International Conference on
Emerging Nuclear Energy Systems
"ICENES 2005"
22 - 26 August, 2005, Brussels, Belgium

THE IAEA INTERNATIONAL PROJECT ON INNOVATIVE NUCLEAR REACTORS AND FUEL CYCLES (INPRO): EXPERIENCE OF ASSESSMENTS AND DEVELOPMENT OF APPROACHES

Y. Sokolov, A.Omoto, I. Facer, M. Khoroshev
International Atomic Energy Agency (IAEA)
Wagramerstrasse 5, P.O.Box 100, A-1400 Vienna, Austria
Tel: +43-1-260026716, Fax: +43-1-260029598, e-mail: M.Khoroshev@iaea.org

Keywords: innovation, reactors, fuel cycles, user requirements, IAEA, INPRO, methodology, safety, environment, waste, economics, proliferation resistance, infrastructure.

ABSTRACT

During the last fifty years remarkable results have been achieved in the application of nuclear technology for the production of electricity. Looking ahead to the next fifty years it is clear that the demand for energy will grow considerably and also new requirements have to be fulfilled for the way nuclear energy will be supplied.

Following a resolution of the General Conference of the IAEA in the year 2000 an International Project on Innovative Nuclear Reactors and Fuel Cycles, referred to as INPRO, was initiated.

Based on scenarios for the next fifty years, requirements for the different aspects of the future of nuclear energy systems, such as economics, environment, safety, waste, proliferation resistance and infrastructure have been identified as well a methodology developed to assess innovative nuclear systems and fuel cycles. On the basis of this assessment, the need for innovations in existing nuclear technology, to be achieved via research, development and demonstration (RD&D), can be defined.

INPRO developed the above-mentioned requirements during its first step, called Phase 1A, which lasted from 2001 to middle of 2003. In the following second step, called Phase 1B (first part), INPRO organized 14 case studies (8 by national teams and 6 by individuals) to test and validate the methodology. INPRO has finished end of 2004 the first part of Phase 1B, by issuing an IAEA report (TECDOC1434) with an upgraded methodology based on the recommendations given in the case studies.

The paper summarizes the status of INPRO as well as the main results and provides an outlook on the future activities.

A method for assessing the operating risk of innovative designs using functional risk based assessment of the conceptual design and potential consequences of incidents will be described.

1. INTRODUCTION

Existing scenarios for global energy use, project that demand will at least double over the next 50 years. Electricity demand is projected to grow even faster. These scenarios suggest that the use of all available generating options, including nuclear energy, will inevitably be required to meet those demands.

In order for nuclear energy to play a meaningful role in the global energy supply in the foreseeable future, innovative approaches will be required to address concerns about economic competitiveness, environment, safety, waste management, potential proliferation risks and necessary infrastructure. Considering these requirements and the future scenarios, the IAEA initiated the International Project on Innovative Nuclear Reactors and Fuel Cycles, referred to as INPRO, following resolutions of the IAEA General Conference.

The overall objectives of INPRO are:

- To help to ensure that nuclear energy is available to contribute in fulfilling, in a sustainable manner, the energy needs in the 21st century.
- To bring together all interested Member States, both technology holders and technology users, to consider jointly the international and national actions required to achieve desired innovations in nuclear reactors and fuel cycles that use sound and economically competitive technology, are based – to the extent possible – on systems with inherent safety features and minimize the risk of proliferation and the impact on the environment.
- To create a process that involves all relevant stakeholders that will have an impact on, draw from, and complement the activities of existing institutions, as well as ongoing initiatives at the national and international level.

In order to fulfil these objectives, the first step of the project (Phase 1A) was dedicated to the definition of requirements, called basic principles, user requirements and criteria, that innovative nuclear energy systems (INS) should meet in several subject areas (economics, safety of nuclear installations, environment, waste management, proliferation resistance and infrastructure). A method to assess innovative nuclear energy systems on a national, regional and/or global basis, referred to as INPRO methodology, was developed. The result of Phase 1A was documented in the IAEA report: IAEA-TECDOC-1362, Guidance for the evaluation of innovative nuclear reactors and fuel cycles [1].

