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

## Status 2007

# *Contact*

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# ***Objectives and Missions of INPRO***

## OBJECTIVES

- To help to ensure that nuclear energy is available to contribute, in a sustainable manner, to the energy needs in the 21st century.
- To bring together technology holders and users so that they can consider jointly the international and national actions required for achieving desired innovations in nuclear reactors and fuel cycles.

## MISSIONS

- To provide a forum for discussion for 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 assess INS on a global, regional and national basis and to establish it as an Agency recommendation;
- To facilitate coordination and cooperation among Member States for planning of INS development and deployment;
- To pay particular attention to the needs of developing countries interested in INS.

# ***Background***

*Six years of development*

The 21st century promises the most competitive, globalized markets in human history, the most rapid pace of technological change ever, and the greatest expansion of energy use, particularly in developing countries. As the IAEA Director General said, technological and institutional innovation is a key factor in ensuring the benefit from the use of nuclear energy for sustainability. (50th General Conference, September 2006).

The International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) was initiated in the year 2001, based on a resolution of the IAEA General Conference in 2000 (GC(44)/RES/21). Thereafter, INPRO activities have been continuously endorsed by resolutions of the IAEA General Conferences and corresponding United Nations General Assembly.

INPRO provides an open international forum for studying the nuclear energy option, its associated requirements and its potential application deployment in IAEA Member States. INPRO helps to make available adequate competence to the development and deployment of Innovative Nuclear Energy Systems (INSs) and to assist Member States in the coordination of related Collaborative Projects.

Since its onset, its members grew to the current number of 28 (as at end of July 2007). Kazakhstan and Algeria expressed their will to join INPRO.

**28 Members** Argentina, Armenia, Belarus, Belgium, Brazil, Bulgaria, Canada, Chile, China, Czech Republic, The EC, France, Germany, India, Indonesia, Japan, Republic of Korea, Morocco, The Netherlands, Pakistan, Russian Federation, Slovakia, South Africa, Spain, Switzerland, Turkey, Ukraine and The USA. **Plus observers**

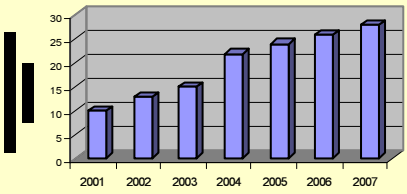


*Fig-1. INPRO members*

*Development of assessment methodology in the initial phase (phase 1)*

INPRO's initial activity (phase 1: 2001-2006) focused on the development of assessment methodology which can be applied for screening an Innovative Nuclear Energy System (INS), comparing different

INS to find a preferred one consistent with the sustainable development of a given state, and identifying RD&D needs.

The INPRO methodology, tested for consistency and completeness, has been reported in IAEA-TECDOC-1434 "Methodology for the assessment of innovative nuclear reactors and fuel cycles". It is being further extended into a User's Manual (soon to be published) consisting of an overview volume plus one specific volume for each INPRO area of assessment, in order to provide guidance to assessors how to apply the INPRO Methodology.

INPRO takes a holistic approach to assess INS in seven areas (Economics, Safety, Waste Management, Environment, Proliferation Resistance, Physical Protection and Infrastructure Issues (See Annex) so that INPRO may facilitate decision making and the implementation process for satisfying future energy needs in a sustainable manner through development and deployment of INS. Currently 9 assessments using this methodology are being carried out. (See - Currently ongoing activities in Phase 2).

INPRO methodology has a set of *Basic Principles*, *User Requirements*, and *Criteria* in a hierarchical manner (Fig.2) as basis for the assessment of INS in the areas of economics, safety, environment, waste management, proliferation resistance, physical protection and infrastructure(Outline of Basic Principles in INPRO methodology – see next page)

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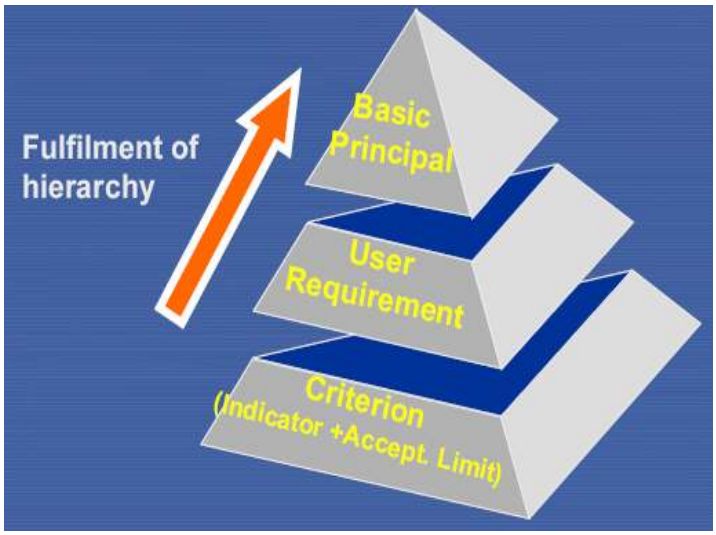


