THE IAEA INTERNATIONAL PROJECT ON INNOVATIVE NUCLEAR REACTORS AND FUEL CYCLES (INPRO): Status and Outlook

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Introduction

- **INPRO : International Project on Innovative Nuclear Reactors and Fuel Cycles.**
- **Basis of INPRO : Resolution at the IAEA General Conference in 2000/2001/2002/2003/2004 in Vienna and at the United Nations General Assembly in 2001/2002/2003.**
- **Text of IAEA General Conference Resolution in September 2000:**
  - IAEA GC 2000 has invited "all interested Member States to combine their efforts under the aegis of the Agency in considering the issues of the nuclear fuel cycle, in particular by examining innovative and proliferation-resistant nuclear technology"

Introduction

- **22 Participants in INPRO (December 2004):**
  - Argentina, Armenia, Brazil, Bulgaria, Canada, Chile, China, Czech Republic, France, Germany, India, Indonesia, Morocco, Republic of Korea, Pakistan, Russia, South Africa, Spain, Switzerland, The Netherlands, Turkey and the European Commission.
  - Number of participants is growing
- **Several Observers in INPRO** (e.g. Australia, Belgium, Croatia, Egypt, Japan, UK, USA, OECD/NEA, etc.)

General Objectives of INPRO

- INPRO General Objectives:
  1. To help to ensure that nuclear energy is available to contribute in fulfilling energy needs in the 21st century in a sustainable manner.
  2. To bring together both technology holders and technology users to consider jointly the actions required to achieve desired innovations in nuclear reactors and fuel cycles.
- INPRO Time horizon is 50 years into the future.

INPRO Mission

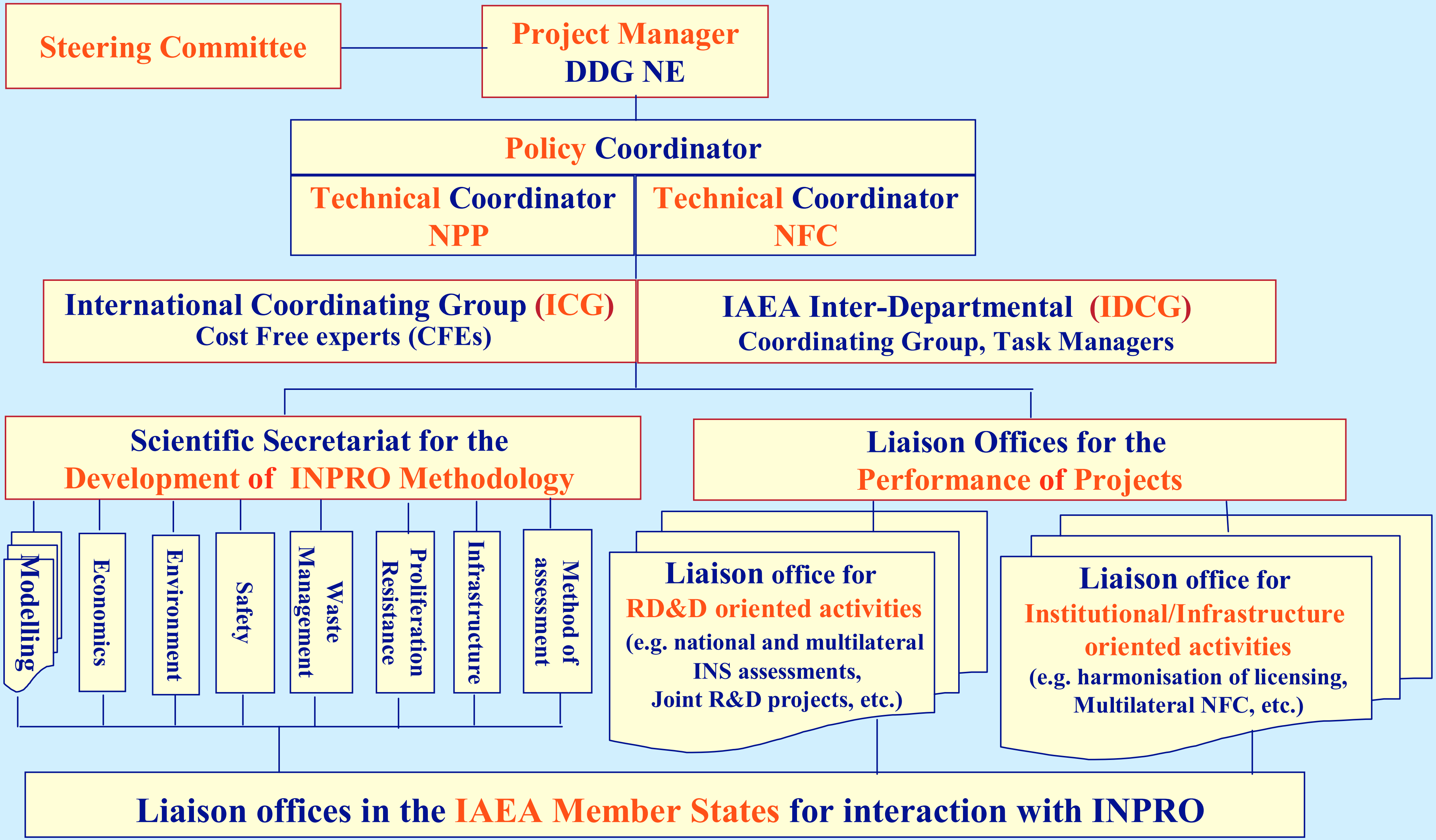
- ✓ To provide a forum for discussion of experts and policy makers from industrialized and developing countries on all aspects of nuclear energy planning as well as on the development and deployment of innovative nuclear energy systems (INS) in the 21st century.

- ✓ To develop the methodology to analyze INS on a global, regional and national basis and establish it as an internationally acknowledged IAEA tool.

- ✓ To assist in coordinating international cooperation for INS development and deployment.

- ✓ To pay particular attention to the needs of developing countries interested in INS.

INPRO Organizational Chart



UN Concept of Sustainability and INPRO

- History of concept of sustainability
  - Brundtland Report, Agenda 21, Commission on Sustainable Development, WEC, Kyoto Protocol, etc.
- UN concept of sustainability : 4 dimensions
  - Economic: durable growth, financial stability, etc.
  - Environmental: depletion of resources, degradation of environment.
  - Social: equity among groups, stability of cultural systems, safety, proliferation threat, etc.
  - Institutional: legal and policy instruments.
- Energy supply important in all 4 dimensions
  - Development of energy supply needed for sustainable development of world.
  - Development of NE needed for sustainable development of energy supply.
  - INPRO assures that NE is available in sustainable manner.

UN Concept of Sustainability and INPRO

UN General Concept of Sustainable Development
including sustainable development of ENERGY supply

- Economic Dimension
- Environmental Dimension
- Social Dimension
- Institutional Dimension

Sustainable Development of Nuclear Energy via the INPRO Methodology
Assessment with holistic approach

- Economics
- Environment
- Waste Management
- Safety
- Proliferation Resistance
- Infrastructure

- Energy supply is fundamental to sustainable development of the world
- Sustainable energy supply needs significant contribution by NE
- INPRO assures that NE is available in a sustainable manner in the 21st century
- INPRO addresses all dimensions of the UN concept of Sustainability

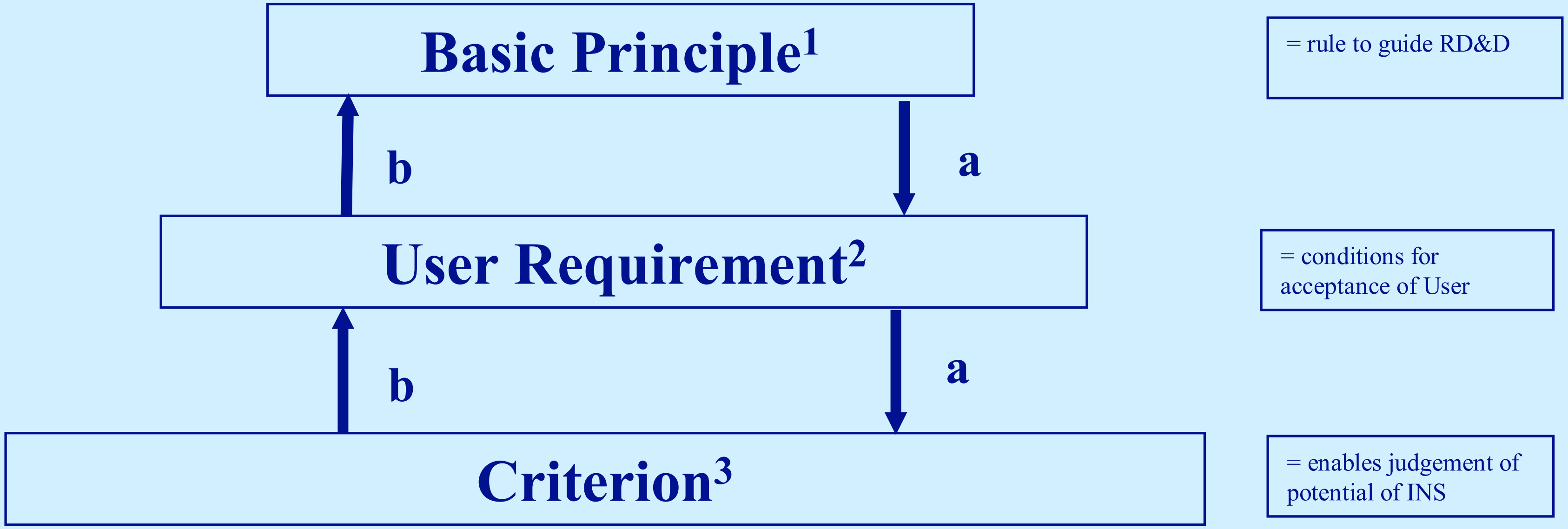
Definition of Selected INPRO Terms

- **Innovative Nuclear Energy System (INS):**
  - INS will position NP to make Major Contribution to Energy Supply in the 21st Century.
  - INS includes Innovative and Evolutionary Designs.
    - Innovative design (= advanced design) incorporating radical conceptual changes in design approaches or system configuration in comparison with existing designs.
    - Evolutionary design (= advanced design) incorporating small to moderate modifications with strong emphasis on maintaining design proveness.
  - INS includes all Components: Mining and Milling, Fuel Production, Enrichment, Fabrication, Production (incl. all types and sizes of reactors), Reprocessing, Materials Management (incl. Transportation and Waste Management), Institutional Measures (e.g. safe guards, etc.).
  - INS includes all Phases (e.g. cradle to grave)

Definition of Selected INPRO Terms

- **Basic Principle**: Statement of a general rule providing guidance for the development of INS.
- **User Requirement**: Conditions to be met to achieve acceptance of INS by User. Definition of measures to fulfill Basic Principle.
- **User**: Has a stake or interest in sectors where INS are applicable, e.g. designers, utilities (electricity, heating, desalination, etc.), regulators, national governments, NGO, press, international organizations and public. Includes countries in development and transition.
- **Criterion:** Consists of an Indicator and an Acceptance Limit. Used for Judgement of Potential of INS to fulfil the corresponding User Requirement.

Definition of Selected INPRO Terms



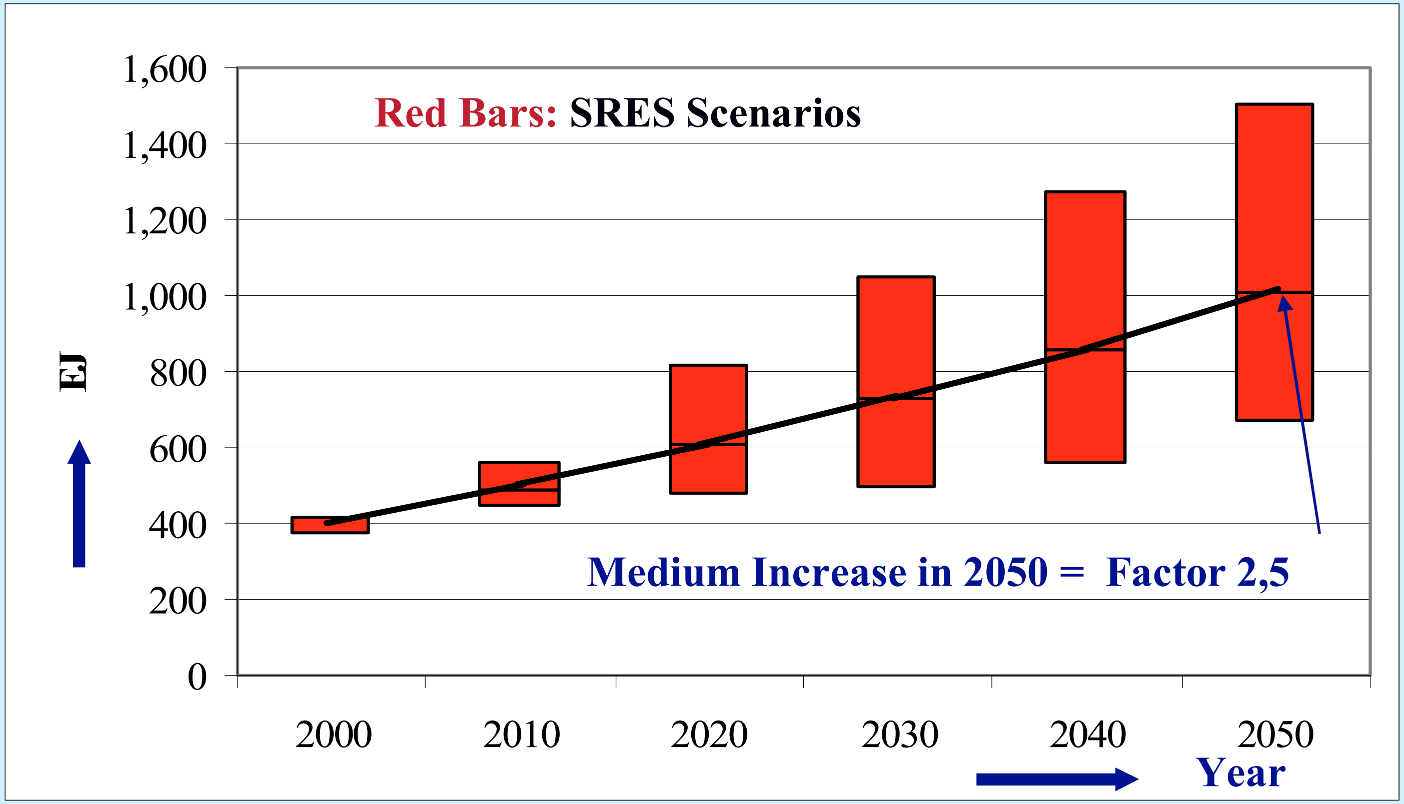
a = Derivation of hierarchy
b = Fulfilment of hierarchy

