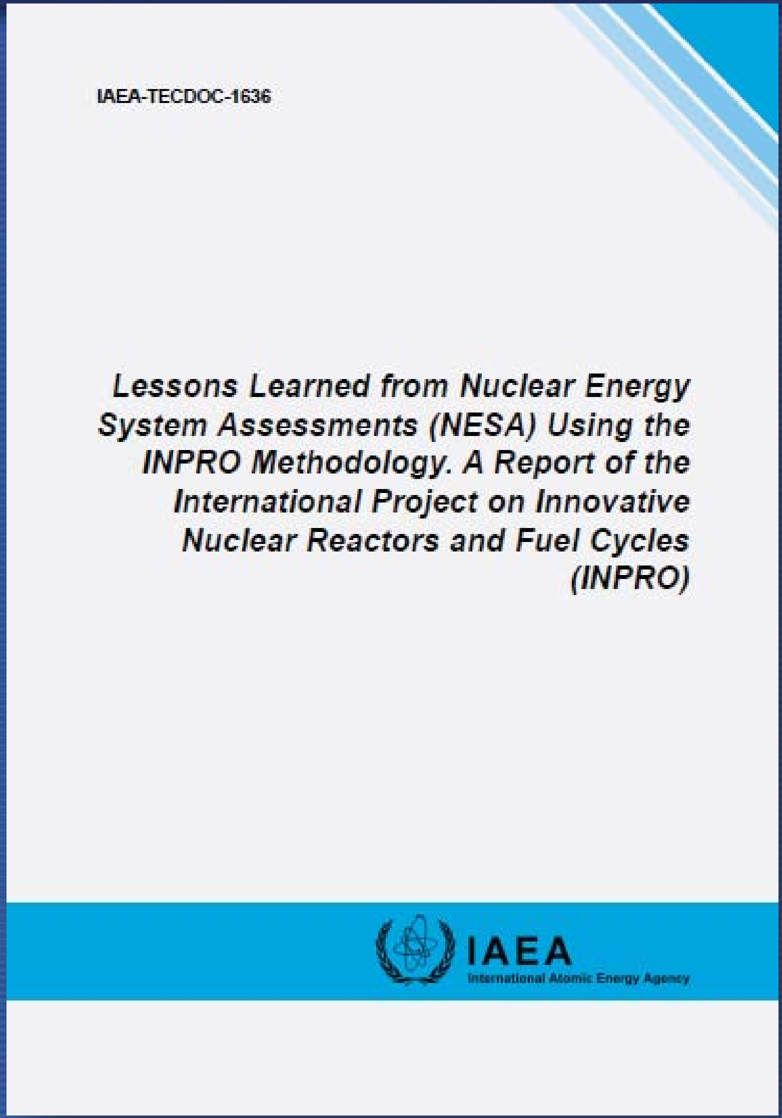
Experience with NESA

- 6 national assessments
  - Argentina, Brazil, India, Republic of Korea as technology developer.
  - Armenia, and Ukraine as technology user.
- Results documented in IAEA report TECDOC-1636