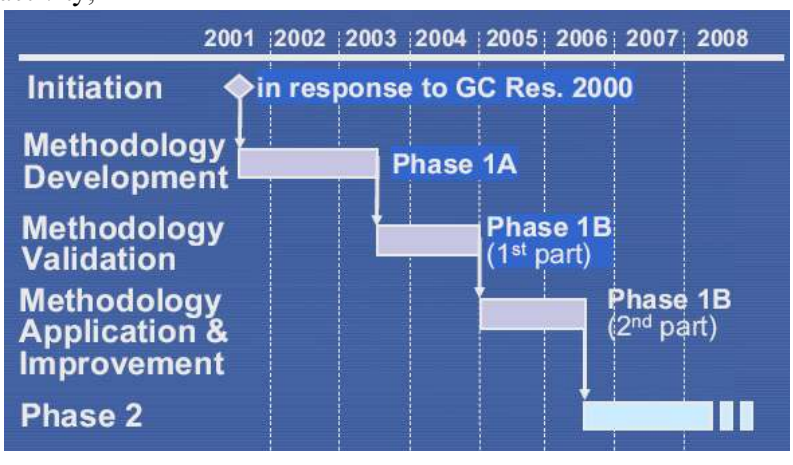

It is intended that:

- The fulfilment of a Criterion (Criteria) for an INS is confirmed by the Indicator(s) complying with the Acceptance Limit(s),
- The fulfilment of a User Requirement(s) is confirmed by the fulfilment of the corresponding Criterion (Criteria) (bottoms up approach), and
- The fulfilment of a Basic Principle is achieved by meeting the related User Requirement(s).

*Fig-2. INPRO hierarchy of BP, UR and Criterion*

*Phase 2 after July 2006*

After reaching a certain level of completion including validation through case studies, in the summer of 2006 INPRO moved to the next phase (called phase 2), which consists of three (3) major pillars of activity;




a) Further improvements of methodology
b) Infrastructure and institutional related activities
c) Collaborative Projects

*Fig-3. INPRO schedule*

## *Outline of Basic Principles in INPRO methodology*

### *Economics*

In the area of ***economics*** one basic principle has been enunciated, namely that to contribute to sustainable development, energy and related products and services from INS must be affordable and available. If energy and related products and services are to be affordable the price to the consumer must be competitive with low cost/priced alternatives. If energy and related products and services are to be available, systems to supply the energy and related products need to be developed and deployed.

### *Safety*

In the area of ***safety of nuclear installations***, the Basic Principles require that INS will enhance the concept of defence-in-depth with an increased emphasis on inherent safety characteristics and passive safety features resulting in a health and environmental risk of INS comparable to that of industrial facilities used for similar purposes, so that there will be no need for evacuation measures outside the plant.

### *Waste Management*

The Basic Principles in the area of ***waste management*** have been derived from the IAEA Safety Fundamentals "The Principles of Radioactive Waste Management". Thus, the generation of waste shall be kept to the minimum practicable securing an acceptable level of protection of human health and the environment without undue burdens on future generations, and all waste generation and management steps shall be taken into account.

### *Environment*

Protection of the ***environment*** is a major consideration in the processes for approving industrial activities in many countries and is a central theme within the concept of sustainable development. There is a *prima facie* case that nuclear power supports sustainable development by providing much needed energy with relatively low burden on the atmosphere, water, and land use. Further deployment of nuclear power would help to alleviate the environmental burden caused by other forms of energy production, particularly the burning of fossil fuels. INPRO has set out two basic principles related to the environment, one dealing with the acceptability of environmental effects caused by nuclear energy and the second dealing with the capability of INS to deliver energy while making efficient use of non-renewable resources.

### *Proliferation Resistance*

The proliferation resistance Basic Principles require that intrinsic features and extrinsic measures be implemented throughout the full life cycle for INS and be optimised, by design and engineering, to provide cost-effective proliferation resistance. In an INS, the attractiveness of nuclear materials and technology for diversion to a nuclear weapons programme should be low and the diversion of nuclear material difficult and detectable.