1 ~ Goal in GIF
2 ~ Criteria in GIF
3 ~ Metrics in GIF

INPRO Hierarchy of Demands on Innovative Nuclear Energy Systems (INS)

Results of INPRO in the Area Economics

SRES = Special Report on Emission Scenarios of the Intergovernmental Panel on Climate Change (IPCC)

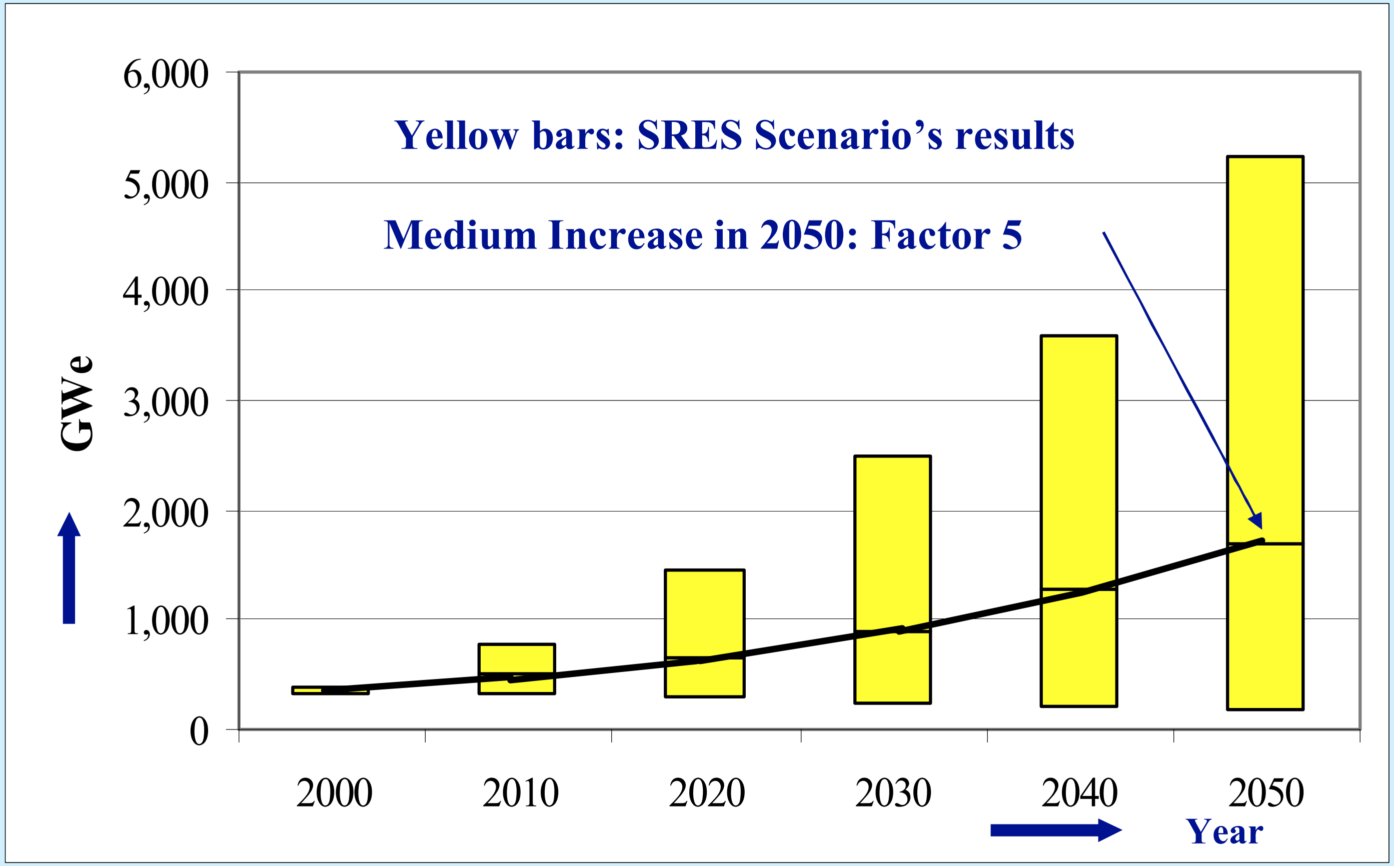


Projected **World Primary Energy** Demand (EJ)

(Source: Intergovernmental Panel on Climate Change, IPCC2000)

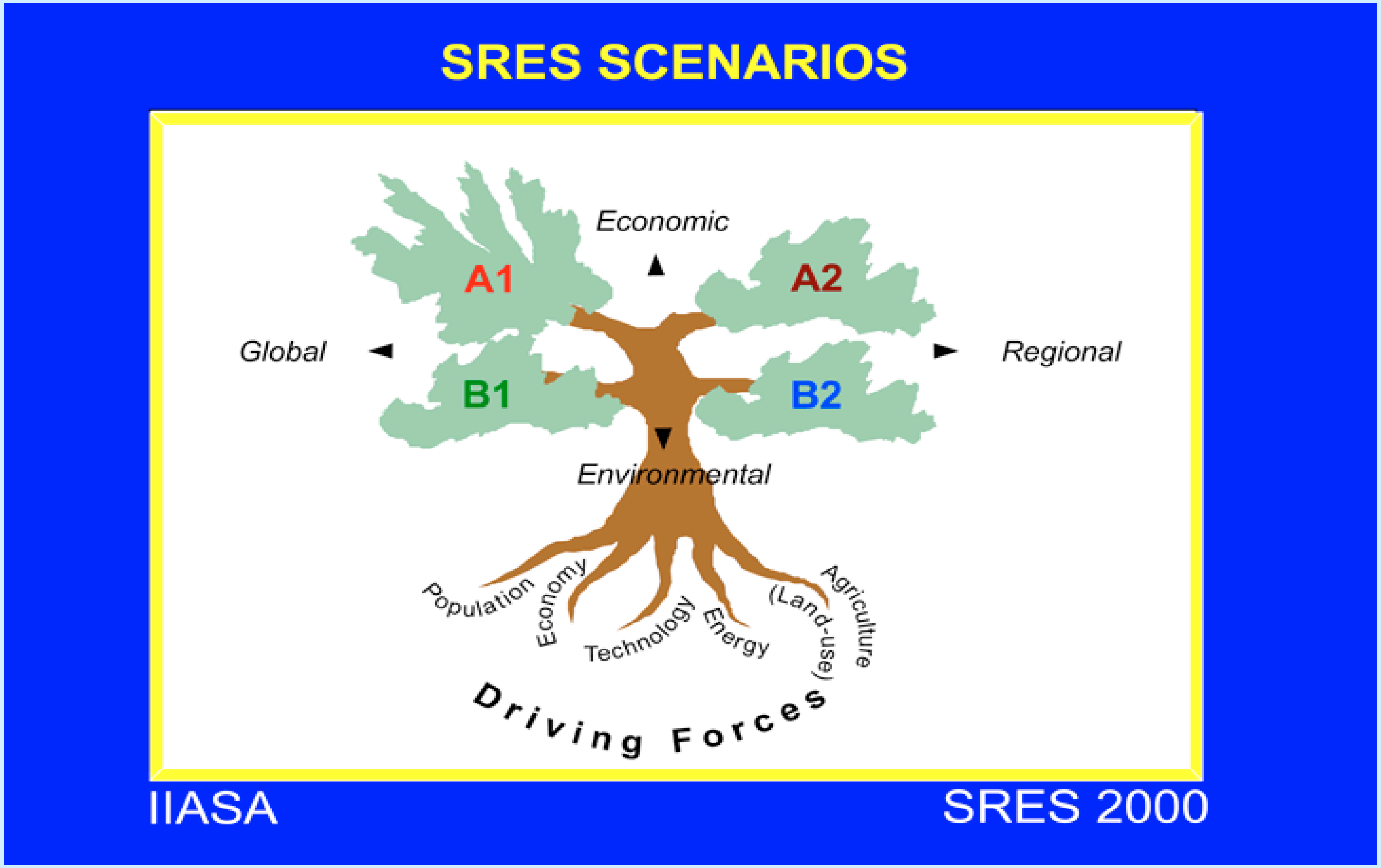
Results of INPRO in the Area Economics

SRES = Special Report on Emission Scenarios of the Intergovernmental Panel on Climate Change (IPCC)



World **Nuclear Electricity** Production (GWe)
(IPCC)

Results of INPRO in the Area Economics

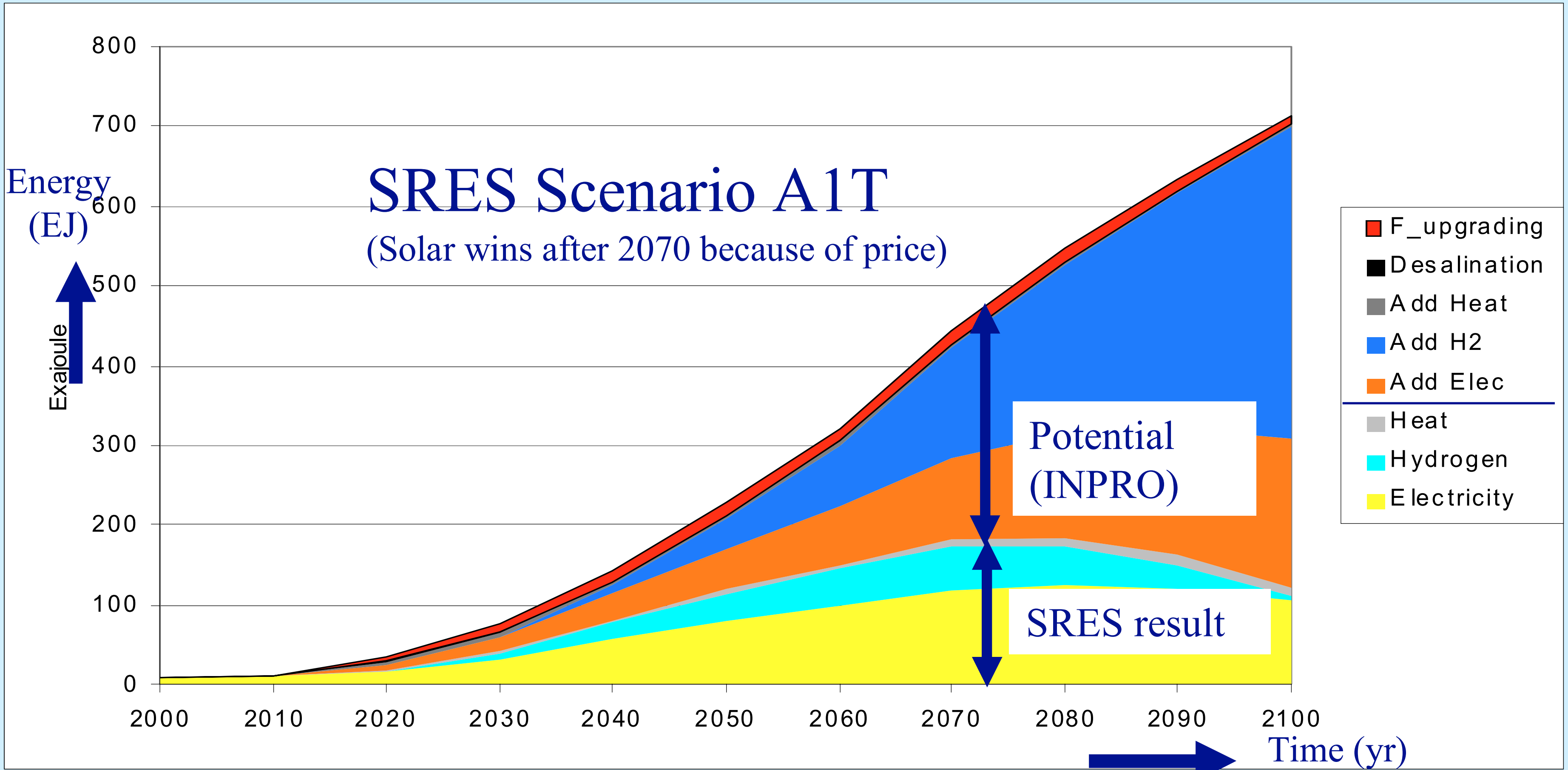


SRES = Special Report on Emission Scenarios of the Intergovernmental Panel on Climate Change (IPCC)

IIASA = International Institute for Applied System Analysis

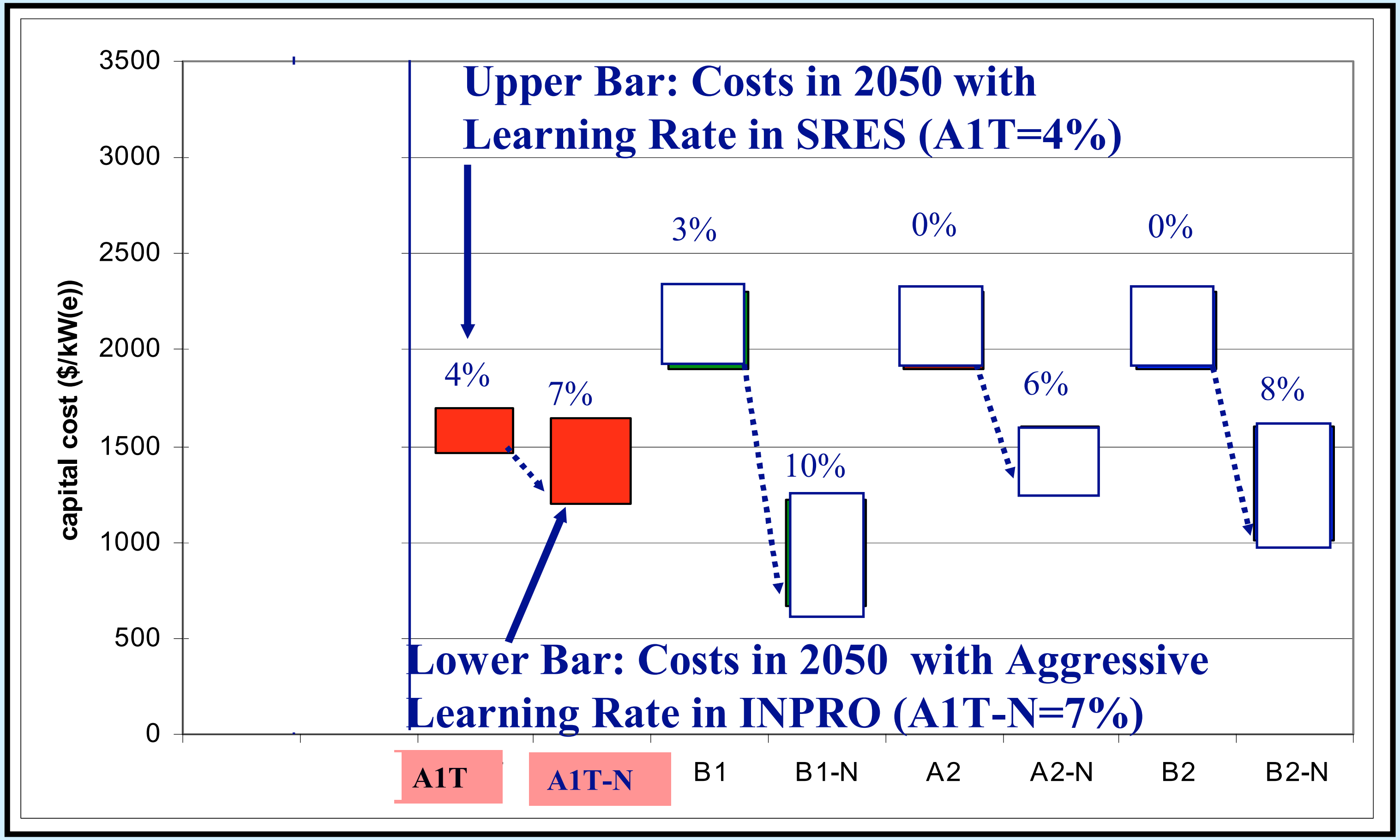
➡ INPRO: Selection of **4 Representative Scenarios** of the Future out of 40