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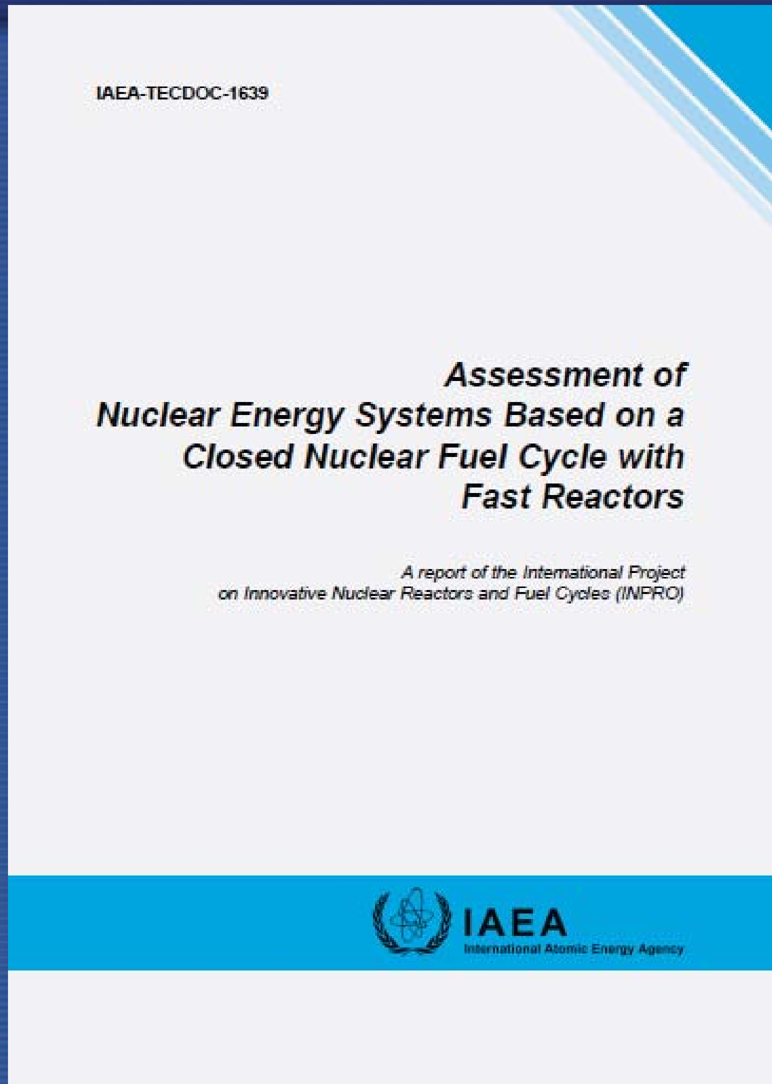
Experience with NESA

- 1 multinational assessment ("Joint Study"):
  - Canada, China, France, India, Japan, Republic of Korea, Russian Federation, and Ukraine.
  - Development of NES of sodium cooled Fast Reactor with Closed NFC.
- Results documented in IAEA report TECDOC-1639


IAEA-TECDOC-1639

Assessment of Nuclear Energy Systems Based on a Closed Nuclear Fuel Cycle with Fast Reactors

A report of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)

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Experience with NESA

- NESA in Belarus
  - Full scope assessment of all INPRO methodology areas
  - Simplified NES consisting of power plant and waste management facilities
  - To be published as IAEA TECDOC in 2011
- NESA on-going in Ukraine
  - Limited scope: economics, infrastructure, WM
  - To be finished in 2012
- NESA Indonesia started late 2011

Effort to Perform a NESA

- **Optimistic estimation of effort** to produce **full scope NESA** of single NES (no options)
- NESA team: One expert per INPRO Methodology area (eight areas)
- Effort of one expert in NESA team:
  - Familiarization with one area : ~ **2 weeks**
  - Collection of input data per area: ~ **10 weeks**
  - Performance of assessment per area: ~ **4 weeks**
- **Total effort for 8 areas ≈ 130 person weeks** ≈ 1 ½ person years
- **Duration of NESA: ≤ 1 year**

NESA Support Package

- NESA Support Package:
  - Based on **feedback from assessors** (IAEA-TECDOC-1636).
  - Training on the INPRO Methodology.
  - Continuous access to IAEA and SM expertise via INPRO group.
  - **Examples of input data** for INPRO assessment Economics, Infrastructure and Waste management
  - **NEST** tool for economic analysis (on CD-ROM).
  - List of design data to be provided by designer (on CD-ROM).

