The INPRO Methodology for Innovative Nuclear Energy System assessment: fuel cycle considerations

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IAEA

Introduction

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

Results of INPRO

- **INPRO Phase 1A: Development of an Innovative Nuclear Energy System (INS) assessment methodology based on holistic approach (includes all components of an INS from cradle to grave)**
  - **Documented in TECDOC-1362 “Guidance for the evaluation of innovative nuclear reactors and fuel cycles” published in June 2003**
- **INPRO Phase 1B (1st part) started in July 2003**
  - **Testing/Validation of INPRO Methodology via 14 Case Studies and reviews by various groups of nuclear community**
  - **INPRO Methodology updated based on results of case studies and consultancies**
  - **Updated Methodology was approved by INPRO Steering Committee (SCM) in December 2004**
  - **IAEA TECDOC 1434 “Methodology for assessment of Innovative nuclear reactors and fuel cycle” is published in Dec.2004**

Results of INPRO
INPRO Schedule

Initiation

(in response to GC Res. 2000)

Phase 1A

(Methodology Development)

Phase 1B (1st part)

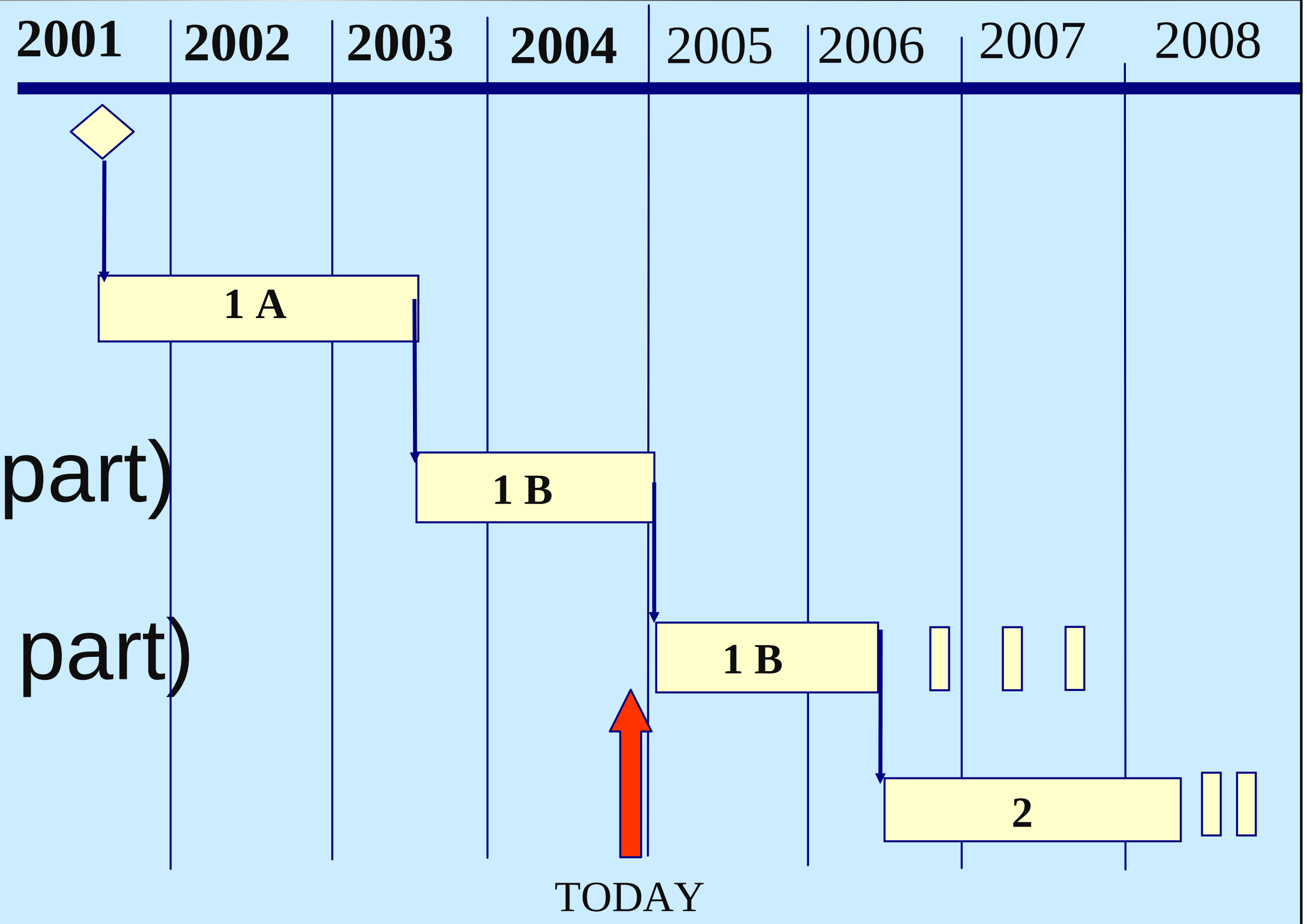
(Methodology Validation)