### *Physical Protection*

One basic principle has been defined by INPRO in this area. It requires implementing an adequate regime on physical protection throughout the lifetime of an INS. The corresponding user requirements are based on the fundamental principles of the amended convention on the physical protection of nuclear materials and facilities and emphasize the need to take into account jointly all aspects of physical protection, proliferation resistance and safety during all design stages of an INS.

***Infrastructure***

The Basic Principle in this area states that regional and international arrangements shall provide options that enable any country that so wish to adopt INS for the supply of energy and related products without making an excessive investment in national infrastructure. The associated User Requirements and Criteria recognise the need for establishing a national legal framework with corresponding institutions, an adequate economic infrastructure to facilitate availability of credit lines, industrial infrastructure to cover mainly construction, transportation, operation and maintenance means, socio-political infrastructure to allow long term commitment and public acceptance and finally appropriate human resources for all the steps of the nuclear program, including safe operations.

# ***Management of the Project***

## Project Management

Mr. Y. Sokolov, INPRO Project Manager, is responsible for the overall implementation of the project, defines the key strategic and policy issues relevant for INPRO and makes a final decision on the scope, contents and methods of work within the project. He is supported by a Policy Coordinator (Mr. A. Omoto) and two Technical Coordinators (Messrs A. Rao and Ch. Ganguly). They are also supported by INPRO Area Coordinators, that provide effective assistance and coordination, both in-house and external, and by the International Coordinating Group (ICG) for the planning, implementation and documentation of INPRO activities within their responsible Areas of Economy, Safety, Waste Management, Environment, Proliferation Resistance, Infrastructure and Physical Protection.

## Steering Committee

The INPRO Steering Committee, consisting of representatives nominated by the INPRO Members is a decision-making organ on key issues of the project, such as future direction and action plan. In its 11th meeting held in July 2007, INPRO Members endorsed 14 Collaborative Projects to be developed in Phase 2 and the most relevant aspects of the INPRO Action Plan 2008-2009.


*Fig-.4.* INPRO Steering Committee meeting

## International Coordination Group (ICG)

The ICG comprises of cost-free experts from participating Member States and regular staff specially assigned for INPRO. They are responsible to plan and implement INPRO activities, seeking advice from the designated Task Advisors and to prepare the deliverables. Responsible officers allocated for Tasks from ICGs are listed in the INPRO Action Plan.

*Fig- 5.* INPRO international coordinating group

## Inter-departmental support

Experts from various departments (especially from Department of Nuclear Safety and Security and Department of Safeguards) are supporting related activities, providing advice and reviewing reports in the area of their competence.

## Resources

The project is being implemented using extra budgetary contributions offered by interested IAEA Member States and the IAEA Regular Budget. Most activities in this project depend on the availability of extra budgetary funds.

# ***Currently ongoing activities in Phase 2***

INPRO activities in Phase 2 include the following tasks:

## a) Support to Members on the application of methodology

The IAEA facilitates and assists Member States in the use of INPRO "Methodology" for assessing and selecting INS according to sustainable development and in the corresponding training of national staff.

Currently there are 9 ongoing assessment studies:

- Joint assessment based on a closed fuel cycle with sodium fast reactors (Russian Federation, Canada, China, France, India, Japan , Republic of Korea and Ukraine);
- Assessment of hydrogen generating INS in national energy mix (India);
- Assessment on the transition from the current NPP fleet towards Generation IV fast neutron systems (France);
- Assessment of additional nuclear generation capacity in the country for the period 2010-2025 for the evaluation of NFC strategies (Argentina);
- Assessment of INS for countries with a small electricity grid (Armenia);
- Assessments of different reactor concepts (Brazil);
- Assessment of advanced HTGR (China);
- Assessment of national INS (Ukraine); and
- Comparison assessment between fast reactors cooled by sodium and by lead/lead-bismuth (European Commission)

A set of manuals are scheduled to be published soon in order to enable a user to perform an assessment of an Innovative Nuclear Energy System using the INPRO Methodology.

## b) Development of a vision on scenarios for nuclear energy development

The INPRO vision activity will develop a holistic perspective on the contribution of INS to a sustainable development and will identify opportunities and challenges on a global and regional scale in the long run. INPRO members can translate the vision into their national nuclear policies to assure that the nuclear energy is a viable and a sustainable option in their countries.