In the following step of the project (called Phase 1B, first part) validation and improvement of the INPRO methodology through several case studies was carried out, as well as further development of analytical tools. The results of this phase were documented in the IAEA report: IAEA-TECDOC-1434, Methodology for the assessment of innovative nuclear reactors and fuel cycles [2] and are presented in this paper.

Upon completion of Phase 1, Phase 2 of INPRO is planned to be initiated as per the decision of the Steering Committee, which represents the participating Member States. Phase 2 should be directed to encourage IAEA Member States to cooperate in the research and development of safe, competitive, environmentally clean, and proliferation resistant innovative nuclear energy systems for sustainable development. This may include identification of technologies appropriate for implementation by Member States and examining the feasibility of commencing international projects related to them.

As of December 2004, INPRO has 22 Members: Argentina, Armenia, Brazil, Bulgaria, Canada, Chile, China, Czech Republic, France, Germany, India, Indonesia, Morocco, Republic of Korea, Pakistan, Russian Federation, South Africa, Spain, Switzerland, The Netherlands, Turkey and the European Commission.

2. INPRO AND THE CONCEPT OF SUSTAINABILITY

The general concept of *sustainability* and considerations specific to the concept of sustainable energy have been incorporated in the INPRO objectives and have been integrated into the INPRO methodology. As INPRO proceeds, its activities will continue to benefit from and be guided by the general IAEA and UN activities related to sustainability and it is anticipated that the output from INPRO will represent an important contribution by the IAEA and its Member States in furthering the global development of sustainable energy.

Ensuring the availability of a secure supply of energy is one important aspect of governments' ultimate responsibility for national security and economic growth. National circumstances and policies will determine the mix of fuels necessary to contribute to the world's collective energy security and global economic growth, and to address the challenge of achieving sustainable development. To address the specific issues relevant to the development and deployment of innovative nuclear energy systems (INS) for sustainable energy supply, within the general framework of sustainability, INPRO established a number of task groups to develop a method for assessing INS in the following areas: economics, safety, environment, waste management, proliferation resistance and infrastructure. By focusing on each of these specific areas in turn, the INPRO methodology ensures that a given INS takes into account the four dimensions of sustainability and is assessed in sufficient detail to establish with confidence the potential of the INS to contribute to sustainable energy supply and hence to meeting the general objective of sustainable development. In addition, the results of such an assessment provide an important input for defining the strategy and the necessary short, medium and long term research, development and demonstration (RD&D) plans to support the development and deployment of a given system or component thereof.

By definition, an INS, in INPRO, encompasses all systems that will position nuclear energy to make a major contribution to global energy supply in the 21st century. In this context, future systems may include evolutionary as well as innovative designs of nuclear facilities. An evolutionary design is an advanced design that achieves improvements over existing designs through small to moderate modifications, with a strong emphasis on maintaining design proveness to minimize technological risks. An innovative design is an advanced design, which incorporates radical conceptual changes in design approaches or system configuration in comparison with existing practice to achieve a breakthrough in performance in selected areas.

3. 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.

An assessor of an INS may be interested in only one component of a complete INS, such as a reactor for electricity production or for desalination, or in several components of a complete system. Regardless of his specific interest, the assessor must include in the evaluation all components of the system to achieve a holistic view and so ensure that the component(s) of interest and the corresponding overall system are sustainable.

An assessment requires the participation of individuals with expertise in the INPRO areas and with adequate knowledge of the nuclear facilities comprising the INS to enable a holistic assessment. The results of such assessments should be available to all stakeholders, not only to nuclear experts. But, the format and language in which the results are communicated to non-nuclear experts has to meet the needs of the stakeholders and doing so represents a challenge that is yet to be addressed.