Phase 1B (2nd part)

(Methodology Application)

Phase 2

(International Cooperation)



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

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

INPRO Objectives and Methodology:

MODELLING of energy systems

Assessment using a holistic approach

Decision on Innovative Nuclear Energy System (INS)

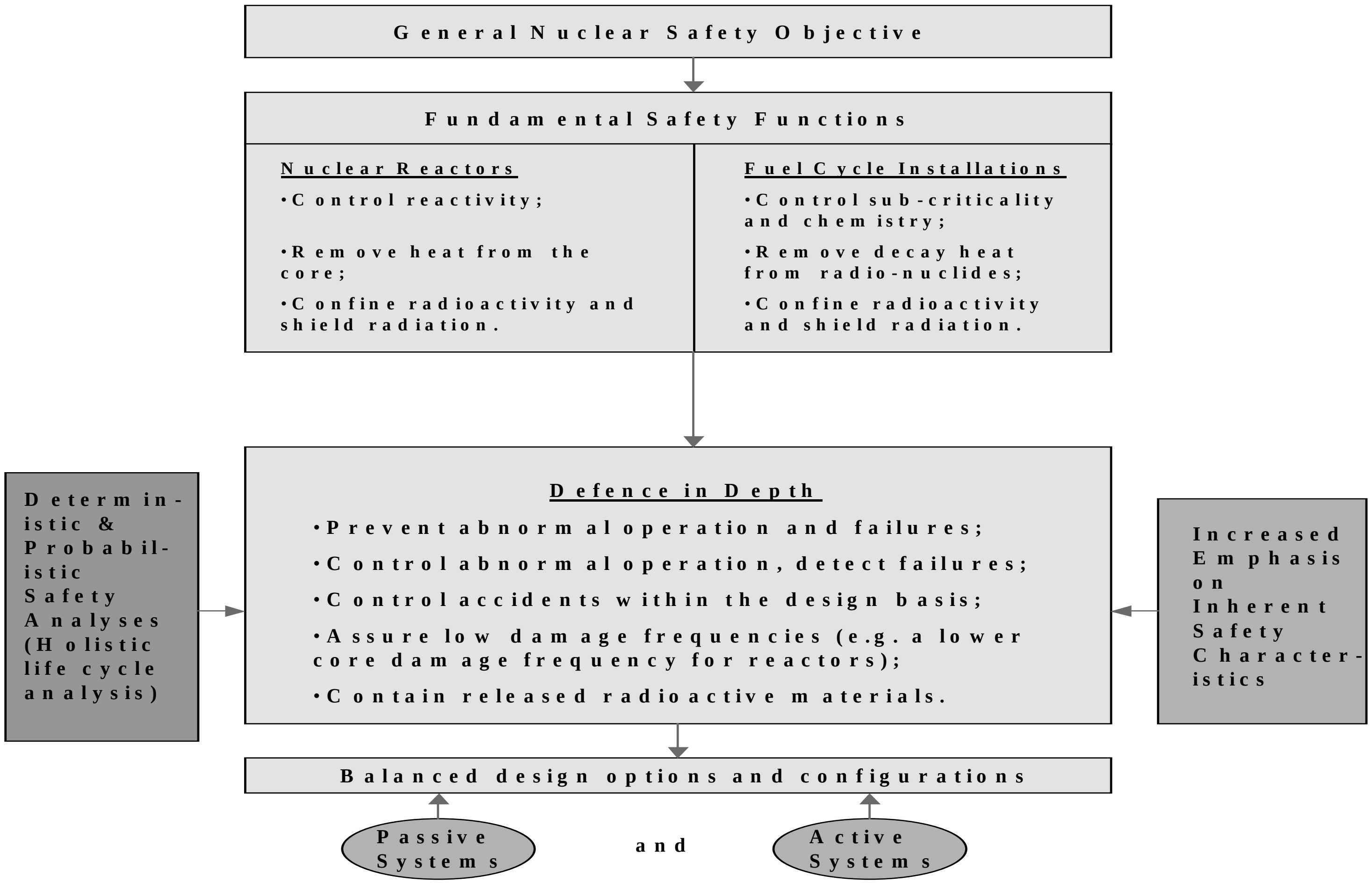
Economics

- **The operator of a NPP - a customer for the products from fuel cycle facilities and innovative fuel cycles must be competitive with alternate fuel strategies,**
- **The capital cost and the operating and maintenance costs of the nuclear fuel cycle facilities must be sufficiently small that the fuel costs to the reactor operator are competitive.**
- **The cost of all these activities and the associated waste management facilities must be such that the fuel costs remain competitive.**
- **The cost of the RD&D must be estimated and an argument that there will be a suitable return on the RD&D investment,**
- **For investment by industry, financial analyses will be required to demonstrate that there is expected to be a financial pay back,**
- **The justification for government investment may be partly financial but could be largely based on the strategic benefits.**

Safety (1)

- For fuel cycle installations the fundamental safety functions are to:
  - control sub-criticality and chemistry;
  - remove decay heat from radio-nuclides; and
  - confine radioactivity and shield radiation.
- To ensure that the fundamental safety functions are adequately fulfilled, an effective defence-in-depth strategy should be implemented.
- Typical safety hazards in fuel cycle facilities (FCF) include:
  - the release of radioactivity,
  - contamination and exposures of workers,
  - criticality, and
  - releases of chemical and stored energy (e.g., from radioactive decay heating, chemical reactions including fires, and failure of pressurized systems).

Safety (2)