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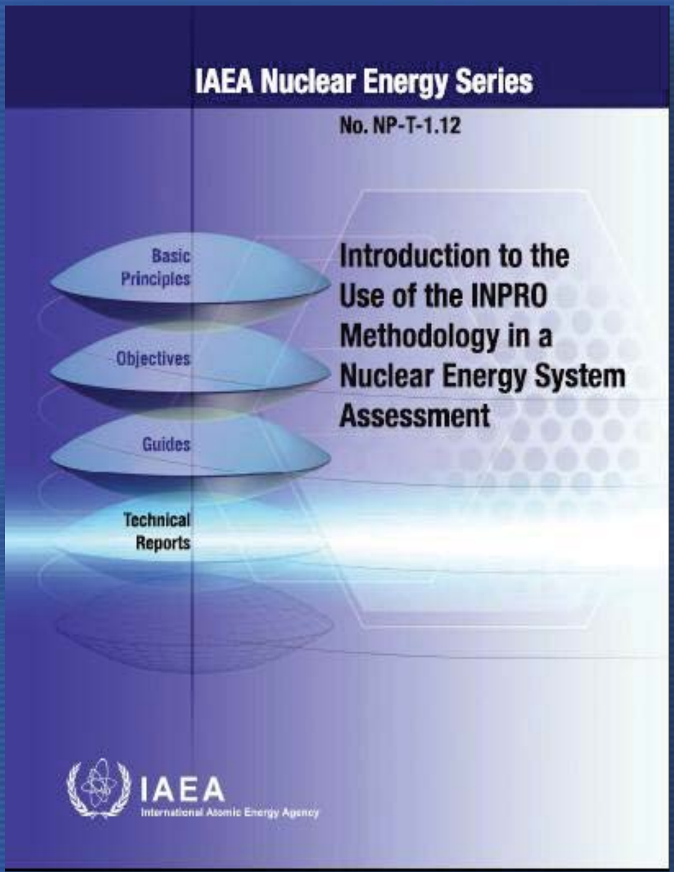
NESA Support Package

Documents to be used in NESA:

IAEA NE series report NP-T-1.12

- Title: Introduction to the use of the INPRO methodology in a NESA.
- User's Guide how to perform a NESA.
- To be used as introduction to and overview of TECDOC-1575 Rev.1.



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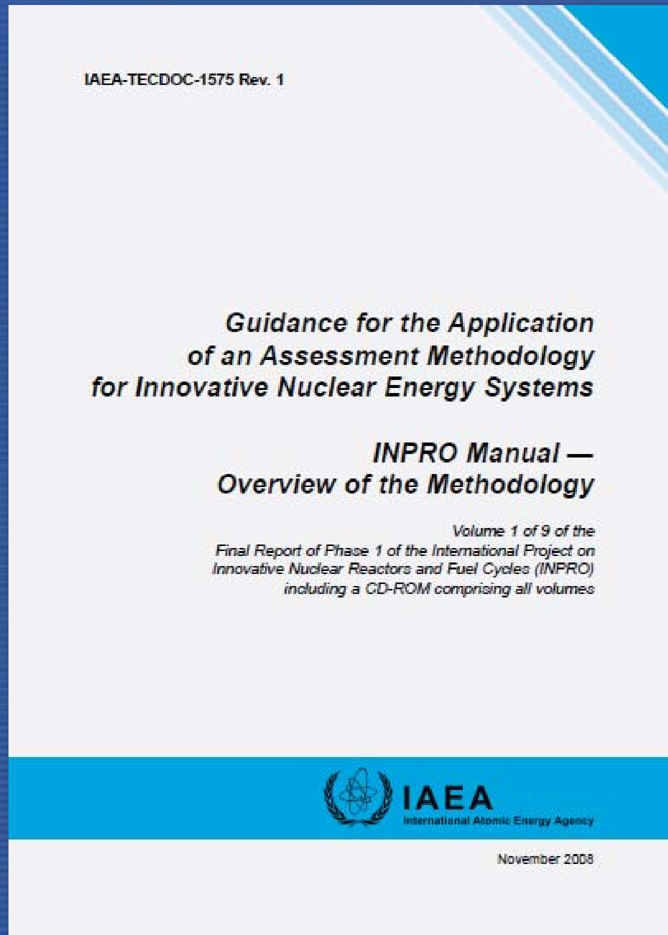
Some documents to be used in NESA:

IAEA-TECDOC-1575 Rev.1:

- Title: Guidance for the application of an assessment methodology for innovative NES.
- INPRO Manual – Overview of the Methodology.
- Detailed description of INPRO Methodology.
- 9 Volumes.