INPRO has defined a set of basic principles, user requirements, and criteria (consisting of Indicators and Acceptance Limits) for each area of interest. The highest level in the INPRO structure is a basic principle (BP), which is a statement of a general rule that provides broad guidance for the development of an INS (or design feature). All basic principles shall be taken into account in all areas considered within INPRO (economics, safety, environment, waste management, infrastructure, and proliferation resistance). User requirements (UR) are the conditions that should be met to achieve users' acceptance of a given INS. Users encompass a broad range of groups including investors, designers, plant operators, regulatory bodies, local organizations and authorities, national governments, NGOs and the media, and last not least the end users of energy (e.g., the public, industry, etc). By establishing user requirements that encompass such a broad constituency INPRO seeks to ensure that an INPRO assessment takes into account the interests and views of all stakeholders. A criterion (CR) (or more than one) is required to determine whether and how well a given user requirement is being met. Indicators may be based on a single parameter, on an aggregate variable, or on a status statement.

BPs, URs, and CRs are broadly based. They represent an idealization of what is desirable taking into account both national, regional and global trends and what is likely to be technologically achievable. It is difficult to factor in step changes in technology, so INPRO has extrapolated current trends. Member States are free to and, indeed, in a number of cases, e.g. economics and infrastructure, should specify country or region or technology specific criteria and user requirements. For some acceptance limits, INPRO has proposed values, e.g., in the area of safety where the limits should be internationally accepted and applied. In the long term, it is expected that internationally agreed acceptance limits would be proposed also in the areas of proliferation resistance, environment, and waste management as well as safety. The INPRO manual under preparation will provide IAEA Member States more detailed information on the selection of Indicators and Acceptance Limits.

At the end of step 2 of INPRO, Phase 1B (first part), methods for performing screening and comparative assessments have been sufficiently developed for application by interested IAEA Member States. On the other hand it is anticipated that feedback from applying the INPRO methodology in the ongoing phase (Phase 1B, second part) will result in further improvements.

4. 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 shall be affordable and available.

In total four user requirements are linked to this basic principle.

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. To develop and deploy innovative energy systems requires investment and those making the investment, be they industry or governments, must be convinced that their choice of investment is wise. The alternatives for investment may be other energy technologies seeking investment for development or deployment or non-energy technology areas. So, to be developed and deployed, INS must compete successfully for investment. In different markets and regions and at different times and stages in the cycle of development and deployment the investor(s) may be different and different factors may assume more or less importance in determining attractiveness of investment. But in any case a sound business case must be made.

Given the nature of nuclear technology, it is recognized that government policies and actions (in some Member States, governments may participate in investment) will have a significant bearing and influence on investor decision making, both when deciding whether or not to invest in development and when deciding to invest in technology deployment/acquisition. For private sector investment profitability and return will be key factors in the business case. It follows that if the price to the consumer is to be competitive and at the same time investors are to receive an attractive return, the cost of production must also be competitive with that of alternatives. To be cost competitive all component costs, e.g., capital costs, operating and maintenance costs, fuel costs, must be considered and managed to keep the total unit energy cost competitive. Limits on fuel costs in turn imply limits on the capital and operating cost of fuel cycle facilities, including mines, fuel processing and enrichment, fuel reprocessing and the decommissioning and long-term management of the wastes from these facilities.

Cost competitiveness of energy from INS will contribute to investor confidence, i.e. to the attractiveness of investing in INS, as will competitive financial figures of merit, e.g., rate of return, which should be at least comparable to the values for competitive energy sources and preferably better. As well, a judgement must be made that the funds required to implement a project can be raised within a given expected investment climate, taking into account other investment options and other priorities requiring a share of available capital and the risk of investment must be acceptable, taking into account the risk of investment in other energy projects.