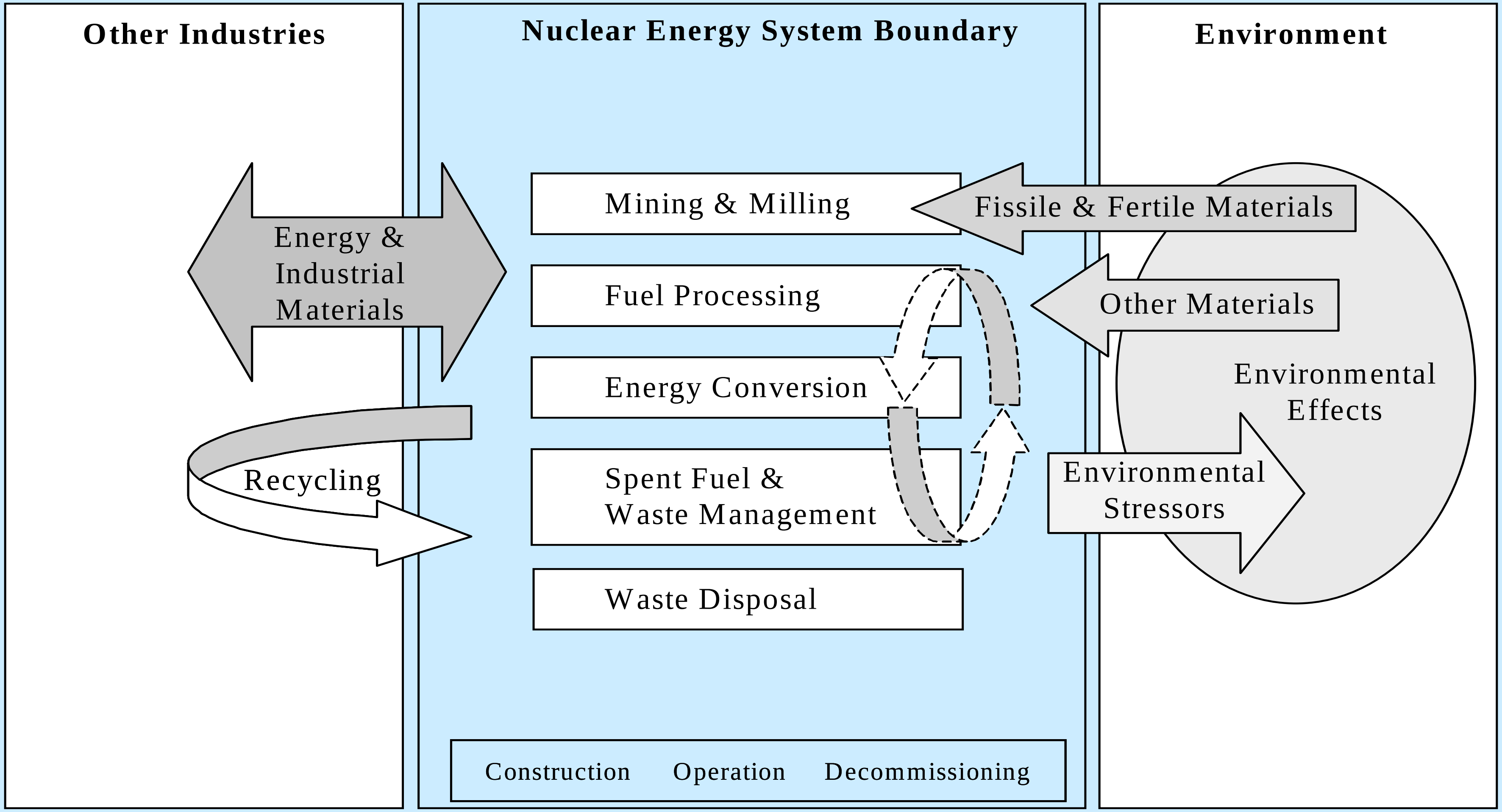


General Nuclear Safety Objective
Fundamental Safety Functions
Nuclear Reactors
•Control reactivity;
•Remove heat from the core;
•Confine radioactivity and shield radiation.
Fuel Cycle Installations
•Control sub-criticality and chemistry;
•Remove decay heat from radio-nuclides;
•Confine radioactivity and shield radiation.
Determ in-istic & Probabil-istic Safety Analyses (Holistic life cycle analysis)
Defence in Depth
•Prevent abnormal operation and failures;
•Control abnormal operation, detect failures;
•Control accidents within the design basis;
•Assure low damage frequencies (e.g. a lower core damage frequency for reactors);
•Contain released radioactive materials.
Increased Emphasis on Inherent Safety Character-istics
Balanced design options and configurations
Passive Systems
and
Active Systems

Environment

- INPRO has set out two basic principles :
  - *The expected (best estimate) adverse environmental effects of the innovative nuclear energy system shall be well within the performance envelope of current nuclear energy systems delivering similar energy products.*
  - *The innovative nuclear energy system shall be capable of contributing to the energy needs in the 21st century while making efficient use of non-renewable resources.*
- Associated User Requirements:
  - To be sustainable the INS must not run out of important resources part way through its intended lifetime.
  - These resources include fissile/fertile materials, water (when supplies are limited or quality is under stress) and other critical materials.
  - The INS should use them at least as efficiently as acceptable alternatives, both nuclear and non-nuclear.