Results of INPRO in the Area Economics



Potential Global Market for Nuclear Electricity, Hydrogen, Heat and Desalination for A1T Scenario with decreased costs

Results of INPRO in the Area Economics



Specific Capital Costs for NPP in 2050 (SRES and INPRO)

Results of INPRO in the Area Economics

- **One Basic Principle defined:**
  - ***Energy and related products and services from INS shall be affordable and available.***
- **Affordable** nuclear energy (NE) means: **costs** must be **competitive to alternative** energy sources
- **Available** NE means: **Investment** in NE must be **attractive**.
- **Four User Requirements and Several Criteria defined**

Results of INPRO in the Area Economics

Economic Basic Principle BP1 – ***Energy and related products and services from INS shall be affordable and available***

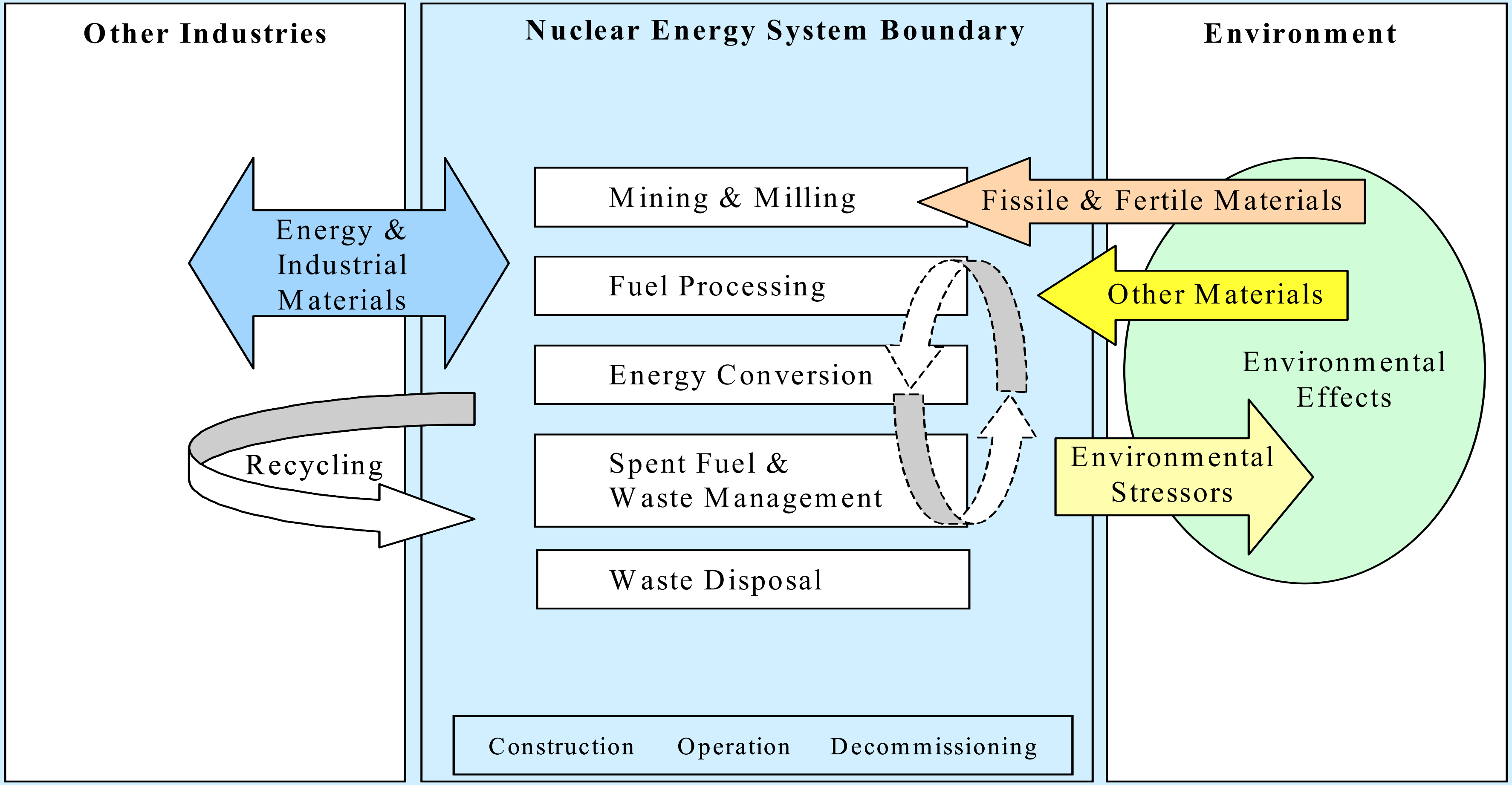
Requirements	Criterion	
	Indicator	Acceptance Limit
UR1.1 ***The cost of energy from INS, taking all relevant costs and credits into account, C_N, should be competitive with that of alternative energy sources, C_A. in the same time frame and geographic region.***	**Cost of nuclear energy, C_N** **Cost of alternative energy, C_A**	$C_N < k . C_A$

Results of INPRO in the Area Economics

<u>Economic Basic Principle BP1</u> – ***Energy and related products and services from INS shall be affordable and available***

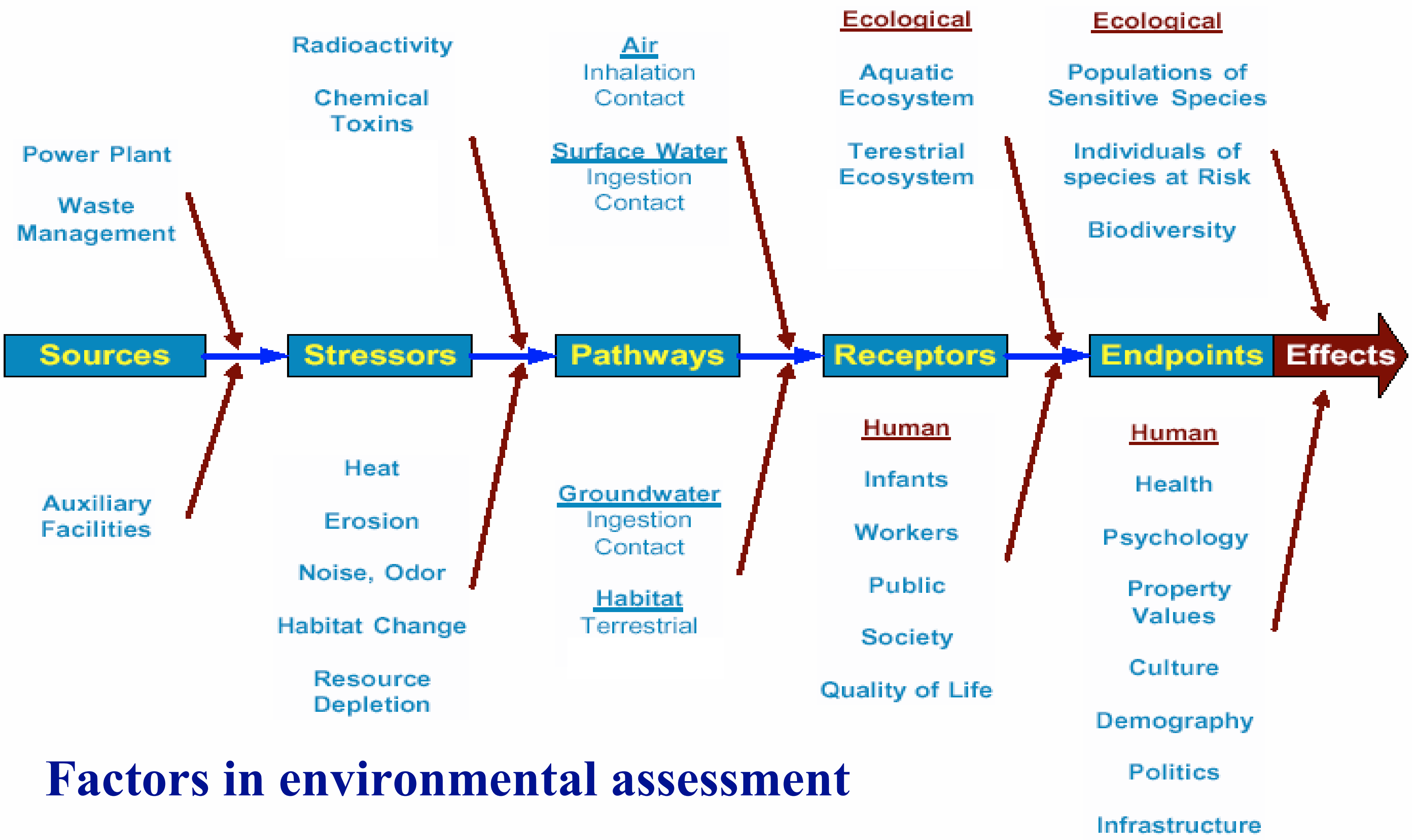
User Requirements	Criteria	
	Indicators	Acceptance Limits
UR1.2 The total investment required to design, construct, and commission innovative nuclear energy systems, including interest during construction, should be such that the necessary investment funds can be raised.	**Financial figures of merit.** (ROI, NPV, IRR, etc.)	**Figures of merit are comparable with or better than those for competing energy technologies of comparable size**
	Total investment.	**The total investment required should be compatible with the ability to raise capital in a given market climate**

Results of INPRO in the Area Environment



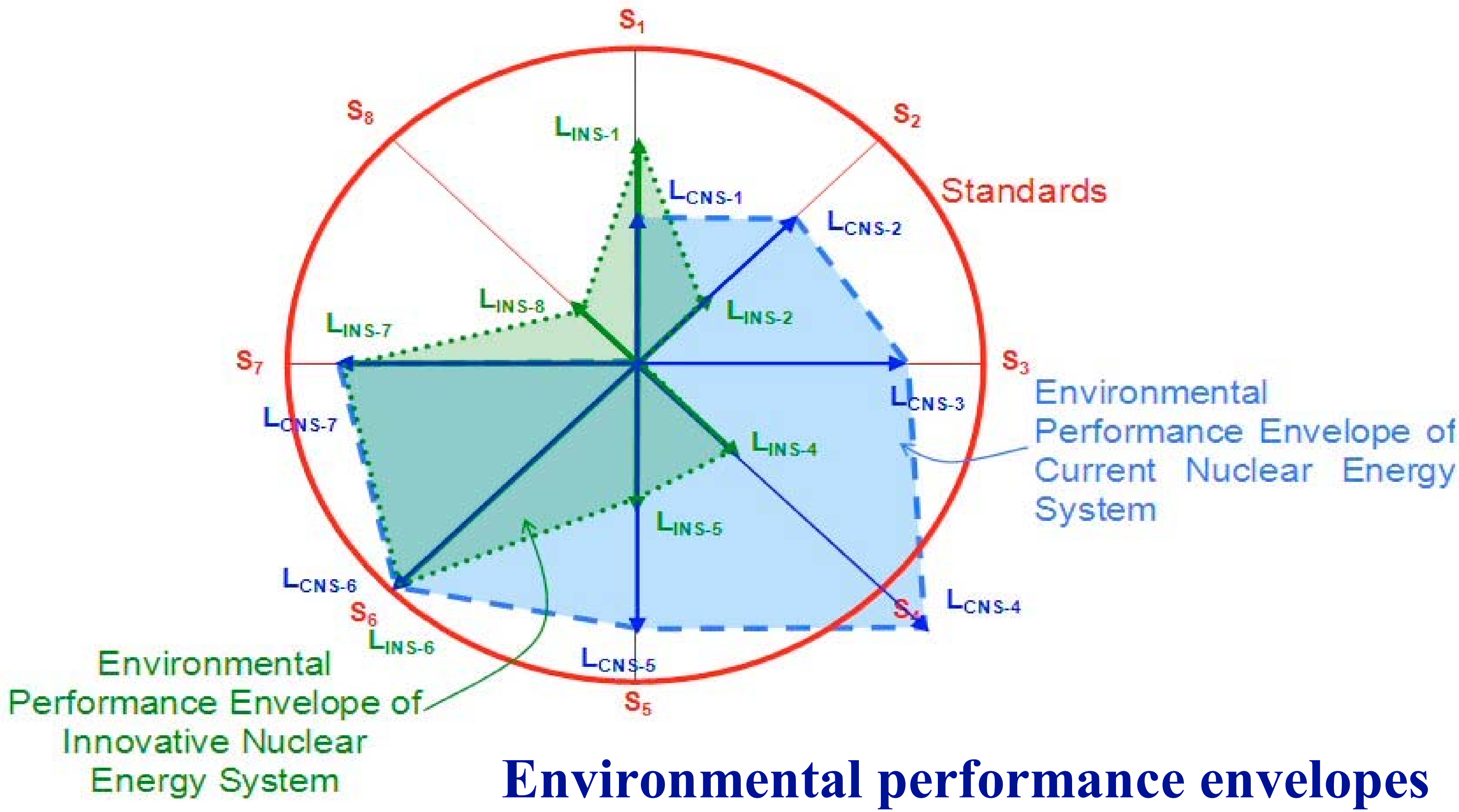
- Holistic Approach for Environmental Assessment

Results of INPRO in the Area Environment



Factors in environmental assessment

Results of INPRO in the Area Environment



Environmental performance envelopes

Results of INPRO in the Area Environment

- **Two Basic Principles defined:**
  1. ***Acceptability of Environmental Effects:***
     - ***The adverse environmental effects of the INS shall be well within the performance envelope of current nuclear energy systems delivering similar energy products.***
  2. ***Fitness for Purpose :***
     - ***The INS shall be capable of contributing to the energy needs in the 21st century while making efficient use of non-renewable resources.***
- **Four User Requirements (UR) and several Criteria for INS defined**
- **Four UR for Assessment Method defined**

Results of INPRO in the Area Environment

Environment Basic Principle No.1: **Acceptability of Environmental Effects** ***The expected (best estimate) adverse environmental effects of the INS shall be well within the performance envelope of current nuclear energy systems delivering similar energy products.***		
User Requirements	**Criteria**	
	Indicators	**Acceptance Limits**
UR1.1 ***The environmental stressors from each part of the INS over the complete life cycle should be controllable to levels meeting or superior to current standards.***	L_{St-i}, **level of stressor *i***	$L_{St-i} \leq S_i$, where S_i is the standard for stressor I
UR1.2 ***The likely adverse environmental effects attributable to the INS should be as low as reasonably practicable, social and economic factors taken into account .***	**Does the INS reflect application of ALARP to limit environmental effects?**	**YES**

Results of INPRO in the Area Environment

Environment Basic Principle 2: Fitness for Purpose
The innovative nuclear energy system shall be capable of contributing to energy needs in the 21st century while making efficient use of non-renewable resources.