Given the uncertainty about the future, ideally, INS should be sufficiently flexible to be able to evolve and adapt in a manner that provides competitive energy for as wide a range of plausible futures and markets as possible. Thus, the ability to adapt specific components of an INS, as well as the overall adaptability of the INS, to accommodate different sized modules, to accommodate market changes and growth, to accommodate different fuels, to meet different energy applications, and to meet the needs of different countries/ regions is desirable. In assessing flexibility of a given component or set of components, possible synergisms with other components of the INS should be considered.

5. SAFETY OF NUCLEAR INSTALLATIONS

In the area of *safety of nuclear installations*, INPRO recognizes that extensive work has been done prior to INPRO to establish safety requirements included in documents such as the Advanced Light Water Reactor Utility Requirements prepared by EPRI, the European Utility Requirements prepared by European Utilities, IAEA Safety Standards Series, e.g., Safety Guides, and INSAG documents. The safety basic principles and user requirements developed within INPRO are based on extrapolation of current trends and seek to encompass the potential interests of developing countries and countries in transition. For nuclear reactors, the fundamental safety functions are to control reactivity, remove heat from the core, and confine radioactive materials and shield radiation. For fuel cycle installations, they are to control sub-criticality and chemistry, remove decay heat from radio-nuclides, and confine radioactivity and shield radiation (see Figure 1).

To ensure that INS will fulfil these fundamental safety functions, INPRO has set out four basic principles:

An INS shall

1. 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 existing installations.*

2. 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.

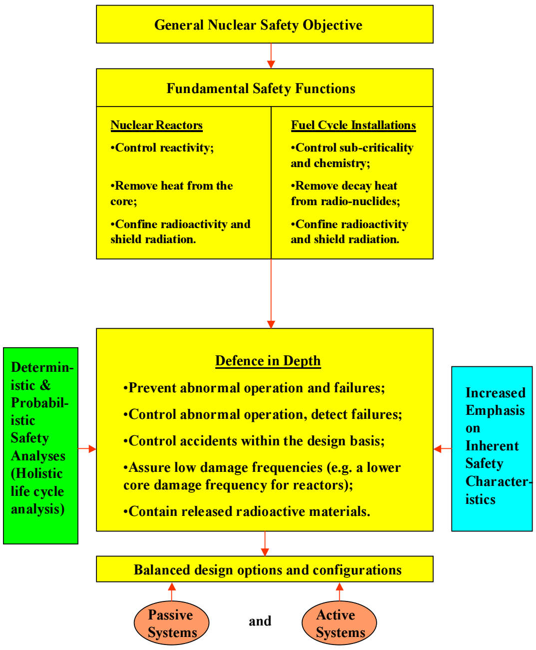

Figure 1: Framework for development of requirements for safety of INS

3. Ensure that the risk from radiation exposures to workers, the public and the environment during construction/commissioning, operation, and decommissioning, shall be comparable to that of other industrial facilities used for similar purposes.

Further, the development of Innovative Nuclear Energy Systems shall:

4. Include associated RD&D work to bring the knowledge of plant characteristics and the capability of analytical methods used for design and safety assessment to at least the same confidence level as for existing plants.

In total fourteen user requirements were derived from these basic principles.

The end point should be the prevention, reduction and containment of radioactive releases to make the health and environmental risk of INS comparable to that of industrial facilities used for similar purposes so that for INS there will be no need for relocation or evacuation measures outside the plant site, apart from those generic emergency measures developed for any industrial facility. RD&D must be carried out before deploying INS, using, e.g., large scale engineering test facilities including, possibly, pilot and prototype plants, to bring the knowledge of plant characteristics and the capability of codes used for safety analyses to the same level as for existing plants. The development of INS should be based on a holistic life cycle analysis that takes into account the risks and impacts of the integrated fuel cycle. Safety analyses will involve a combination of deterministic and probabilistic assessments, including best estimate plus uncertainty analysis.

Risk based assessment of innovative nuclear power plants

One of the issues facing the assessment of innovated nuclear power plant designs is that the design is often at the conceptual stage, and detailed analysis of the risk from operation using a full Probabilistic Safety Analysis (PSA) is not possible.