The holistic approach for the environmental analysis of INS within INPRO



Waste management

- Four INPRO Basic Principles for INS have been derived from these nine IAEA fundamental principles.
  - the generation of waste shall be kept by design to the minimum practicable,
  - waste shall be managed so as to secure an acceptable level of protection of human health and the environment regardless of the time or place at which impacts may occur,
  - waste shall be managed in such a way that undue burdens are not imposed on future generations, and
  - interdependencies among all waste generation and management steps shall be taken into account

Proliferation resistance

- Proliferation resistance is a combination of
  - Intrinsic features result from the technical design of INS
  - Extrinsic measures are based on States' decisions and undertakings related to nuclear energy systems
    - Intrinsic features consist of technical features that:
    - a) reduce the attractiveness for nuclear weapons programmes of nuclear material during production, use, transport, storage and disposal, including material characteristics such as isotopic content, chemical form, bulk and mass, and radiation properties;
    - b) prevent or inhibit the diversion of nuclear material, including the confining of nuclear material to locations with limited points of access, and materials that are difficult to move without being detected because of size, weight, or radiation;
    - c) prevent or inhibit the undeclared production of direct-use material, including reactors designed to prevent undeclared target materials from being irradiated in or near the core of a reactor; reactor cores with small reactivity margins that would prevent operation of the reactor with undeclared targets; and fuel cycle facilities and processes that are difficult to modify; and
    - d) that facilitate nuclear material accounting and verification, including continuity of knowledge.

Infrastructure

- Nuclear power infrastructure comprises all features/ substructures that are necessary for the successful deployment and operation of nuclear power plants including legal, institutional, industrial, economic and social features/substructures
- Basic Principle that regional and international arrangements shall provide options that enable any country to adopt INS without making an excessive investment in national infrastructure.
- The associated User Requirements recognize
  - the need for establishing a national legal framework, t
  - hat the industrial and economic infrastructure of a country planning to install an INS be adequate,
  - that measure are taken to secure public acceptance, and
  - that adequate human resources are available for safe operations.

INPRO method of assessment

- The INPRO *method of assessment* provides a tool that can be used to:
  - Screen an INS to evaluate whether it is compatible with the objective of ensuring that nuclear energy is available to contribute to meeting the energy needs in the 21st century in a sustainable manner;
  - Compare different INS or components thereof to find a preferred or optimum INS consistent with the needs of a given IAEA Member State; and to
  - Identify RD&D required to improve the performance of existing components of an INS or to develop new components.