User Requirements	Criteria	
	Indicator	Acceptance Limit
UR2.1 *The INS should be able to contribute to the world's energy needs during the 21st century without running out of fissile/fertile material and other non-renewable materials, with account taken of reasonably expected uses of these materials external to the energy system. In addition, the system should make efficient use of non-renewable resources.*	Fj (t) : quantity of fissile/fertile material j available for use in the INS at time t.	$Fj(t) > 0 \ \forall \ t < 100$ years.
	Qi (t) : quantity of material i available for use in the INS at time t.	$Qi(t) > 0 \ \forall \ t < 100$ years.
	P (t): power available (from both internal and external sources) for use in the INS at time t.	$P(t) \geq PINS(t) \ \forall \ t < 100$ years, where PINS(t) is the power required by the INS at time t.
UR2.2 *The energy output of the INS should exceed the energy required to implement and operate the system within an acceptably short period.*	T_{EQ} : time required to match the total energy input with energy output (yrs).	$T_{EQ} \leq k \cdot T_L$ T_L : intended life cycle of nuclear system. $k < 1$

Results of INPRO in the Area Safety of Nuclear Installations

General Nuclear Safety Objective

Fundamental Safety Functions

Nuclear Reactors
- Control Reactivity
- Remove Heat from Core
- Confine Radioactivity and Shield Radiation

Fuel Cycle Installations
- Control Sub-criticality and Chemistry
- Remove Decay Heat from Radio-nuclides
- Confine Radioactivity and Shield Radiation

Deterministic & Probabilistic Safety Analysis (Holistic Life Cycle Analysis)

Defence in Depth
- Prevent abnormal operation and failures
- Control abnormal operation, detect failures
- Control accidents within design basis
- Assure low damage frequencies
- Contain released radioactive materials

Increased Emphasis on Inherent Safety Characteristics

Passive Systems

Balanced design options and configurations

Active Systems

Approach to Development of Basic Principles, User Requirements and Criteria for INS in the Area of Safety

Results of INPRO in the Area Safety of Nuclear Installations

Level of defence-in-depth	INSAG Objectives	Innovation Direction (INPRO)	
1	Prevention of abnormal operation and failures.	Enhance prevention by increased emphasis on inherently safe design characteristics and passive safety features, and by further reducing human actions in the routine operation of the plant	More independence of levels from each other
2	Control of abnormal operation and detection of failures.	Give priority to advanced control and monitoring systems with enhanced reliability, intelligence and the ability to anticipate and compensate abnormal transients.	
3	Control of accidents within the design basis.	Achieve fundamental safety functions by optimised combination of active & passive design features; limit consequences such as fuel failures; minimize reliance on human intervention by increasing grace period, e.g. between several hours and several days.	
4	Control of severe plant conditions, including prevention and mitigation of the consequences of severe accidents.	Increase reliability and capability of systems to control and monitor complex accident sequences; decrease expected frequency of severe plant conditions; e.g. for reactors, reduce severe core damage frequency by at least one order of magnitude relative to existing plants and designs, and even more for urban-sited facilities.	
5	Mitigation of radiological consequences of significant releases of radioactive materials	Avoid the necessity for evacuation or relocation measures outside the plant site.	

Results of INPRO in the Area Safety of Nuclear Installations

- **Four Basic Principles defined:**

  The Innovative Nuclear Reactors and Fuel Cycle Installations shall:

  - ***Incorporate enhanced defense in depth***
  - ***Incorporate increased emphasis on inherent safety and passive features***
  - ***Be so save that they can be sited in locations similar to other industrial facilities used for similar purpose***
  - ***Include associated RD&D***
- **Fourteen User Requirements and Several Criteria defined**

Results of INPRO in the Area Safety of Nuclear Installations

<table>
<tr><td colspan="4"><u>Safety Basic Principle 1:</u> Installations of an INS shall incorporate enhanced defence in depth as a part of their fundamental safety approach and ensure that the levels of protection in defence in depth shall be more independent from each other than in current installations.</td></tr>
<tr><td colspan="2" rowspan="2">User Requirements
(in total seven for BP 1)</td><td colspan="2">Criteria</td></tr>
<tr><td>Indicators</td><td>Acceptance Limits</td></tr>
<tr><td rowspan="3">►</td><td rowspan="3">UR1.1 Installations of an INS should be more robust relative to existing designs regarding system and component failures as well as operation.

(Correlates to Level 1 of Defence in Depth)</td><td>Robustness of design (simplicity, margins).</td><td>Superior to existing designs.</td></tr>
<tr><td>Grace period until human actions are required.</td><td>Superior to existing designs.</td></tr>
<tr><td>Inertia to cope with transients.</td><td>Superior to existing designs.</td></tr>
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Results of INPRO in the Area Safety of Nuclear Installations

Safety Basic Principle 1: *Installations of an INS shall incorporate enhanced defence-in-depth as a part of their fundamental safety approach and ensure that the levels of protection in defence-in-depth shall be more independent from each other than in current installations*

User Requirement	Criteria	
	Indicators	Acceptance Limit
UR1.5 ***The innovative nuclear reactors and fuel cycle installations should not need relocation or evacuation measures outside the plant site, apart from those generic emergency measures developed for any industrial facility used for similar purpose.*** ***(Correlates to level 5 of DID)***	Calculated frequency of large release of radioactive materials to the environment.	$<10^{-6}$ per plant$_*$year, or excluded by design.

Results of INPRO in the Area Safety of Nuclear Installations

Safety Basic Principle 2: ***Installations of an INS shall excel in safety and reliability by incorporating into their designs, when appropriate, increased emphasis on inherently safe characteristics and passive systems as a part of their fundamental safety approach.***

User Requirements	Criteria	
	Indicators	**Acceptance Limits**
UR2.1 ***INS should strive for elimination or minimization of some hazards relative to existing plants by incorporating inherently safe characteristics and/or passive systems, when appropriate.***	**Sample indicators: Stored energy, flammability, criticality, inventory of radioactive materials, available excess reactivity, reactivity feedback.**	**Superior to existing designs.**
	Expected frequency of abnormal operation and accidents.	**Lower frequencies compared to existing facilities.**

Results of INPRO in the Area Waste Management

- Four Basic Principles (derived from IAEA Safety Series No. 111-F)
  - *Minimize waste generation*
  - *Secure acceptable level of protection for human health and the environment*
  - *Avoid undue burdens on future generations*
  - *Consider all interdependencies among all steps of waste generation to optimize safety*
- Seven User Requirements and Several Criteria defined by INPRO

Results of INPRO in the Area Waste Management

Waste management Basic Principle BP1: Waste minimization
Generation of radioactive waste in an INS shall be kept to the minimum practicable

User Requirement	Criteria	
	Indicators	Acceptance Limits
UR1.1 Reduction of Waste at the Source: *The INS should be designed to minimize the generation of wastes and particularly wastes containing long-lived toxic components that would be mobile in a repository environment.*	Alpha-emitters and other long-lived radionuclides per GWa	ALARP
	Total activity per GWa	ALARP
	Mass per GWa	ALARP
	Volume per GWa	ALARP
	Chemically toxic elements that would become part of the radioactive waste per GWa	ALARP(as low as reasonable practical, social and economic factors taken into account)

Results of INPRO in the Area Waste Management

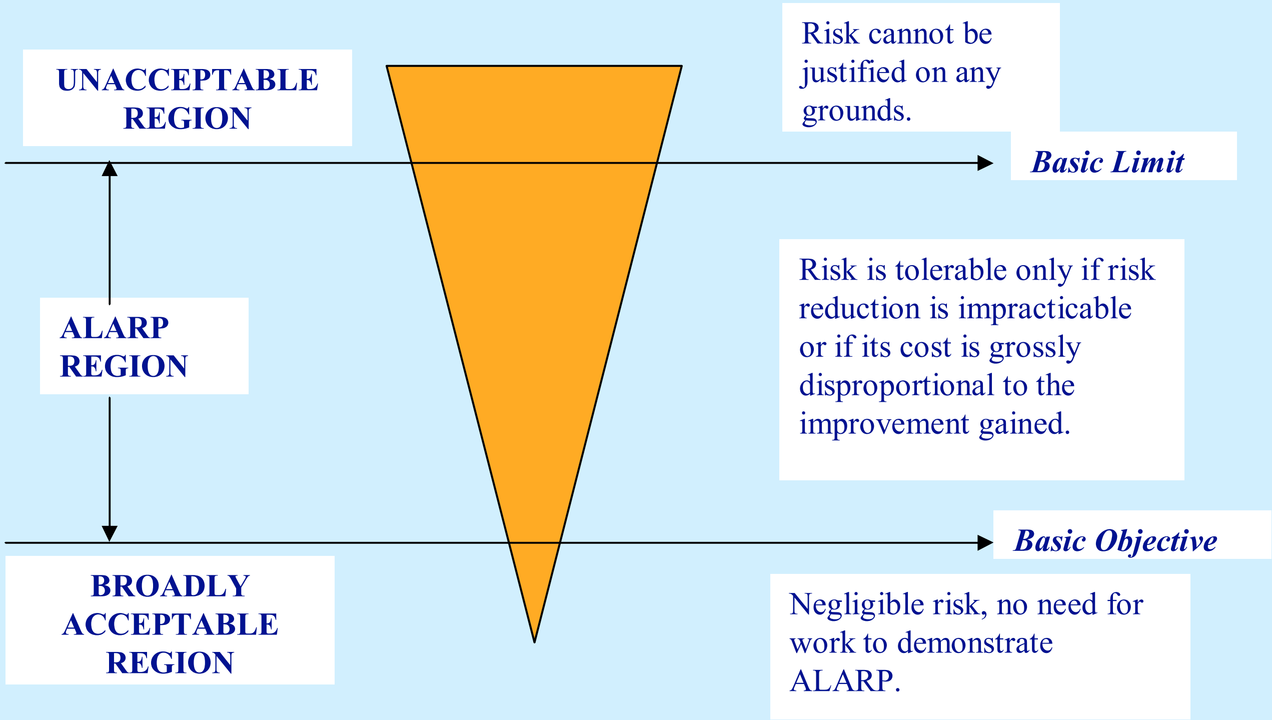


Illustration of the concept of ALARP.

Results of INPRO in the Area Waste Management

- Examples of methods to reduce waste:
  - Segregation of waste streams
  - Recycling and reuse of materials
  - Optimizing the design to facilitate decommissioning and dismantling
  - Extraction of long-lived decay products in mining and milling
  - Reduction of secondary waste

Results of INPRO in the Area Waste Management

- Technologies worthy of consideration for further development include:
  - Use of non-aqueous methods of processing spent fuel;
  - Improvement of existing aqueous methods of processing spent fuel;
  - Partition and transmutation (P&T);
  - Application of advanced materials, such as cobalt-free steels, to reduce activation;
  - Improved fuel cycle efficiency;
  - Improved efficiency of reactors; and
  - Improved decontamination technology.

Results of INPRO in the Area Waste Management

Waste management Basic Principle BP2: Protection of human health and the environment *Radioactive waste in an INS shall be managed in such a way as to secure an acceptable level of protection for human health and the environment, regardless of the time or place at which impacts may occur.*		
User Requirements	**Criteria**	
	Indicators	**Acceptance Limits**
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 optimised.***	**2.1.1 Estimated dose rate to an individual of the critical group** **2.1.2 Radiological exposure of workers** **2.1.3 Estimated concentrations of chemical toxins in working areas**	**2.1.1 Meets regulatory standards of specific Member State.** 2.1.2 Meets regulatory standards of specific Member State. 2.1.3 Meet regulatory standards of specific Member State.
UR2.2: (Protection of the Environment) ***The cumulative releases of radio-nuclides and chemical toxins from waste management components of the INS should be optimised.***	**Estimated releases of radio-nuclides and chemical toxins from waste management facilities**	Meet regulatory standards of specific Member State.

Results of INPRO in the Area Waste Management

Waste Management Basic Principle BP3*:* Burden on future generations

Radioactive waste in an INS shall be managed in such a way that it will not impose undue burdens on future generations.