## c) The IAEA is providing Support to Member States' capacity building and decision making

IAEA provides qualified analytical tools necessary to evaluate the opportunities and challenges facing INS. This will include consideration of how global energy resources may influence the national decisions on future nuclear energy systems. The IAEA provides training support to INPRO methodology users through workshops.

*Fig-6.* Participants of the first workshop was convened in June 2006 in Vienna

d) Infrastructure and institutional areas

INPRO will monitor and propose, upon necessity, arrangements on nuclear infrastructure that would facilitate the development and deployment of INS, integrating the potential synergies with other international initiatives. These arrangements may address issues such as regional approach to smooth deployment of INS, licensing and financing for developing countries.

e) Collaborative Projects

The IAEA will coordinate and support INPRO Collaborative Projects identified by INPRO Members to a commonly study enabling technologies and approaches to topics of major interest.

f) Common User Criteria/Requirements

The IAEA will identify common user requirements and criteria from developing countries with respect to the reactor systems necessary in the 21st century, focussing on small and medium sized reactors, and potentially establishing joint actions by technology holders and users for development and deployment of such reactor systems.

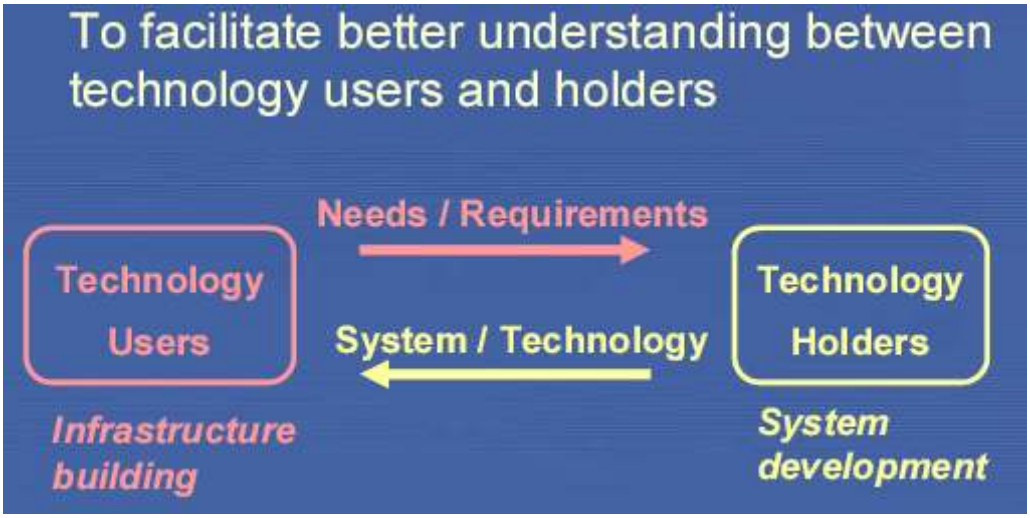



*Fig-7.* The purpose of establishing Common User Criteria/Requirement

# ***Collaborative Projects***

The IAEA is expected to facilitate coordination among Member States for planning of the development and deployment of INS. Collaborative projects under IAEA/INPRO auspices can be carried out using one of the following options:

- Coordinated Research Project (CRP)
- Technical Cooperation Project (TCP)
- Joint Initiatives (JI),

Fourteen Collaborative Projects, as Joint Initiatives (JI), were currently proposed by INPRO members and they were endorsed in the 11$^{th}$ Steering Committee meeting of INPRO (July 2007). They can be categorized in the following groups:

**Scenarios of Nuclear Energy development**

- Global architecture of INS operating in closed fuel cycle and using both thermal and fast reactors (GAINS)
- Scenarios in the period of raw materials insufficiency during the 21$^{st}$ century

**Safety issues**

- Performance assessment of passive gaseous provisions (PGAP)
- Safety issues for advanced high temperature reactors and their combined operation with hydrogen producing plants
- Safe operation in a power system having limited capacity

**Proliferation Resistance**

- Acquisition/diversion pathway analysis for the assessment of proliferation resistance

**Technical challenges in Reactor technologies**

- Technological challenges of liquid metals and molten salts used as coolants of advanced high temperature reactors, accelerator driven systems (ADS) and fast reactors (FR)
- Advanced water cooled reactors
- Integrated approach for the design of the decay heat removal system of Liquid Metal Reactors