However, an approach, based upon the consideration of the fundamental safety functions that need to be achieved in the protection of any design, using a simplified event tree based analysis can be performed. A method has been developed to consider, at a functional level, the anticipated performance of the safety functions and the consequences of the safety functions failure.

The safety functions considered are fault detection, reactor shutdown, heat removal, primary circuit integrity and containment performance. Irrespective of the design these fundamental safety functions need to be achieved. The method of achieving the functionality is not important to the assessment. If the functionality is achieved by inherent characteristics of the design then the failure probability of the function could be considered to be extremely low, or even possibly 0.

For each design an assessment of the frequency of a range of initiating events is estimated, and for each initiating event a target reliability, or expected reliability, for each of the safety functions is identified. A structured event tree is included in the model and a range of 8 different end states for the event tree, based upon the performance of the safety functions, are defined. For each end state the consequences of the failure, for the specific design under consideration are included in the analysis and a risk curve calculated.

This risk curve presents the frequency of exceeding a specific loss for the particular design. It can demonstrate the benefits of high reliability of systems or the economic benefits of not needing to achieve such high reliabilities, and also the benefits of inherent characteristics such as fundamental fuel integrity and protection of fission products from release.

This approach should be used in conjunction with the INPRO basic principles and user requirements. The risk based approach can provide an alternative view of the relative risk of fundamentally different designs, all of which may, in their own manner, satisfy the basic principles.

A similar approach has already been developed for the assessment of the cost effectiveness of modifications to already operating design. This existing approach is more detailed but it also allows for the consideration of modifications that can change the reliability of plant systems and equipment or influence the frequency of faults occurring on the plant. [3].

6. 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 (and four user requirements) 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 in a sustainable manner in the future:

1. (Acceptability of Expected Adverse Environmental Effects) *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.*

2. (Fitness for Purpose) *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.*

Adherence to the principle that the present generation should not compromise the ability of future generations to fulfill their needs requires that the future be left with a healthy environment. Notwithstanding the major environmental advantages of nuclear technology in meeting global energy needs, the potential adverse effects that the various components of the nuclear fuel cycle may have on the environment must be prevented or mitigated effectively to make nuclear energy sustainable in the long term. Environmental effects include: physical, chemical or biological changes in the environment; health effects on people, plants and animals; effects on quality of life of people, plants and animals; effects on the economy; use/depletion of resources; and cumulative effects resulting from the influence of the system in conjunction with other influences on the environment. Both radiological and non-radiological effects as well as trade-offs and synergies among the effects from different system components and different environmental stressors need to be considered.

To be sustainable the system 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 system should also use them at least as efficiently as acceptable alternatives, both nuclear and non-nuclear.

All relevant factors (sources, stressors, pathways, receptors and endpoints) must be accounted for in the analysis of the environmental effects of a proposed energy system, and the environmental performance of a proposed technology needs to be evaluated as an integrated whole by considering the likely environmental effects of the entire collection of processes, activities and facilities in the energy system at all stages of its life cycle.

7. WASTE MANAGEMENT

Because *waste management* involves longer time scales and, in many cases, different source terms and pathways, compared with those considered in the safety of nuclear installations, this topic is dealt with in a separate chapter. The IAEA sets out nine fundamental principles for radioactive waste management in the document "Principles of Radioactive Waste Management Safety Fundamentals". Four INPRO basic principles for INS have been derived from these nine fundamental principles:

1. (Minimization) *Generation of radioactive waste in an INS shall be kept to the minimum practicable.*

2. (Protection of human health and 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.*