User Requirements	Criteria: Indicators	Criteria: Acceptance Limits
UR3.1 (End State): ***An achievable end state should be specified for each class of waste, which provides permanent safety without further modification. The planned energy system should be such that the waste is brought to this end state as soon as reasonably practicable. The end state should be such that any release of hazardous materials to the environment will be below that which is acceptable today.***	**3.1.1 Availability of technology.** **3.1.2.Time required.** **3.1.3 Availability of resources.** **3.1.4 Safety of the end state (long-term expected dose to an individual of the critical group).** **3.1.5 Time to reach the end state.**	**3.1.1 All required technology is currently available or reasonably expected to be available on a schedule compatible with the schedule for introducing the proposed innovative fuel cycle.** **3.1.2 Any time required to bring the technology to the industrial scale must be less than the time specified to achieve the end state.** **3.1.3 Resources (funding, space, capacity, etc.) available for achieving the end state compatible with the size and growth rate of the energy system.** **3.1.4 Meet regulatory standards of specific Member State.** **3.1.5 As short as reasonably practicable.**

Results of INPRO in the Area Waste Management

Waste Management Basic Principle BP4: Waste optimization *Interactions and relationships among all waste generation and management steps shall be accounted for in the design of the INS, such that overall operational and long-term safety is optimized.*		
User Requirements	**Criteria**	
	Indicators	**Acceptance Limits**
UR4.1 (Waste Classification): *The radioactive waste arising from the INS should be classified to facilitate waste management in all parts of the INS.*	**Classification scheme.**	**The scheme permits unambiguous, practical segregation and measurement of waste arisings.**

Results of INPRO in the Area Waste Management

Waste Management Basic Principle BP4: Waste optimization

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

Results of INPRO in the Area Waste Management

Waste Management Element	RD&D Targets	Expected time for results
Methods of characterizing waste in the nuclear fuel cycle	**Reduce occupational exposure and improve efficiency.** **Facilitate showing compliance with waste acceptance criteria**	Short (<5a)
Waste treatment and conditioning methods	**Reduce radiological impact from storage and disposal of waste** **Decrease the amount of hazardous material requiring disposal.** **Improve the waste forms (chemical durability, mechanical stability, etc.)**	Medium (5 – 10 a)
Reprocessing of spent fuel (inc. partitioning)	**Improve waste stream characteristics** **Reduce secondary waste** **Improve separation of recyclable nuclides**	Medium to Long
Interim Storage Methods	**Increase safety of interim storage**	Short to Medium

Results of INPRO in the Area Proliferation Resistance

- **Definition of Proliferation Resistance**:
  - Characteristics of nuclear energy system that impedes diversion or undeclared production of nuclear material or misuse of technology
- **Intrinsic Features**:
  - Technical design (e.g., core with small reactivity margins)
- **Extrinsic Measures**:
  - Control and verification agreements (e.g., IAEA safeguards)

Results of INPRO in the Area Proliferation Resistance

- Two Basic Principles defined:
  - *Provide proliferation resistant features in INS to minimize the possibilities of misuse of nuclear materials for nuclear weapons.*
  - *Provide balanced combination of of intrinsic and extrinsic measures in INS.*
- Five User Requirements and Several Criteria defined

Results of INPRO in the Area Proliferation Resistance

Basic Principle BP1: *Proliferation resistance features and measures shall be implemented throughout the full life cycle for INS to help ensure that INSs will continue to be an unattractive means to acquire fissile material for a nuclear weapons programme.*		
User Requirements	**Criteria**	
	Indicators	**Acceptance Limits**
UR1.1 ***States' commitments, obligations and policies regarding non-proliferation and disarmament should be adequate.***	**1.1.1 States' commitments, obligations and policies regarding non-proliferation and disarmament.**	**1.1.1 A set of commitments, obligations and policies regarded as acceptable by the international community.**
UR1.2 ***The attractiveness of nuclear material in an INS for a nuclear weapons programme should be low. This includes the attractiveness of undeclared nuclear material that could credibly be produced or processed in the INS.***	**1.1.2 Material Attractiveness.**	**1.1.1 ALARP.**

Results of INPRO in the Area Infrastructure

- **Definition of one Basic Principle:**
  - ***Regional and international arrangements shall provide options that enable any country that so wishes to adopt INS for the supply of energy and related products without making an excessive investment in national infrastructure.***
- **Definition of 4 User Requirements and several Recommendations to facilitate deployment of NP in the area of :**
  - **Legal and Institutional Infrastructure**
  - **Economic and Industrial Infrastructure**
  - **Socio-Political Infrastructure**

Results of INPRO in the Area Infrastructure

Infrastructure Basic Principle BP1: ***Regional and international arrangements shall provide options that enable any country that so wishes to adopt INS for the supply of energy and related products without making an excessive investment in national infrastructure.***

User Requirements	Criteria	
	Indicators	Acceptance Limits
UR1.1 (Legal and institutional infrastructure): ***Prior to deployment of an INS installation, a national legal framework should be established covering the issues of nuclear liability, safety and radiation protection, control of operation and security, and proliferation resistance.***	**1.1.1 Legal framework established.** **1.1.2. Safety and radiation protection arrangements established.**	**1.11. and 1.1.2. In accordance with international standards.**

Results of INPRO in the Area Infrastructure

- **Recommendations** in the area of **Legal and Institutional Infrastructure**:

  - **License** for INS should be based on INPRO Requirements and **internationally accepted**.
  - **International** or regional nuclear **authorities** and inspection bodies should be established.
  - Handling of **liability and insurance risk** should be **comparable to other industries**.

Results of INPRO in the Area Infrastructure

- **Recommendations** in the area of **Economic and Industrial Infrastructure**:

  - Nuclear components in different countries should be part of an **international multi-component system.**
  - **Market demand,** especially that of **developing countries,** has **to be recognized** by developers of INS.
  - **Supply of full scope**, including management and operation of INS.

Results of INPRO in the Area Infrastructure

- **Recommendations** in the area of **Socio Political Infrastructure**:
  - *Improvement of* ***Public Acceptance*** *via:*
    - ***Demonstration of the response*** *of INS* ***to the concerns*** *about safety, waste and proliferation*
    - ***World wide application of the INPRO Requirements*** *on safety, waste and proliferation.*
    - ***Enhanced Communication*** *between the public and other stakeholders*
- **Recommendation** for **Human Resources and Knowledge**
    - ***Enhance international cooperation***

Tools for Modelling

- Codes to be used for modelling energy scenarios and optimizing INS
  - MESSAGE: Model of energy supply systems and their general environmental impact
  - MAED: model for analysis of energy demand
  - WASP: Wien automatic system planning package
  - ENEP: Energy and power evaluation system
  - FINPLAN: Model for financial analysis of electric sector expansion plans
  - SIMPACTS: simplified approach for estimating impacts of electricity generation
  - DESAE: Optimization of INS
  - SYRTEX: Competitiveness of INS

Tools for modeling

DESAE: Input and Output data

INPUT DATA:

Reactor Types

Reactor Power
(as a function of time)

Costs of:
Fuel;
Operating & Maintenance
Capital,
etc.

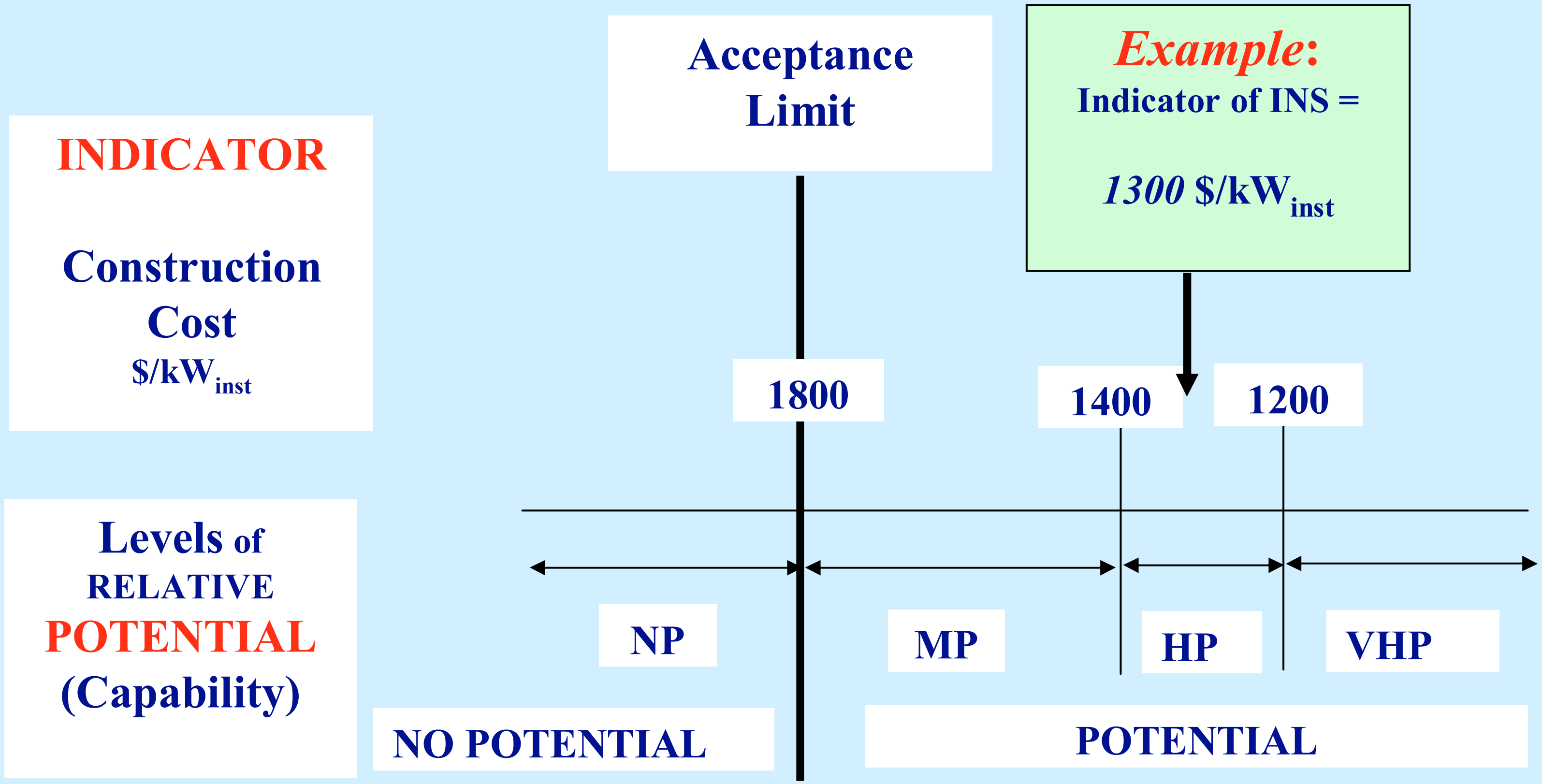
DESAE

MAIN OUTPUT DATA :

Natural parameters:
- **Energy production;**
- **Consumption of natural Uranium;**
- **Spent Fuel;**
- **Quantity of Fissile Isotopes;**
- **Quantity of Recycled Isotopes;**
- **Quantity of Minor actinides;**
- **Activity of Spent Fuel;**
- **Quantity of Critical materials;**
- **Quantity of dangerous materials.**

Economics:
- **Required Investments;**
- **Current price of energy;**
- **Net present value of Investment.**

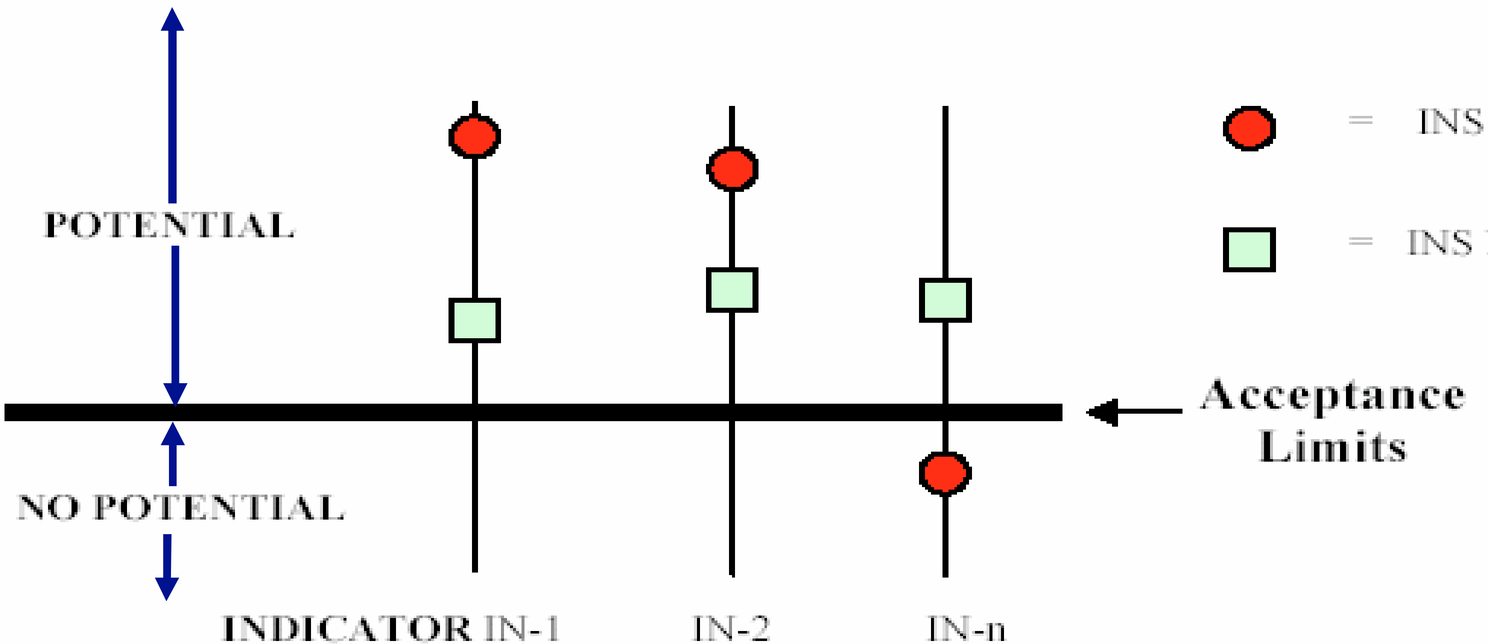
Results of INPRO in the area of method of assessment



Result of assessment (example) of INS against Indicator Construction Cost:

⇨ INS has High Potential (HP) to fulfil this Criterion

Result of INPRO assessment of two INS



INS is superior for Indicator IN-1 and 2, however

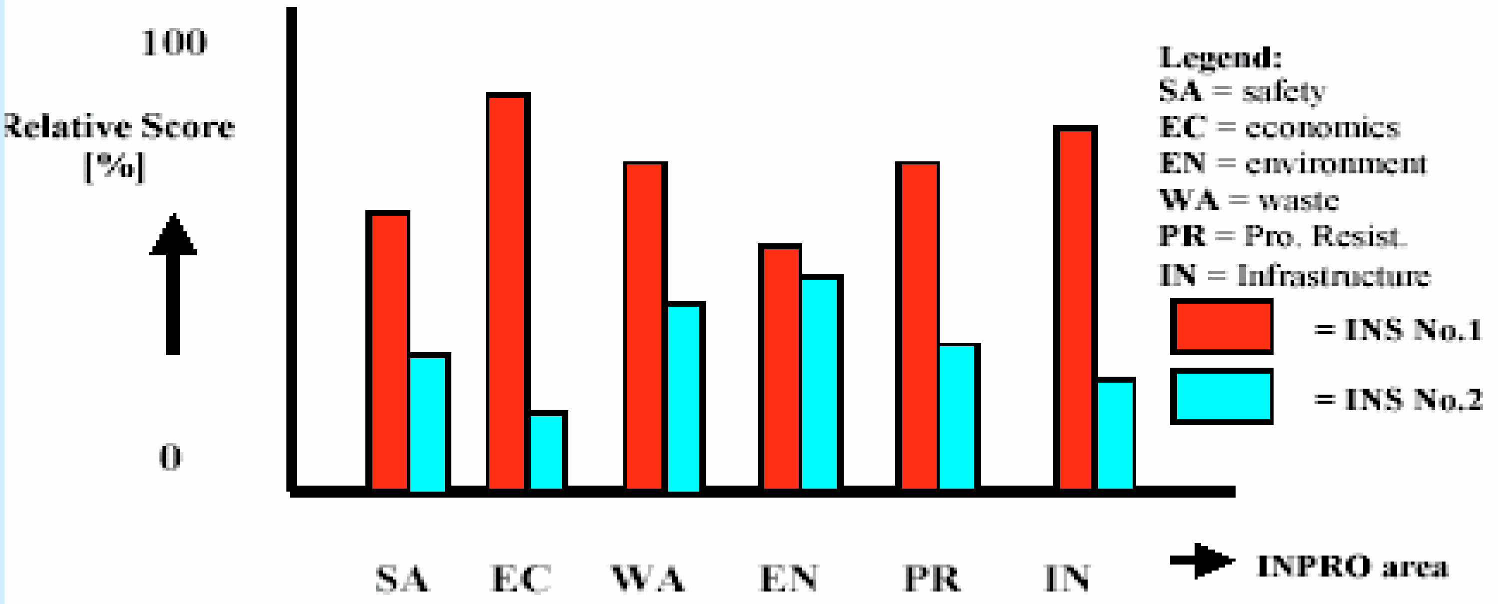
INS No1. is not acceptable (not sustainable) for Indicator IN-n , and needs either different component or RD&D

Treatment of uncertainties in INPRO

Stage of development of an INS (or a component thereof)	Level of Maturity of an INS	Level of Uncertainty of Judgement
No theoretical or experimental evidence exists that any of the Criteria cannot be met by the INS, due to some physical, technological or other limitation, which cannot be overcome by later technology developments.	Pre-Conceptual	Very High
Most important (Not all) components of the INS have been theoretically demonstrated or experimentally verified, and there is theoretical evidence that this INS could meet all the Criteria.	Conceptual Feasibility Established	High
All components of the INS have been theoretically demonstrated and, where necessary, experimentally verified and meet the Criteria.	Feasibility Demonstrated	Moderate
All components of the INS have been designed in enough detail to prepare a bid. If needed, a Pilot Plant (reduced size) was built and is operating successfully.	Developed and Demonstrated	Low
First of a kind plant (full size) built and operating.	Commercially Proven	Lower
Series of plants built and operated.	Full Commercial Exploitation	Lowest

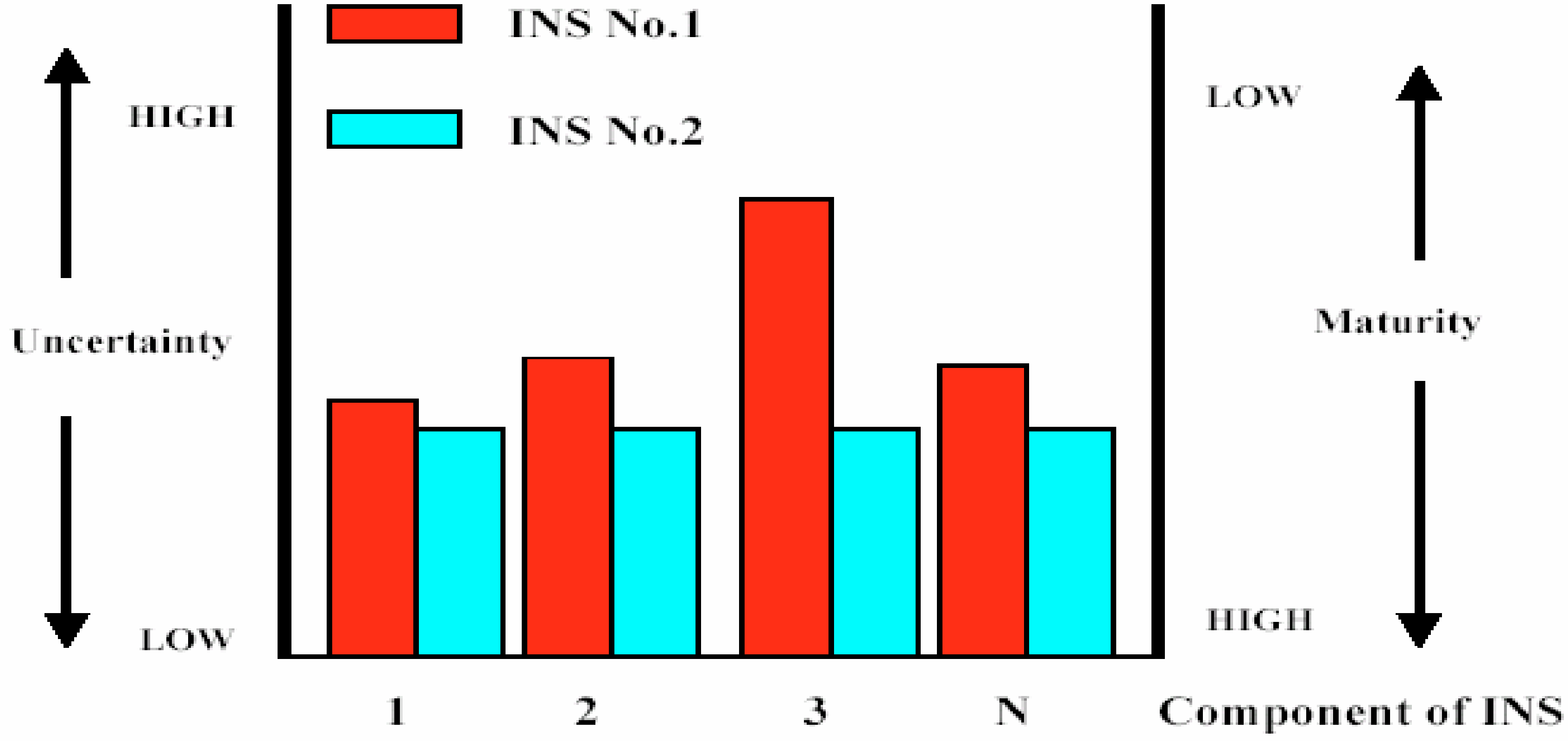
Comparison of two INS regarding their capability/potential

INS No.1 has higher capabilities

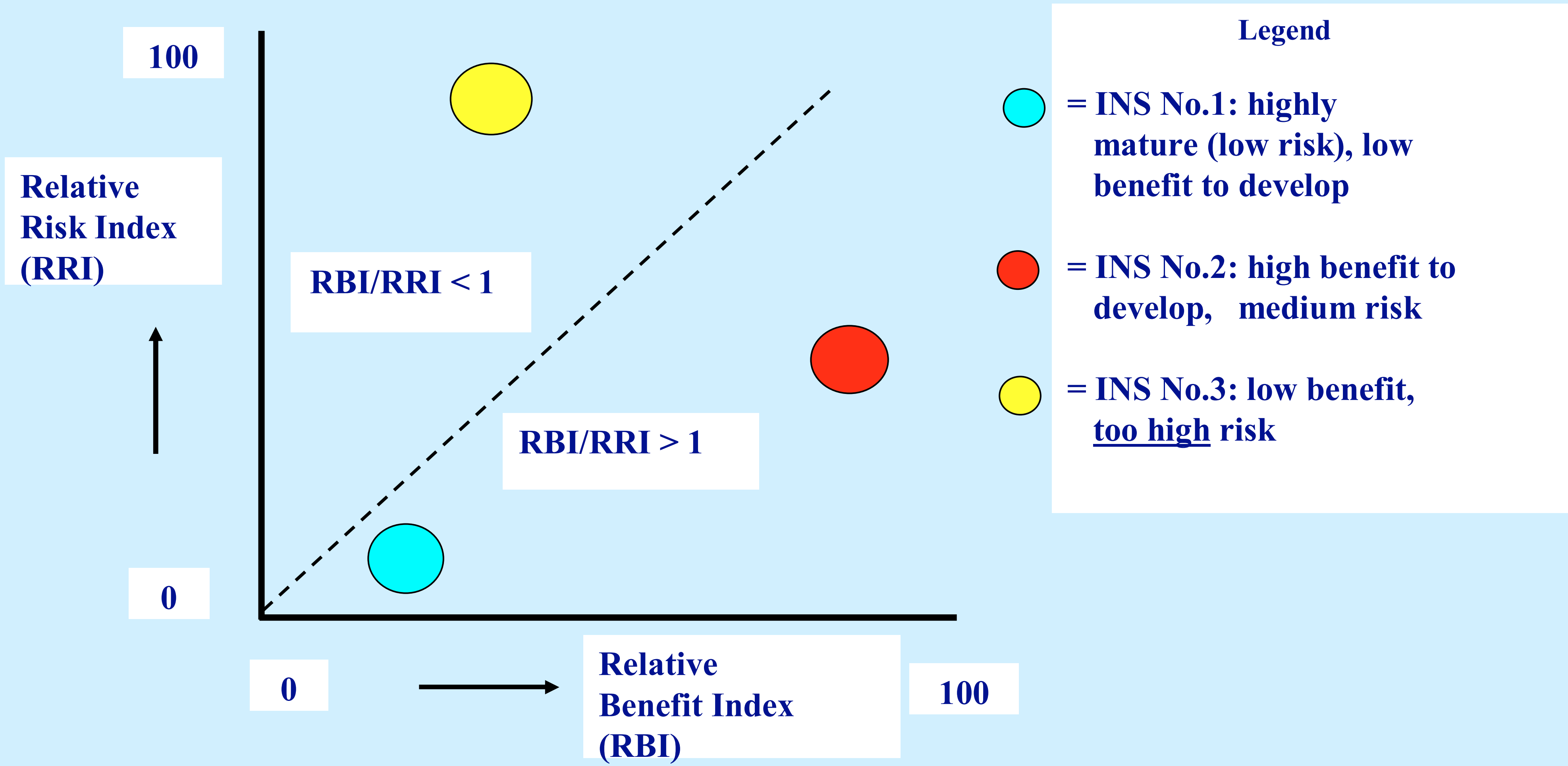


Comparison of two INS regarding Uncertainty/Maturity

INS No.1 has higher Uncertainty because of lower Maturity



Relative index of benefit and risk of RD&D



INPRO Schedule

Initiation

(in response to GC Res. 2000)

Phase 1A

(Methodology Development)

Phase 1B (1st part)

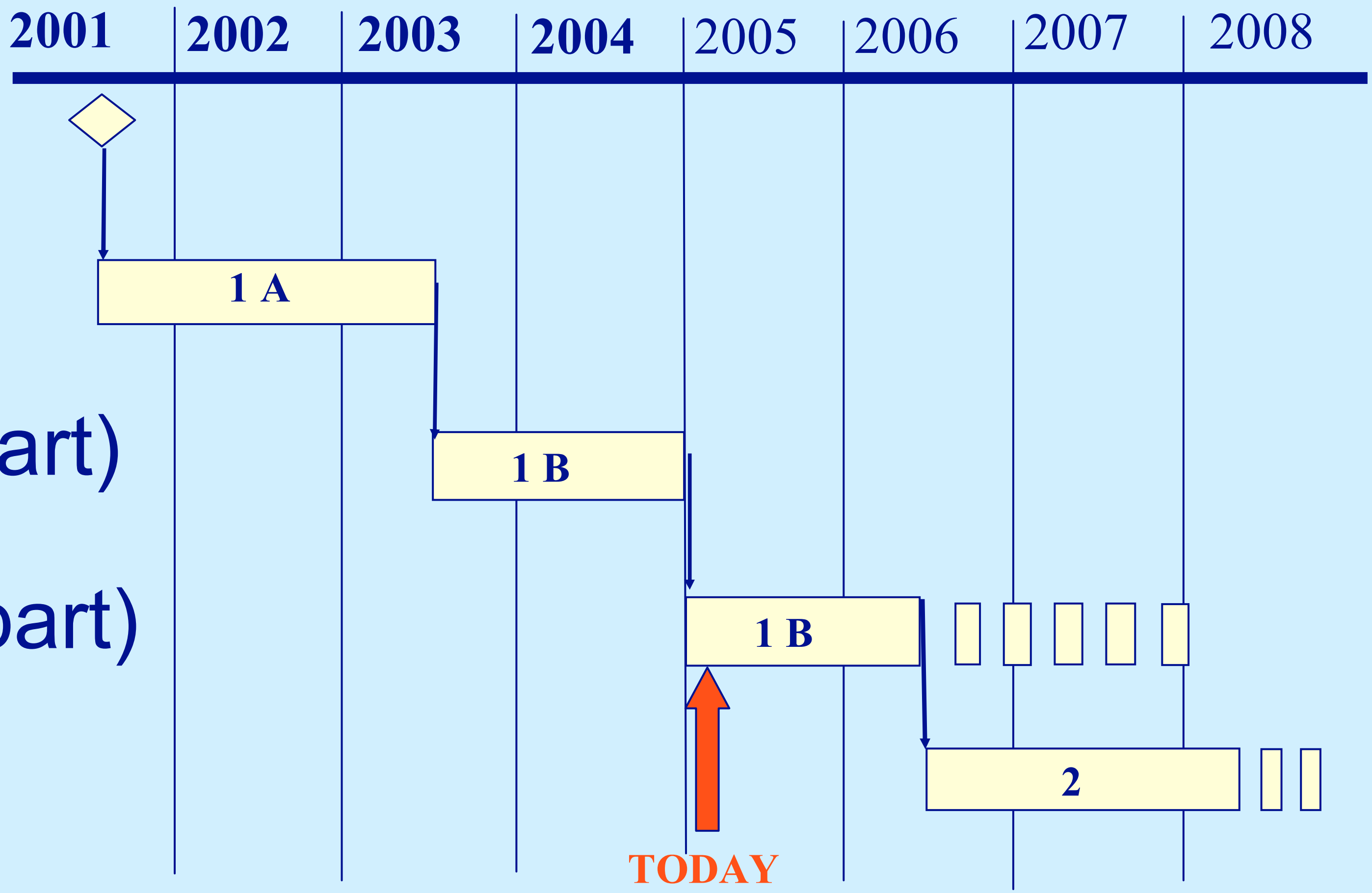
(Methodology Validation)

Phase 1B (2nd part)

(Methodology Application)

Phase 2

(International Cooperation)



Conclusion of Phase 1A

- Formulation by INPRO in Phase 1A of Basic Principles, User Requirements and Criteria for Assessment of INS in all Areas (Economics, Environment, Safety, Waste Management, proliferation Resistance) and Recommendations in Cross Cutting Issues
- Documentation of Results of Phase 1A in an IAEA report (TECDOC-1362, Guidance for the evaluation of innovative nuclear reactors and fuel cycles) in June 2003.