Comparison of capability of two INS

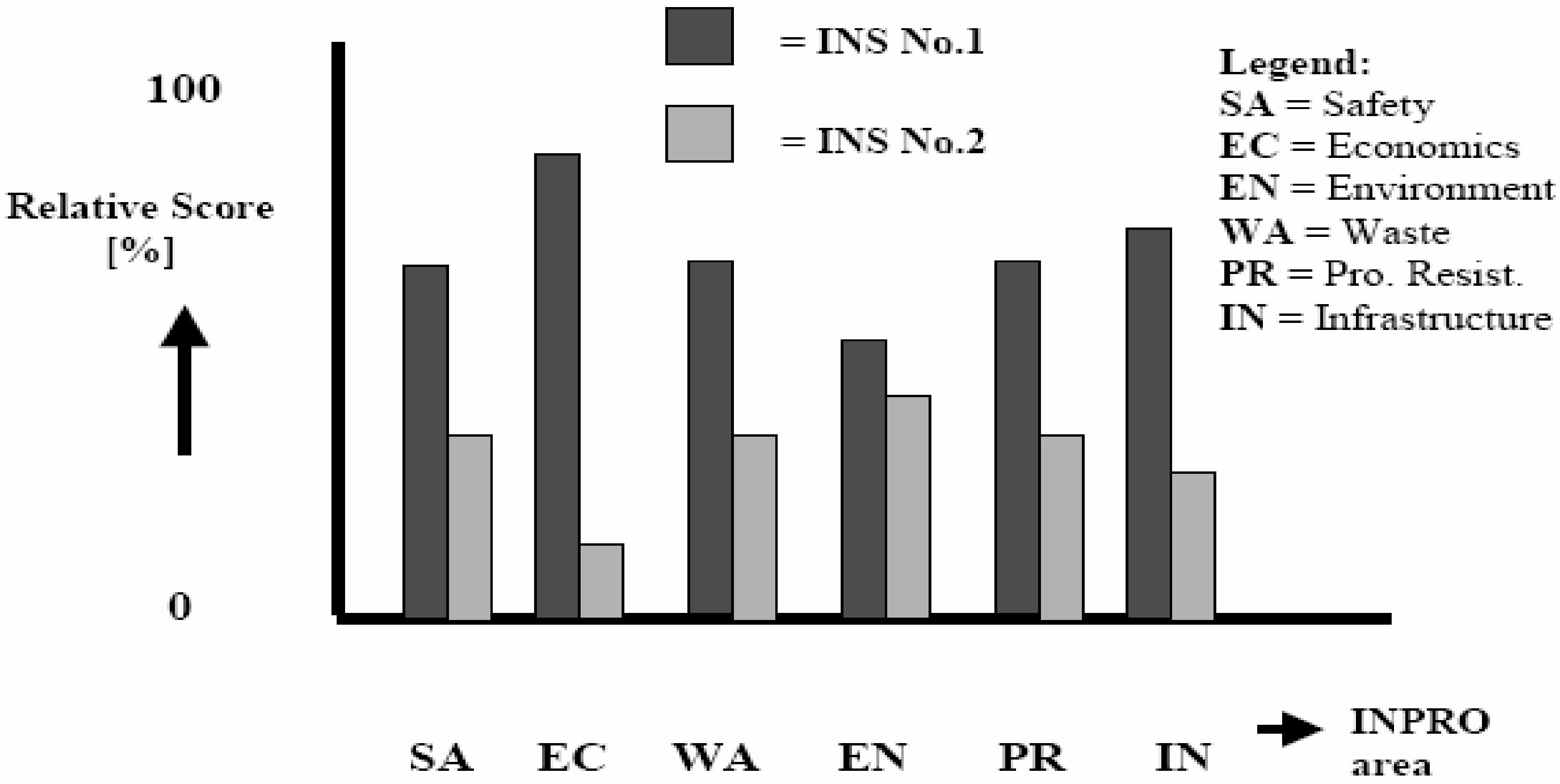


Figure 3.4. Outcome of comparison of capability of two INS.

Ad Hoc Group Meeting VIC, 13-15 October 2004

Activities endorsed by INPRO SC
(2-3 of December 2004)

For Phase 1B (2nd part, 2005 – mid 2006):

- Performance of national or multilateral assessments of complete innovative nuclear energy systems (INS) by MS with updated INPRO Methodology.
- Continuous improvement of Methodology based on feed back from assessments.
- Development of modeling tools.
- Review of multilateral nuclear fuel cycles as a possible component of INSs.
- Definition of scope and implementation options for joint RD&D for INS development
- Collection of data on INS, to be published in IAEA TECDOCS (e.g. small and medium reactors, innovative fuel cycles, etc.).

(2/2)

Activities endorsed by INPRO SC

For INPRO Phase 2, starting mid 2006:

- **RD&D oriented activities including:**
  - Development and demonstration of INSs by MS (facilitated and coordinated by the Agency);
- **Infrastructure/Institutional oriented activities including:**
  - Harmonization of licensing, codes and standards;
  - Selection of technological and infrastructure options of INS for MNFC.
- **Methodology oriented activities including:**
  - Further development and maintenance of methodology

INPRO Phase IB activities

- INS assessments:
  - **Joint assessment of an INS based on closed fuel cycle with fast reactors. Participants for this study are China, France, India, Republic of Korea, Russian Federation with Japan as an observer.**
  - **Transition from current fleet of NPPs to Generation IV systems in France.**
  - **Introduction of nuclear electricity power production based on either ACR700 or CAREM300 in Argentina.**
  - **INS assessment for a country with small grids in Armenia.**

Conclusion (1)