IAEA-TECDOC-1575 Rev. 1

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

INPRO Manual —
Overview of the Methodology

Volume 1 of 9 of the
Final Report of Phase 1 of the International Project on
Innovative Nuclear Reactors and Fuel Cycles (INPRO)
including a CD-ROM comprising all volumes

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November 2008

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NESA Support Package

NESA Support package: INPRO area of INFRASTRUCTURE

Introduction

The following **Table I1** list the necessary input for an INPRO assessment of a nuclear energy system (NES) and examples[1] of such input data. The examples in Table I1, i.e. the links to websites, primarily define the format of the information and not so much the content and may be used primarily by any country as examples of information. The examples demonstrate the fact of existence and availability of needed input data in other countries. Non existence of such input data in the assessed country leads to a negative judgement on the potential of the infrastructure of the

#	CR	IN and AL or EP with AC	Ref	Input	Examples of input data sources	Link to Table I2
1	CR1.1 legal aspects	**EP1.1.1: Scope of the nuclear law.** Areas of nuclear law: Regulatory body; Radiation and Environmental protection; Safety of nuclear installations; Nuclear liability and coverage; Export and import of controls of nuclear materials; Safeguards of nuclear materials and Security; and physical protection of nuclear material and nuclear facilities. **AC1.1.1**: Evidence is available to the INPRO assessor that all areas listed above are covered by nuclear law.	p.19 p.20	Text of national nuclear law **OR** result of independent assessment of nuclear law by expert organization such as IAEA	To assess EP1.1.1 and EP1.1.2 full text of nuclear legislation is usually available from the official site of regulatory body or government. The national nuclear law can be compared to the following examples of full scope and adequate nuclear law: http://www.nrc.gov/about-nrc/governing-laws.html (US), http://www.nuclearsafety.gc.ca/eng/lawsregs/index.cfm (Canada), http://www.stuk.fi/julkaisut_maaraykset/en_GB/lainsaadanto/ (Finland). Many national nuclear laws of most of the countries are available from the site of Nuclear Energy Agency (issue date later 2000) http://www.nea.fr/html/law/nlb/index.html or (issue date in the range 1968-2000) http://www.nea.fr/html/law/nlb/nlb-1968-2000.html. Demonstration of the overriding considerations usually can be found among main principles of the laws, e.g. (in the case of Ukraine) at page 6 of http://www.nea.fr/html/law/nlb/NLB-56-SUP.pdf. As well, institutional responsibilities are at p.12 to 15 (the same reference), most important terms and definitions are at p.3,4, issues of waste management – p.31, physical protection – p.33, safeguards – p.36, export &import –p.43, etc. Alternatively EP1.1.1 and EP1.1.2 can be assessed using results of an independent assessment of the national nuclear law (see also EP1.2.3).	go to tab I2
2		**EP1.1.2: Adequacy of nuclear law.** **AC1.1.2**: Evidence is available to the INPRO assessor that the 6 questions on page 20 of Volume 3 of TECDOC-1575 have been answered satisfactorily, i.e. an affirmative answer (YES) for questions 1, 3 (first part), 4, and 6; and, a negative answer (NO) to the questions 2, 3 (second part) and 5	p.20			go to tab I2

- Area of **Infrastructure & Waste Management**
- Sources and Examples of Input data for assessment.
- Available on CD-ROM and in eNESA