Conclusion of Phase 1B (1st part)

- INPRO Phase 1B (1st part) started in July 2003: Testing/Validation of INPRO Methodology via
  - 6 National Case Studies performed by Member States:
    - Argentina with CAREM-X (integrated small PWR),
    - India with AHWR (advanced heavy water reactor),
    - Korea with DUPIC (PWR fuel into HWR),
    - Russia with BN family (fast sodium cooled reactor)
    - China with PBR (small pebble bed reactor)
    - Czech Republic with Molten Salt Reactor
  - Consultancies with industry and regulators

Conclusion of Phase 1B (1st part)

- 8 Individual Case Studies performed by experts :
  - Russia (International fuel center, SMR, ADS/fusion/renewables, Hydrogen/ desalination, Modeling DESAE code)
  - India (International fuel center)
  - France (FBR)
  - Argentina (autonomous fuel cycle)
- INPRO Methodology updated based on results of case studies and consultancies
- New TECDOC-1434 (Methodology for the assessment of innovative nuclear reactors and fuel cycles) published in December 2004

Ongoing and Planned Activities in Phase 1B (2nd part)

INPRO Phase 1B (2nd part), starting 2005

- Performance of Assessments of complete innovative nuclear energy systems (INS) by MS.
  - Joint assessment of INS based on closed fuel cycle and fast reactors (China, France, India, Korea, Russia and Japan as observer);
  - Assessment of hydrogen generating INS (India);
  - Study on transition from LWRs to Gen IV fast neutron system (France);
  - Assessment of the introduction of a nuclear bloc of 700 Mwe (Argentina);
  - Assessment of INS for country with small grid (Armenia); and
  - Assessment of whole fuel cycle of DUPIC in the area of PR (Republic of Korea)

Ongoing and Planned Activities in Phase 1B (2nd part)

- Based on feed back from assessments:
  - Completion of the INPRO manual;
  - Creation of data bank on INS data, to be published in IAEA TECDOCS (e.g. small and medium reactors, RD&D, etc.);
  - Continuous Improvement of Methodology; and
  - Definition of scope of joint RD&D for INS development (to be performed in Phase 2)
- Development of modeling tools, e.g. DESAE code.
- Review of options for multilateral nuclear fuel centers.

Planned Activities in INPRO Phase 2

INPRO Phase 2, starting mid 2006

- Research, development and demonstration (RD&D) oriented activities:
  - Facilitation of assessments of INS in MS;
  - Provision of forum for identification and prioritisation of RD&D (as defined in Phase 1B);
  - Assistance in assessing RD&D progress and reorientation; and
  - Preparation of country profiles on RD&D programs.

Planned Activities in INPRO Phase 2

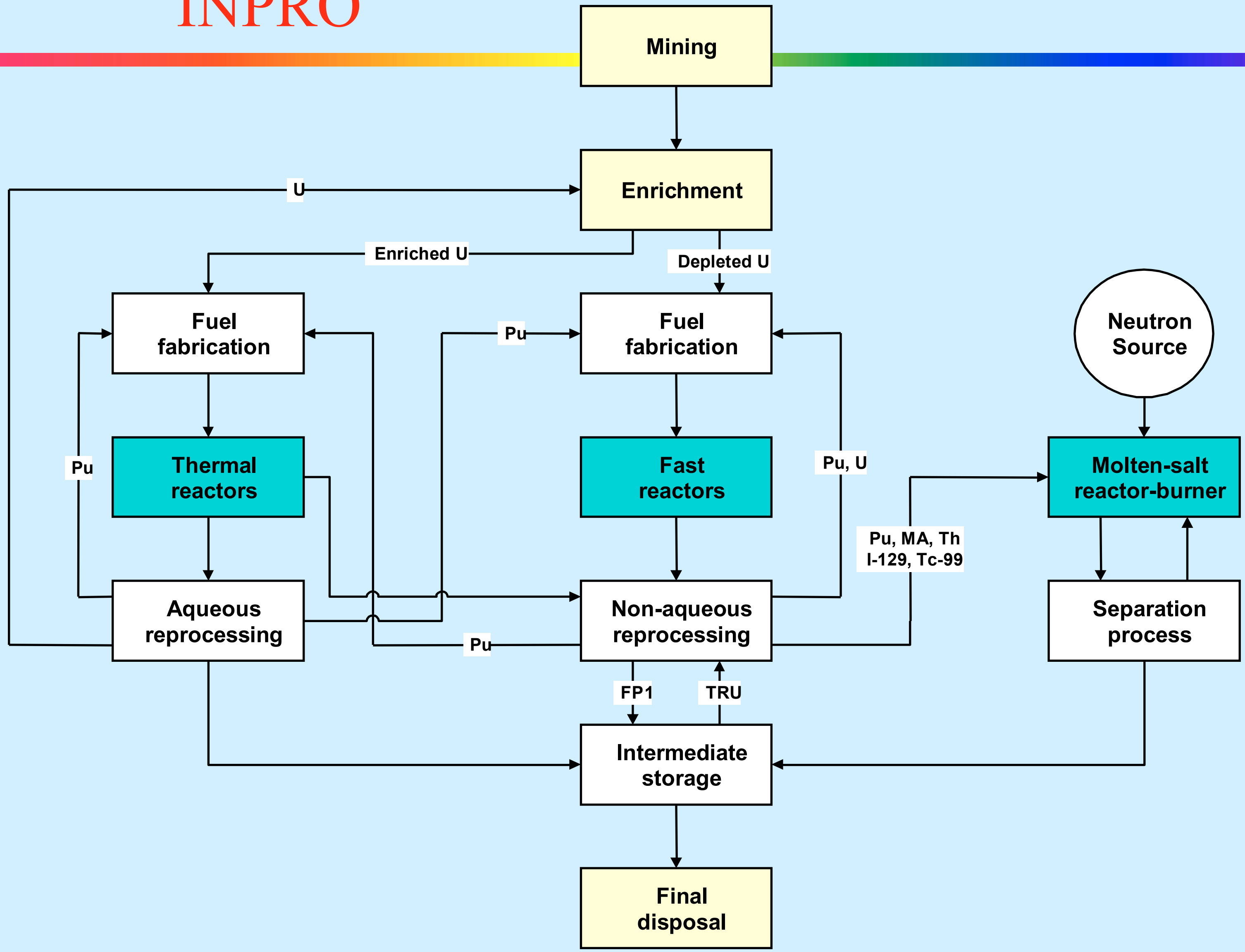
- Institutional/Infrastructure oriented activities
  - Evaluation of potential role of INS for sustainable development;
  - Promotion of use of INS for electricity production and non-nuclear applications;
  - Assistance in harmonization of licensing and of industrial codes and standards;
  - Facilitation of international design certification; and
  - Support of analyses for optimized fuel cycle strategies
- Methodology oriented activities:
  - Continuous Development of INPRO methodology;
  - Refinement of INPRO assessment method.

INPRO today

- An international project with growing membership (22), jointly implemented by the IAEA and INPRO members.
- Of clear interest to MS, including both developed and developing countries.
- Has produced a holistic methodology :
  - to assess capabilities of innovative nuclear energy systems (INSs), and
  - to identify improvements to be achieved via RD&D .
- Creates an important opportunity for cooperative international RD&D on INSs.

BACKUP Slides

INPRO



Example of INS (Russia)

INPRO-GIF Interactions

- Continuous Participation of IAEA in GIF policy and expert groups.
- GIF participation in INPRO SCMs as observer.
- Ongoing discussion by GIF and INPRO secretariat about options of general cooperation.
- Performance of comparison of both assessment. methodologies in January 2004, based on GIF peer review of INPRO Methodology.
- GIF participation in INPRO meetings on Proliferation Resistance.

Objectives of GIF and INPRO

GIF

Objective: Develop nuclear energy systems which :

- are deployable by ~2030;
- offer significant advances in sustainability, safety and reliability,proliferation and physical protection,
- can compete in various markets;
- offer various energy applications: electricity, hydrogen, clean water, and heat.

INPRO

The objective is:

- to help to ensure that nuclear energy is available to contribute, in a sustainable manner, to energy needs in the 21st century.
- to bring together all interested MS, both technology holders and users, to consider jointly actions required to achieve desired innovations in INS ……
- to create a process that involves all relevant stakeholders…..

Targets of GIF and INPRO

GIF

- Definition of innovative reactor systems and fuel to be deployed after 30 years (after 2030).
- Deployment of NE in next 30 years with Generation III systems, to be done by industry + market.
- Definition how to spend government money in R&D, by technology holders. local,
- regional and global

INPRO

- Definition of innovative nuclear energy systems INS to be deployed within next 50 years and beyond.
- Development of such INS suitable for all MS, especially for developing countries.
- Achievement of a sustainable development of nuclear energy primarily

Assessment methodology in GIF and INPRO

GIF	INPRO
- Used for screening of reactor and fuel concepts to select superior designs compared to existing LWR's.	- To be used for finding suitable INS for all interested MS.
- To be used for R&D control	- Holistic view on NE system.
	- Assure sustainability of INS
- Methodology consists of	- Methodology consists of
- 8 goals	- 14 basic principles
- 15 criteria	- 38 user requirements
- 24 metrics	- about 100 criteria

Status of GIF and INPRO

GIF	INPRO
- 6 concepts (reactor + fuel) chosen. - R&D programs to be started. - Multinational cooperation programs for R&D to be established.	- Methodology for assessment defined (Phase 1A). - Methodology tested and validated (Phase 1B, 1st part). - Methodology to be applied to define suitable INS for MS and necessary R&D (Phase 1B, 2nd part). - Multinational R&D programs to be established (Phase 2).

Types of Indicators

- **Real** Indicator: experimentally verified or calculated value reflecting a property of INS,e.g. overnight construction cost
- **Integer** Indicator: number in a list,e.g. number of barriers
- **Logical** Indicator: yes or no, e.g. is level of knowledge adequate?

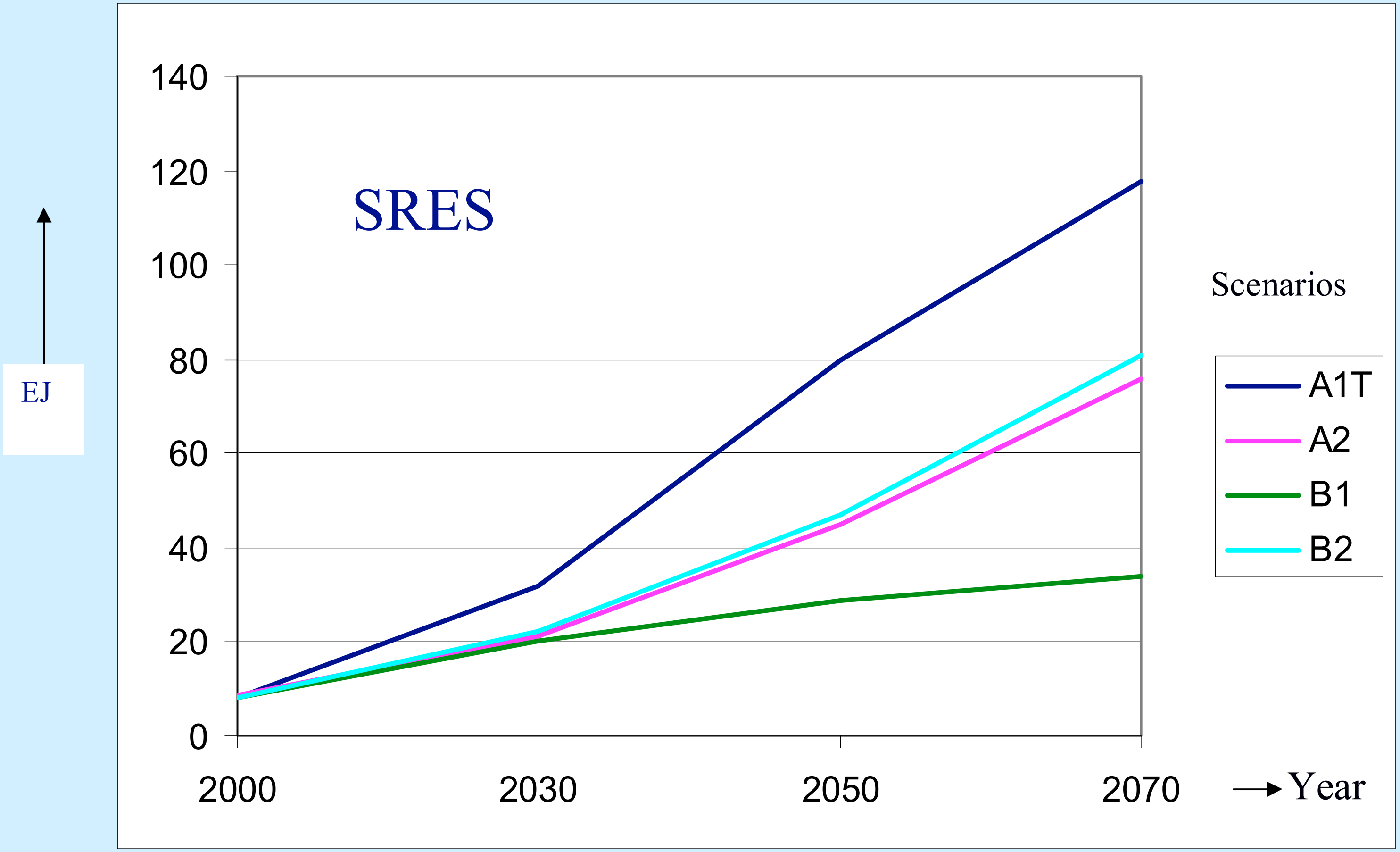
Acceptance Limit (AL)