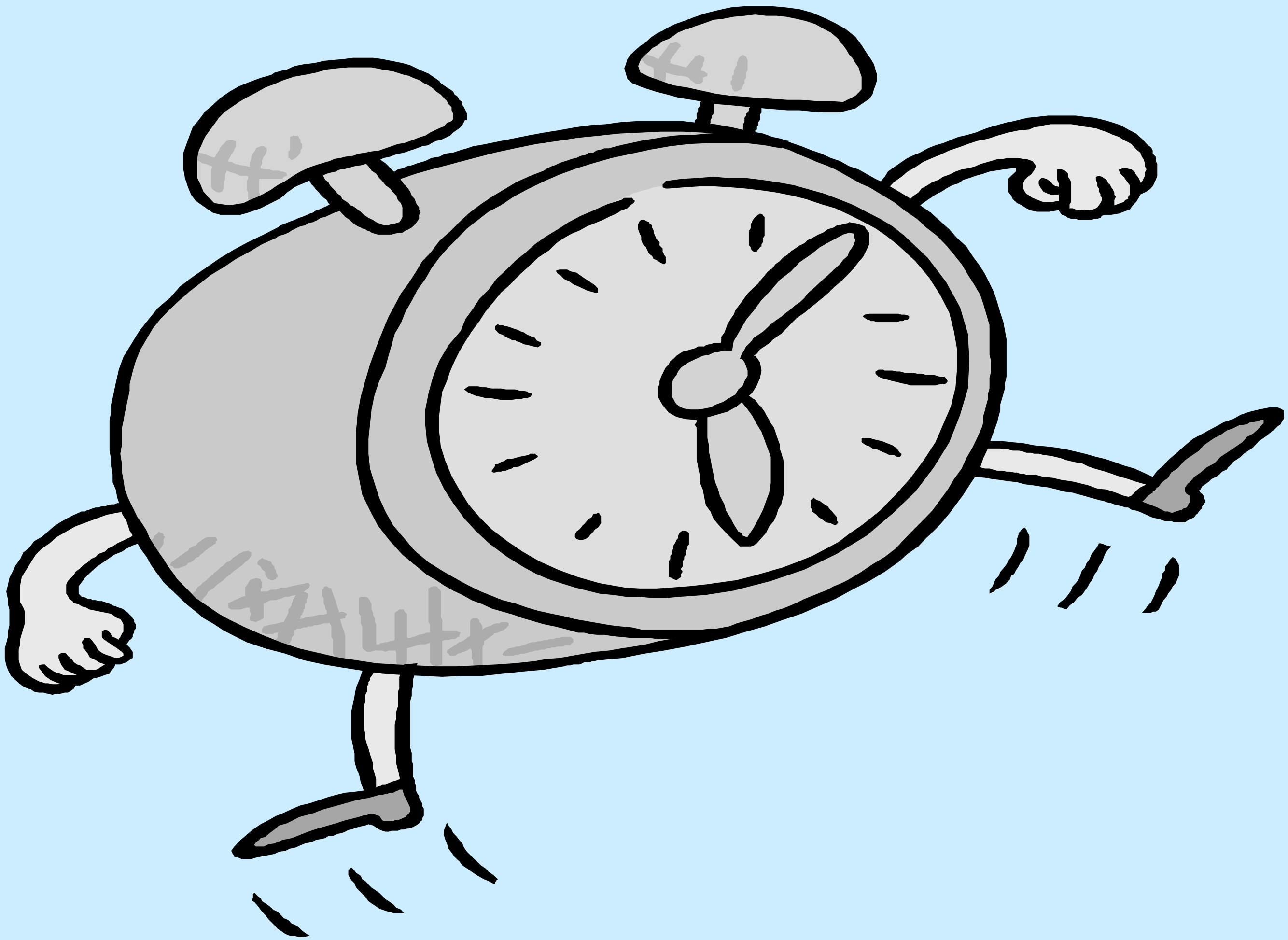
INPRO is

- an international project with growing membership (22), jointly implemented by the IAEA and INPRO members.
- increased interest also from nuclear industry
- 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 R&D .
- **creates an important opportunity for cooperative international RD&D on INSs.**