NESA Support Package

#	Parameter	Dimension	Equation or input data sources/examples	Reference*	Descriptions and comments
2.10	T_{Ct}	[years] and it is used as dimensionless	-- (input data) – Examples are at http://www.brucepower.com/uc/GetDocument.aspx?docid=2403	Examples are in tables 4.15, 4.16 (p.p.66, 68)	The construction time. According to the Methodology approach the value of this parameter is negative (i.e. -6 years or -4 years etc). *This parameter can be met in Table E2 (but for FPP)*
3	*LUOM*	[$/kWh] or [mills/kWh]	$LUOM = \frac{\left(\frac{O\&M}{P}\right)_{FIX}}{8760 \cdot Lf} + \left(\frac{O\&M}{KWh}\right)_{VAR}$	(12)	Levelized unit lifecycle operation and maintenance cost. This parameter includes all costs save NPP construction/decommissioning and fuel frontend/backend costs (e.g. NPP staff salaries, auxiliary equipment and materials purchasing, non-fuel waste management etc). It should be calculated by the assessor. *This parameter can be met in Table E2 (but for FPP)*
3.1	$\left(\frac{O\&M}{P}\right)_{FIX}$	[$/kWe]	-- (input data) – One is able to find necessary examples in **OECD/NEA publication "Progected costs of generating electricity" (2005 Update)**. Other examles are available at http://www.cameco.com/common/pdf/media/factsheets_publications/WNA_The_New_Economics_of_Nuclear_Power.pdf, and http://www.nei.org/resourcesandstats/documentlibrary/reliableandaffordableenergy/graphicsandcharts/uselectricityproductioncostsandcomponents/	Examples are in tables 4.4, 4.5 (p.p.50, 51)	Annual fixed operation and maintenance cost (i.e. cost of O&M works that depend on time flow and don't depend on energy production). It should be calculated and presented to user by designer. *This parameter can be met in Table E2 (but for FPP), Table E5 and Table E6 (for FPP)*
3.2	$\left(\frac{O\&M}{KWh}\right)_{VAR}$	[$/kWh]		Examples are in tables 4.4, 4.5 (p.p.50, 51)	Variable operation and maintenance cost (i.e. cost of O&M works that depend on amount of energy produced). It should be calculated and presented to user by designer. *This parameter can be met in Table E2 (but for FPP), Table E5 and Table E6 (for FPP)*
3.3	*Lf*	See 2.7			
4	*LUFC*	[$/kWh] or [mills/kWh]	$LUFC = \frac{\left(\frac{\$}{Kg}\right)_{FE,1^{st}Core}}{\eta \cdot \delta_{th} \cdot Lh_{FP}} + \frac{\left(\frac{\$}{Kg}\right)_{FE,REf}}{Q \cdot \eta} + \frac{\left(\frac{\$}{Kg}\right)_{SF}}{Q \cdot \eta}$	(13), (14), (15), (14a), (15a)	Levelized unit lifecycle fuel cost. This parameter represents the levelized cost of the fuel including both frontend and backend per unit of electric energy received from this fuel. Usually frontend costs of the fuel are divided in two (or more) parts. One part describes refueling and other parts (one or more) describe conditionally 'first core' (accounting fuel deposit and enrichment variations). It should be calculated by the assessor.

#	Parameter	Dimension	Equation or input data sources/examples	Reference*	Descriptions and comments
2.8	*r*	[1/year] or [%/year]	-- (input data) – Examples are at http://www.bank.gov.ua/ENGL/STATIST/ and at http://www.nbrb.by/engl/statistics/refrate.asp and http://www.boj.or.jp/en/type/stat/boj_stat/discount.htm	Example is in table 4.13 (p.63)	Real discount rate. This parameter usually is defined and published in the country of forthcoming NPP construction by the corresponding financial institutions (e.g. National Bank, see here for the links http://www.bis.org/cbanks.htm). For developing countries usually it is 0.10 – 0.12 $year^{-1}$ (or 10 – 12%/year). But everybody has to be careful with definition of "*r*" because from the point of view of investments one should put it equal to the "loan interest rate" and loan interest rate value can be as higher of real discount rate so lower of him depending on the specific investment conditions. In the case assessor has no information on specific investment conditions he can use published real discount rate. *This parameter can be met in Table E1 (below), Table E2, Table E3, Table E4.*
2.9	t_{LIFE}	[years] and it is used as dimensionless	-- (input data) – Examples are at http://apw.ee.pw.edu.pl/tresc/-eng/13-VVER-1500reactor.pdf, and at http://www.world-nuclear.org/sym/2002/pdf/paulson.pdf	Examples are in tables 4.4, 4.5 (p.p.50, 51)	The life time of the plant. For recently designed PWRs it is 60 years. For those of the designs, e.g. HWR with pressure tube replacement envisaged, where NPP life time can be extended by the replacement of the equipment one should take into account non-zero back fitting costs (see line 2.5) for extended lifetime. The life time of the plant should be calculated and presented to user by designer. *This parameter can be met in Table E2 (but for FPP), Table E5 and Table E6 (for FPP)*