- Target (qualitative or quantitative) to be compared with value of Indicator
- Comparison leads to judgement :
  - Indicator value of INS on proper side of AL defines: INS has “potential” or capability to fulfil the Criterion
  - Indictor on “bad” side of AL: INS has no “potential’ or capability to fulfil the Criterion

Example of use of methodology

Basic Principles BP	User Requirements UR		Indicators IN		Acceptance Limits AL		INS value of Indicator	Judgement of Potential (capability)	Rationale for judgement
BP1	UR1.1		IN1.1		AL1.1	**AL1.1 by MS**	X1	P	X1<AL1.1
	UR1.n		IN1.n	**IN1.n by MS**	AL1.n	AL1.n by MS	Xn		
BP2	UR2.1		IN2.1		AL2.1		X2	NP	X2>Al2.1
	UR2.n		IN2.n		AL2.n				
BPn	URn.1		INn.1		ALn.1				
	URn.n	**URn. n by MS**	INn.n		ALn.n				

Phase 1A Results of INPRO in the Area Economics

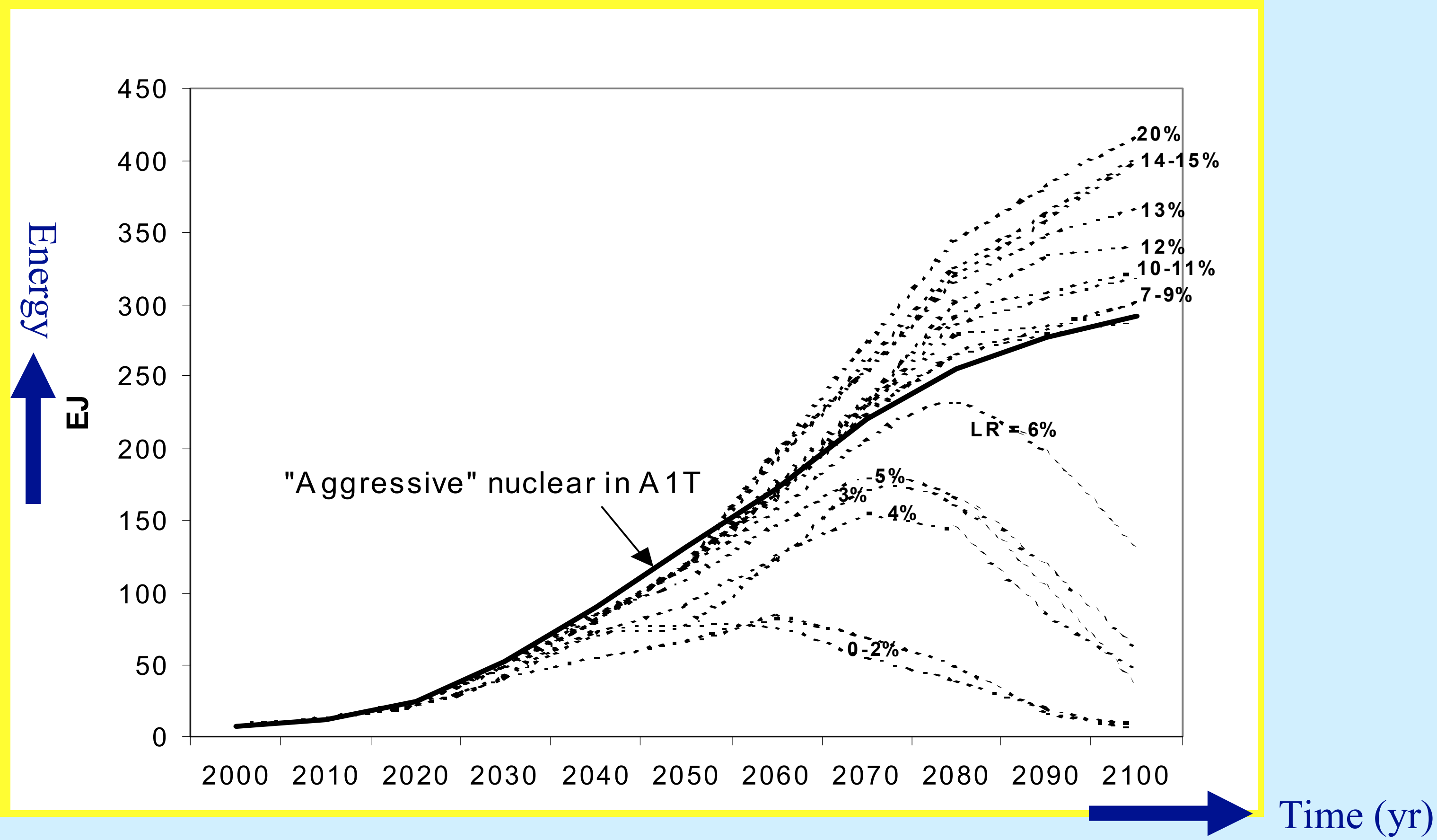


Nuclear electricity production (EJ) for the four selected SRES scenarios

Phase 1A Results of INPRO in the Area Economics

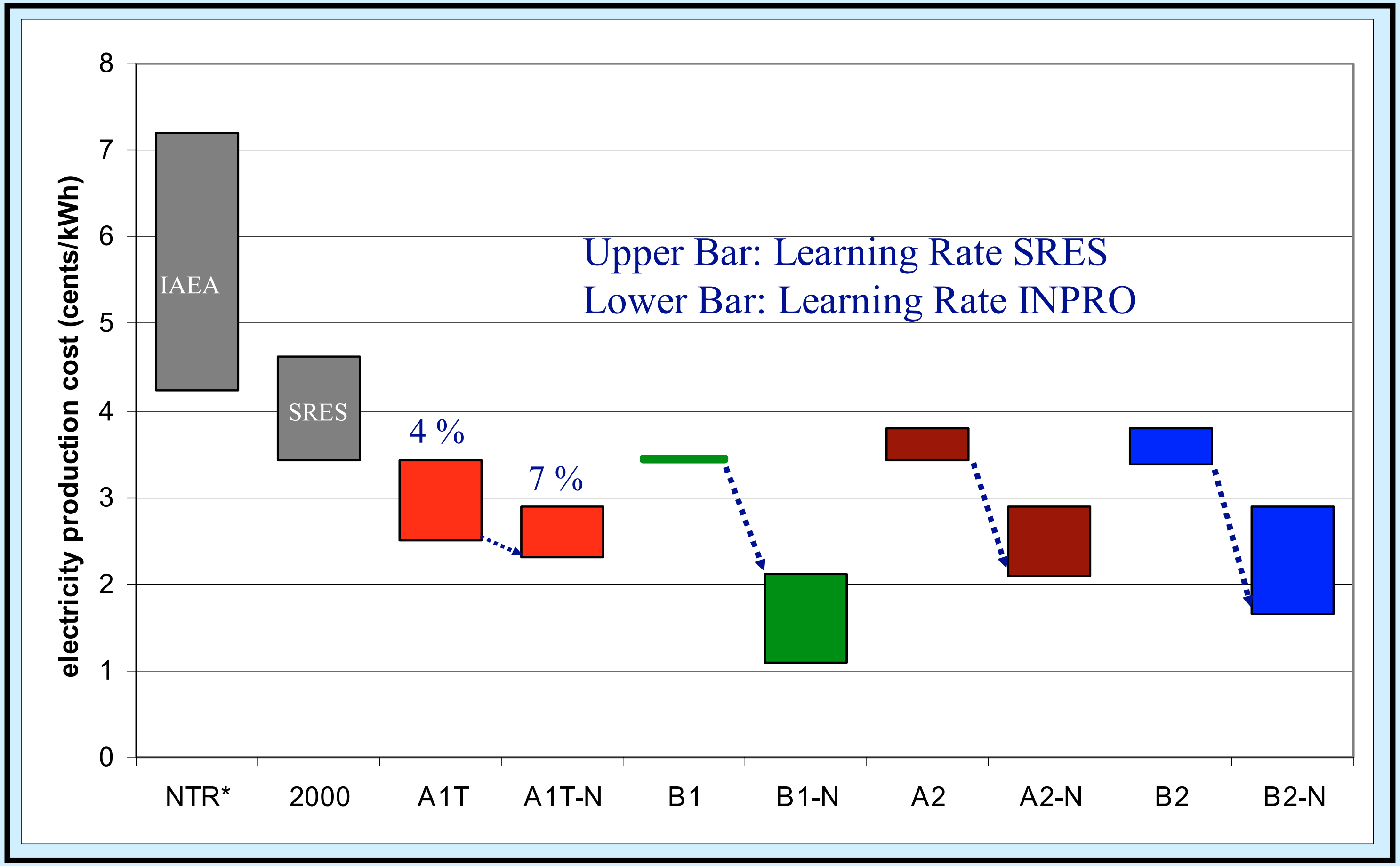
- SRES Predictions for 4 Scenarios:
  - Competition to Nuclear is Dependent on Scenario and Region
  - Main Competitors to Nuclear are:
    - Solar in Scenario A1T,
    - Coal in Scenario A2,
    - Renewables & Solar in Scenario B1,
    - Coal+Gas+Biomass+Solar in Scenario B2

Phase 1A Results of INPRO in the Area Economics



Concept of learning Rates: 7% learning rate for Nuclear necessary to compete against other technologies

Phase 1A Results of INPRO in the Area Economics

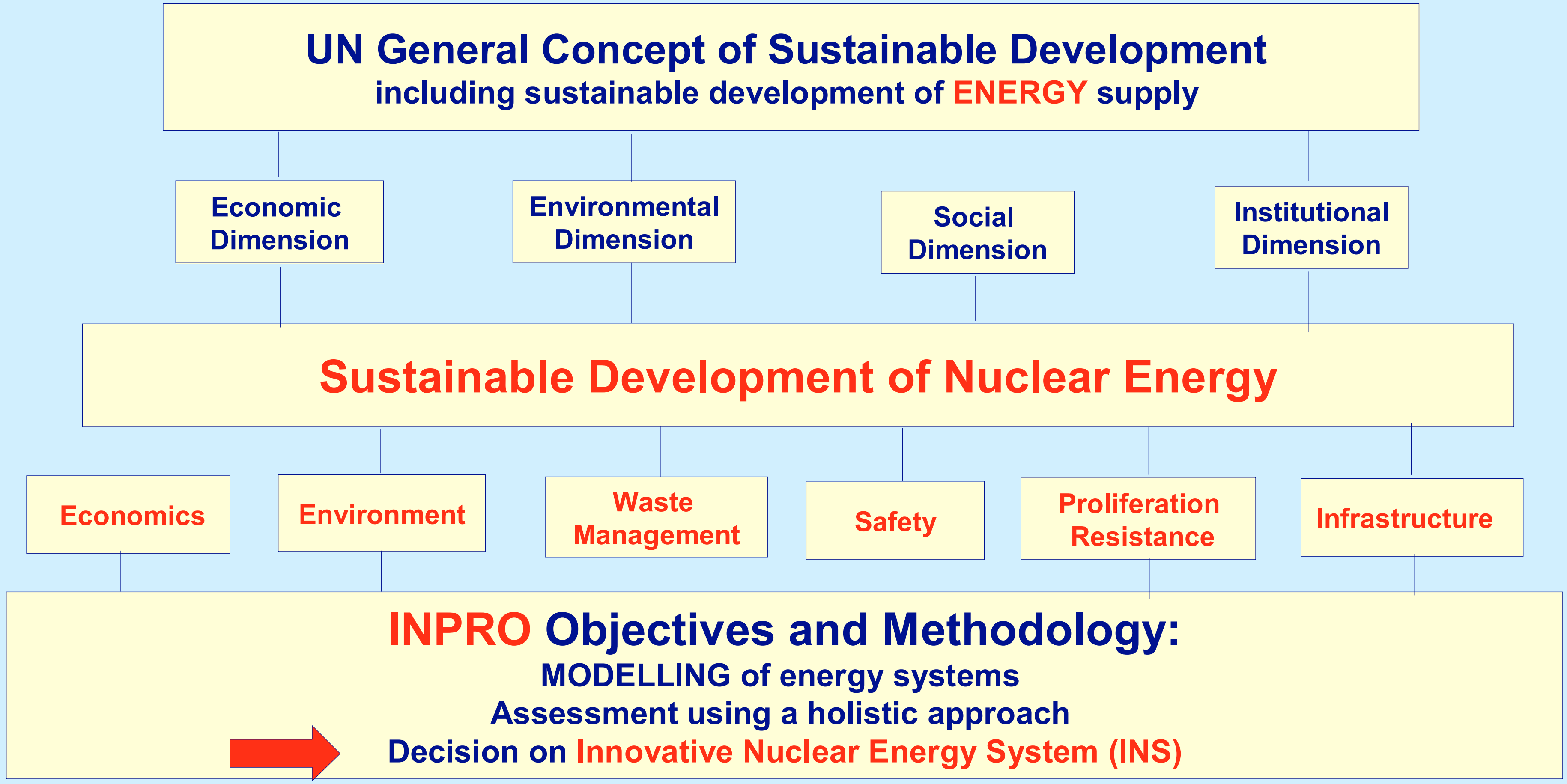


Ranges for electricity production costs in 2050 for NPP (SRES)

Results of INPRO in the Area Nuclear Power Prospects and Potentials

- Current role of Nuclear Power
  - 442 operating plants supply 16% of global electricity generation
  - Electricity produced by nuclear power: 20% USA, 27% Spain, 31% Germany, 34% Japan, 39% Korea, 44% Sweden, 77% France
  - Steady increase of availability of NP’s
    - Equivalent to 33 new plants with 1000 MWe each since 1990
  - 35 reactors under construction
    - Growth centered in Asia

UN Concept of Sustainability and INPRO



- Energy supply is fundamental to sustainable development of the world
- Sustainable energy supply needs significant contribution by NE
- INPRO assures that NE is available in a sustainable manner in the 21^{st} century
- INPRO addresses all dimensions of the concept of Sustainability