**Environment & Nuclear Fuel Cycle &Infrastructure**

- Methodologies for ranking radionuclides from nuclear reactors, based on their environmental impact on humans
- Options for management of spent nuclear fuel and radioactive waste in a small country
- Legal, institutional and technical issues of introduction of movable NPPs with small and medium sized reactors in the developing countries
- Further investigations of the $^{233}$U/Th fuel cycles
- Joint assessment on advanced and innovative nuclear fuel cycles used in the INSs based on closed fuel cycle

# ***Examples of Collaborative Projects – Joint Initiatives***

***a) Global architecture of INS operating in closed fuel cycle and using both thermal and fast reactors (GAINS)***

The objectives of the GAINS Project are to:

- develop a framework (a common methodological platform, assumptions and boundary conditions) for the assessment of the transition from the current thermal reactors to a sustainable deployment of nuclear energy till 2050 and afterwards up to 2100,
- develop a reference base case for transition to architecture of the global INS capable to meet in a sustainable manner requirements of energy supply, recognizing regional differences in availability of material resources, energy growth rate and nuclear energy deployment options,
- perform sensitivity studies to assess the impact of different key assumptions and to consider the effect different transition scenarios would have on sustainability metrics.

***b) Options for management of spent nuclear fuel and radioactive waste in a small country***

The objectives of the Project are:

- Review feasible technical and economically sound options of spent fuel management available globally and selection of 3-4 reference options applicable to the conditions of a country with small territory.
- For each reference scenario of nuclear power development provide evaluation of key indicators relevant to different reference SNF (Spent Nuclear Fuel) management alternatives with identification of level of uncertainties in the results of evaluation.
- Analyze results of assessment and define key challenges for each reference SNF management option. Identify near, medium and long-term institutional measures and technical solutions for each reference SNF management option.

***c) Performance assessment of passive gaseous provisions (PGAP)***

This CP addresses the issue of reliability of passive safety system to be used in Gas-Cooled Fast Reactor, which is one of the systems selected for Generation –IV technology development.
The main objective of the Project is to conduct a benchmark in order to reach an international consensus on the definition of the reliability of the subject passive system, and on a methodology to assess this reliability.

# ***Strengths of INPRO***

**Motivation**: INPRO aims at integrating views from all stakeholders, notably from nuclear technology holders and developers respectively and nuclear technology users. User Requirements developed with the participation of end users are an essential element of INPRO.

- **Time horizon:** The INPRO time horizon covers the coming five decades. Energy scenarios envisaged for this period are determined by an expected transformation of the energy sector in light of limited fossil fuel supplies and of the potential climate change; new applications such as hydrogen as an energy carrier and seawater desalination for the production of drinking water are also considered.
- **Scope:** INPRO provides a holistic assessment of innovative nuclear energy systems and technologies encompassing all the installations of the nuclear fuel cycle, including the reactors, and also all the areas having an impact in the consideration of sustainable development (economic competitiveness, environmental aspects, infrastructures, security and physical protection, proliferation resistance, safety and waste management). INPRO is aimed at examining the prospects of nuclear technology against this very broad background.
- **Mandate:** INPRO was initiated on the basis of an IAEA General Conference resolution. It is established as an open process and access to results is provided to all IAEA Member States.
- **Proliferation resistance:** The mandate of the IAEA in the area of safeguards helps to ensure that the issue of proliferation resistance is considered at every stage of INPRO.
- **Synergy:** INPRO avoids duplication of other IAEA activities and takes advantage of synergies with other international initiatives on nuclear technology development.

*Fig.- 8.* Participants of the INPRO-GIF meeting

# Participation in INPRO

Typically, the first step is a letter sent to the IAEA, addressed to the INPRO Project Manager, endorsed by the responsible government department, announcing the wish of a Member State to join INPRO as a member or as observer.
Observers do not need to provide major contributions to the project, although they are invited to finance their attendance to INPRO meetings by their own means.
INPRO membership requests received by IAEA will be responded by the INPRO Project Manager, offering mainly the following possible modes of participation:

- Delivering direct monetary contributions ('extra budgetary').
- Providing Cost-Free-Experts;
- Performing agreed INS assessment studies;
- Participating actively in Collaborative Projects.

When agreement is reached on the mode of participation, the Member State becomes officially recognised as a member or observer of INPRO.

# Key benefits to Member States

Developing and developed countries, which are considering the possibility to build nuclear power plants within the medium or long term, will receive guidance through INPRO to facilitate establishing the corresponding advanced or innovative nuclear energy system according to a sustainable development. INPRO is an effective way to identify the real needs of Member States and to provide assistance in addressing their needs by making authoritative information, making available qualified tools and advice and by facilitating international cooperation.

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