Area of Economics:

- Algorithmic table with detailed list of equations, parameters, remarks and links to examples of input data necessary to perform all economics calculations.
- Table and examples on CD-ROM.
- and …

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NESA Support Package

SENSITIVITY ANALYSIS. PERTURBED PARAMETERS INPUT

names	units	PWR numbers	PWR years	HWR numbers	HWR years	fossil power plant numbers	fossil power plant years
Lifetime of the plant	years	0		0		0	
Real discount rate	1/year	0		0		0	
Load factor (average)	__	0		0		0	

MAIN RESULTS (sensitivity analysis)

name	units	numbers
RI_i (PWR)	__	0.83357
RI_i (HWR)	__	0.86269

about this tool | main rules for users | contacts

INPUT DATA

names	units	PWR numbers	PWR years	HWR numbers	HWR years	fossil power plant numbers	fossil power plant years
Net electric power	kWe	600000		666000		380000	
Construction time	years	4		6		3	
Lifetime of the plant	years	60		35		40	
Load factor (average)	__	0.9		0.8		0.75	
Decommissioning cost	mills/kWh	1		0.04485		0	
Backfitting cost	mills/kWh	0		0		0	
Overnight cost	$/kWe	1145		1697		376	
Contingency cost	$/kWe	225		85		38	
Owners cost	$/kWe	137		0		380	
Normalized capital investments schedule (share per year) during construction	__	0	0	0.074	0	0	0
	__	0	1	0.217	1	1	1.5
	__	0	2	0.282	2	0	2
	__	1	3.8	0.223	3	0	3
	__	0	4	0.132	4	0	4
	__	0	5	0.061	5	0	5
	__	0	6	0.011	6	0	6
Fixed operation&maintenance cost	$/kWe	49		54.94		0	
Variable operation&maintenance cost	mills/kWh	0.9		0		6	
Fossil fuel price	$/GJ					4.78	
Fossil fuel price annual increase rate	__					0.01	
Nuclear fuel backend cost	$/kg	400		73			
Spent nuclear fuel average burnup	MWd/kg	40		7.5			
Net thermal efficiency of the plant	__	0.30928		0.30862		0.584615	
Reactor core average power dencity	kW/kg	28.89		23.5			
Natural U purchase cost	$/unit	50		50			
U conversion cost	$/unit	8		8			
U enrichment cost	$/unit	110		0			
Nuclear fuel fabrication cost	$/unit	275		65			
Amount of services (U purchase)	unit/kg	1		1			
Amount of services (U conversion)	unit/kg	1		1			
Amount of services (U enrichment)	unit/kg	SWU		SWU			
Amount of services (fuel fabrication)	unit/kg	1		1			
Number of stages in the frontend of FC		4		3			
time from U purchasing till fuel loading	years	-1.5		-1.5			
time from U conversion till fuel loading	years	-1		-1			
time from U enrichment till fuel loading	years	-0.75		0			
time from fuel fabrication till loading	years	-0.5		-0.8			
HM change "Purchasing-Conversion"	kg/kg	1		1			
HM change "Conversion-Enrichment"	kg/kg	F		F			
HM change "Enrichment-Fabrication"	kg/kg	1		1			
HM change "Fabrication-Operation"	kg/kg	1		1			
Losses at natural U purchasing	__	0		0			
Losses at U conversion	__	0.005		0.005			
Losses at U enrichment	__	0		0			
Losses at fuel fabrication	__	0.01		0.005			
first core lowest U235 concentration	__	0.02		0.00711			
first core medium U235 concentration	__	0.03		0.00711			
refuelling fuel U235 concentration	__	0.0355		0.00711			
natural U235 concentration	__	0.00711		0.00711			
enrichment tails U235 concentration	__	0.0025		0.0025			