Conclusion (2)

- By creating Methodology to ascertain whether a given nuclear energy system is sustainable, INPRO has performed a decisive step towards fulfilling its objective "to help to ensure that NE is available in a sustainable manner within the 21st century".
- Methodology will be used to identify complementarities and synergisms among systems of interest to different Member States, in both technology and in infrastructure, and so will assist in identifying possible paths to a globally sustainable nuclear energy system based on diverse national and regional components.
- INPRO creates a process that involves all relevant stakeholders" by providing a forum where experts and policy makers from industrialized and developing countries can discuss technical, economical, environmental, proliferation resistance and social aspects of nuclear energy planning as well as the development and deployment of Innovative Nuclear Energy Systems in the 21st century.

Thank you



Initial meeting on INPRO joint assessment of an INS based on closed fuel cycle with fast reactors

1st December 2004

•Initial meeting on INPRO joint study

1st December 2004

- **Objectives:**
- Joint Study will cover innovative nuclear energy systems based on closed nuclear fuel cycle with fast reactors.
- Potential INSs, which, in line with the principles of the INPRO methodology, must satisfy the conditions for sustainable development at global, regional and national level in the 21st century
- The INSs will be based on the most promising solutions

Joint Study participants

- **Dates for the study: beginning of 2005 – middle of 2006.**
- **Participants:**
- **China,**
- **France**
- **India,**
- **Russian Federation,**
- **Republic of Korea**
- **Japan as observer**

The Study is open to any IAEA Member States to join or participate in, provided they agree to the Terms of Reference agreed upon when the Study was set up by the Parties.

Joint Study stages

- It is proposed that the study will be carried out in three stages.
  - Stage 1: Suggestions of INSs based on a closed nuclear fuel cycle with fast reactors.
  - Stage 2: Assessment of the proposed INSs using the INPRO methodology.
  - Stage 3: Elaboration and preparation of a conclusion on the long-term viability of INSs,

INSs Assessment

- INPRO methodology:
  - Holistic approach of examination should be used for the whole system
    - from the mining of the raw materials to the final disposal of waste for
  - Using a top-to-bottom and bottom-to-top approach,
    - at the initial stage examining the innovative nuclear energy systems as a whole, then moving on to an examination of the individual components of the system (fuel cycle as a system component and different types of reactors) using the same approach.
  - All thematic areas of INPRO
    - economics, safety, environmental protection, waste management, proliferation resistance and infrastructure

Stage 2:

INSs Assessment

- Requirements for INSs may be elaborated as regards economics, safety, waste, proliferation resistance and infrastructure issues, specific national conditions and
- Optimization of the parameters of fast reactors and closed fuel cycle technologies, based on national and regional priorities and specifics, and global energy demand.
- The studies results may contribute to the further improvement and enhancement of the INPRO methodology.

Joint Study management

- THE PARTIES PARTICIPATING IN THE STUDY WILL ESTABLISH A SCIENTIFIC AND TECHNICAL COMMITTEE
- THE THEMATIC SPECIALIST ACTIVITIES WILL BE SET UP BY THE COMMITTEE UNDER THE STUDY SUCH AS:
  - SYSTEMS APPROACH AND INTEGRATION
  - FUEL CYCLE
  - REACTOR
- SCIENTIFIC AND TECHNICAL COMMITTEE, March 2005 (Russia, Moscow)
  - SPECIFICATION OF THE GOAL AND ESTABLISHMENT OF THE CONTENT AND WORK SCHEDULE, COMPOSITION OF THE WORKING BODIES

Expected Study outcome

- **Joint report of countries participating in the Study**
  - **The role and potential of an INSs based on a closed nuclear fuel cycle with fast reactors in satisfying the conditions for sustainable development at global, regional and national level in the 21st century.**
- **The Parties will also determine:**
  - **Priorities for R&D on INSs based on a closed nuclear fuel cycle with fast reactors, and**
  - **Mutual interest in cooperation in these areas and appropriate recommendations to the INPRO Steering Committee.**