general input data (country specific)

names	units	numbers
Real discount rate	1/year	0.12
Price per unit of electricity sold	mills/kWh	61.28
Market income	M$/year	3000
Market share	__	0.5
Profit margin	__	0.1
Time of growth	year	2.5
Adjusting coefficient	__	2.4

MAIN RESULTS

name	units	numbers
LUEC (PWR)	mills/kWh	47.1514
LUEC (HWR)	mills/kWh	48.7129
LUEC (FPP)	mills/kWh	53.4546
IRR (PWR)	__	0.1568
IRR (HWR)	__	0.1548
IRRlimit	__	0.1836
ROI (PWR)	__	0.25073
ROI (HWR)	__	0.19474
ROIlimit	__	0.15975
total PWR ivestments	M$	1390.89
total HWR ivestments	M$	1567.78
total FPP ivestments	M$	357.628
ivestments_limit	M$	900

Sensitivity analisys results are below

Excel based tool called:

“NESA Economics Support Tool” (NEST)

- All calculations to produce input for economics assessment
- NEST on CD-ROM.

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INPRO
International Project on Innovative Nuclear Reactors and Fuel Cycles

NESA Support Package

INPRO requirements and role of designer in a NESA performed by a technology user

INPRO Area	Basic principle BP	User Requirement UR	Role of technology holder in NESA performed by technology user	
Waste management	**BP1: Generation of radioactive waste** in an INS shall be kept to the minimum practicable	**UR1.1: 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	Provide information (presentation and report) on all wastes produced by all nuclear facilities considered in NESA, i.e. a list of alpha emitters and long lived radioactive nuclides in the waste, and characteristic values of the waste such as activity, mass, and volume (per GWa).	WM1
			Provide information (presentation and report) on all chemically toxic elements as part of radioactive waste (per GWa) of facilities considered in NESA.	WM2
			Provide information (presentation and report) for each facility considered in NESA describing the strategy to minimize waste, evidence of its implementation, and the results of an independent peer review of this waste minimization study of such facilities.	WM3
	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	**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	For all waste management facilities considered in NESA provide information (presentation and report) that contains: - for a reference site estimated dose rate to an individual of the critical group (public dose); - radiological exposure of workers (occupational dose); and - estimated concentrations of chemical toxins in working areas of such facilities.	WM4

- List of input to be provided by designer (technology holder): available on CD-ROM.

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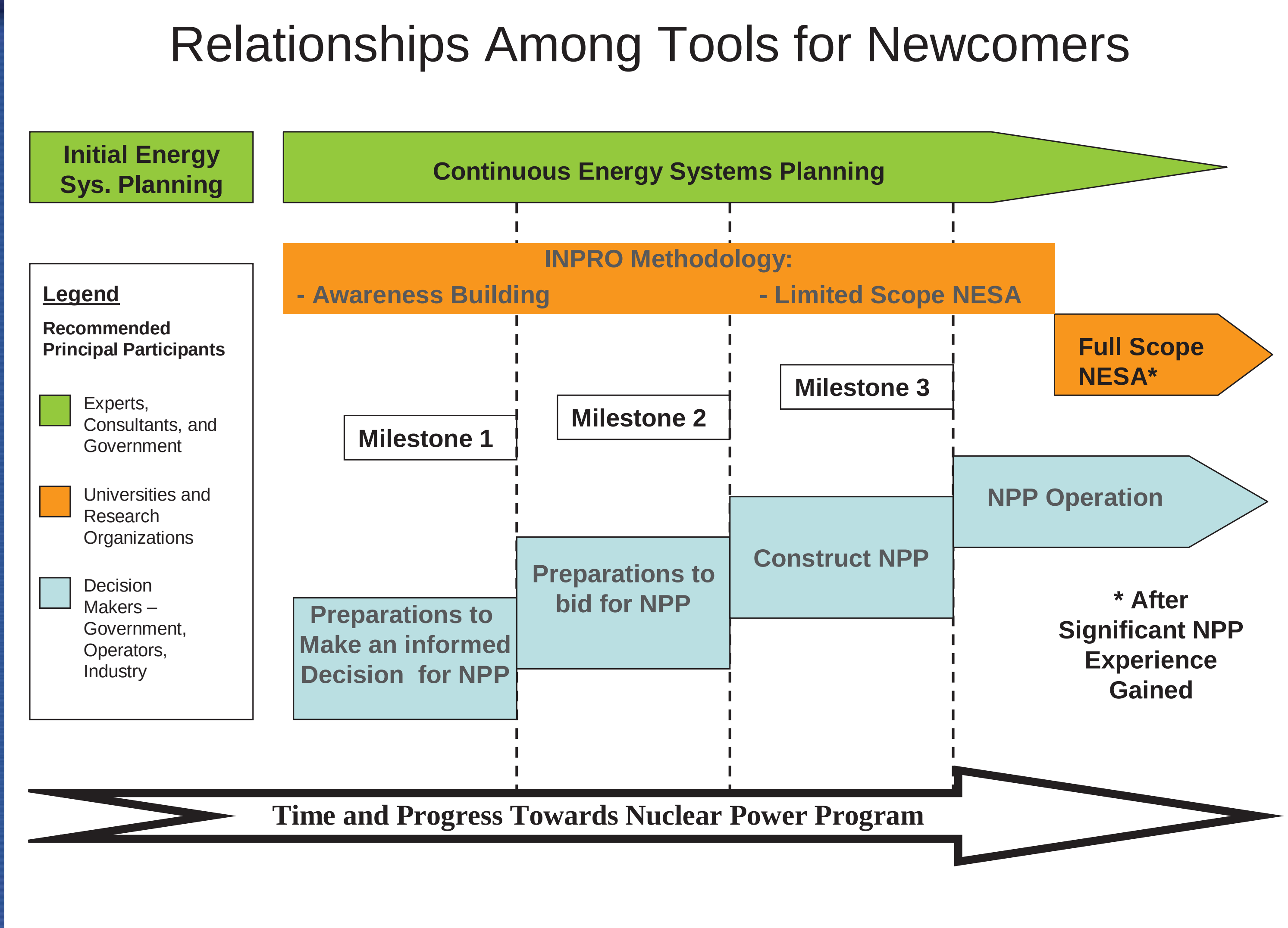
IAEA Tools for embarking countries



Getting Started

Recommendations for a newcomer:

- Assume a simple NES – reactor(s), necessary waste management facilities and purchase of fuel (start simple!).
- Use the NESA to get familiar with all nuclear issues , i.e. perform assessment at User Requirement level.
- Later in the project, assess areas in detail where country is responsible: economics, waste management, and infrastructure.
- Expand the assessment to include all INPRO areas.
- Expand the assessment to include additional facilities or facilities located in other countries that provide services.

Conclusions

Application of INPRO Methodology by all potential users

Awareness Building	Limited Scope NESA	Full Scope NESA
Training Tool: • Familiarization with key issues of long term sustainability. • Human Resources development.	**Focussed Assessment**: • **Developer**: Determination of R&D needs. • **User**: Selection of options, educated consumer. • **Newcomers:** Bid related issues.	**Holistic Assessment**: • Confirmation of sustainability. • Identification of actions to achieve long-term sustainability.

Progress Towards Sustainable Nuclear Power Program →

Conclusions

- NESA applying the INPRO methodology can be used to:
  - Confirm sustainability of nuclear energy systems (NES) at least until the end of the 21^{st} century
  - Identify actions to be taken to achieve sustainable NES
  - Support long-term strategic planning of NES

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Thank you for your attention!

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