3. (Burdens 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.*

4. (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.*

Thus, 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. These principles in turn lead to INPRO user requirements (in total seven) to minimize the generation of waste with emphasis on waste containing long-lived toxic components that would be mobile in repository environment, to limit exposures to radiation and chemicals from waste, to specify a permanently safe end states for all wastes and to move wastes to this end state as early as practical, to classify wastes and to ensure that intermediate steps do not inhibit or complicate the achievement of the end state, and to accumulate assets for managing all wastes in the life cycle so that the accumulated liability at any stage of the life cycle is covered. It is also expected that prior work carried out by the IAEA in waste management will be used to the extent possible. RD&D is recommended to be carried out in a number of areas including partitioning and transmutation of long-lived fission products and minor actinides and long term human factors analysis to facilitate assessments of long term risks for waste management systems that require long term institutional controls.

8. PROLIFERATION RESISTANCE

In designing future nuclear energy systems, it is important to consider the potential for such systems to be misused for the purpose of producing nuclear weapons. Such considerations are among the key considerations behind the international non-proliferation regime a fundamental component of which is the IAEA safeguards system. INPRO set out to provide guidance on incorporating proliferation resistance into INS. The INPRO results in this area are largely based on the international consensus reached in October 2002 at a meeting held in Como, Italy and at follow up meetings held in March 2004 in Cheju, Republic of Korea, and in September 2004 in Vienna, Austria, where the feedback from the case studies were taken into account. Proliferation resistance is a combination of intrinsic features and extrinsic measures. Intrinsic features result from the technical design of INS including those that facilitate the implementation of extrinsic measures. 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.

Five categories of extrinsic features are defined, as follows: a) commitments, obligations and policies of states, such as the Treaty on the Non-Proliferation of Nuclear Weapons and the IAEA safeguards agreements and protocols additional to such agreements; b) agreements between exporting and importing states on exclusive use of nuclear energy systems for agreed purposes; c) commercial, legal or institutional arrangements that control access to nuclear material and technology; d) verification measures by the IAEA or by regional, bilateral and national measures; and e) legal and institutional measures to address violations of measures defined above.

INPRO has produced two basic principles (and five user requirements) that require that proliferation resistance features and measures be implemented throughout the full life cycle for INS and that both intrinsic features and extrinsic measures be utilized:

1. *Proliferation resistant features and measures shall be implemented throughout the full life cycle for INS to help ensure that INS will continue to be an unattractive means to acquire fissile material for a nuclear weapons programme.*

2. *Both intrinsic features and extrinsic measures are essential, and neither should be considered sufficient by itself.*

To comply with these basic principles requires that: the commitment and obligations of States be adequate; the attractiveness of nuclear material with respect to its suitability for conversion into nuclear explosive devices be low; the diversion of nuclear material be difficult and be detectable; multiple features and measures be incorporated in INS covering plausible acquisition paths of fissile material for a nuclear weapons programme; and that the combination of intrinsic features and extrinsic measures be optimized during design and engineering to provide cost-effective proliferation resistance. RD&D is needed in a number of areas, in particular, in developing a process to assess the proliferation resistance of a defined INS, taking into account the respective maturity level of the INS and the level of detail available.

9. INFRASTRUCTURE

Issues other than technical requirements are important to potential users of INS. Many of the factors that will either facilitate or obstruct the on-going deployment of nuclear power over the next fifty years relate to nuclear power *infrastructure*, both national infrastructure and that based on international arrangements. 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. Globalization and the importance of developing countries in future world energy markets point to the need to adapt infrastructures, both nationally and regionally, and to do so in a way that will facilitate the deployment of nuclear power systems in developing countries.

In a world with a growing need for sustainable energy, harmonization of regulations and licensing procedures could facilitate the application of nuclear technology. Such harmonization among different markets is in the interest of suppliers and developers of technology as well as users and investors. The development of innovative reactors to comply with the basic principles, user requirements and criteria dealing with safety, environment, waste management, and proliferation resistance set out in this report should facilitate such harmonization and could make it possible to change the way the production of nuclear energy is regulated. When, for example, 'there is no need for relocation or evacuation measures outside the plant site, apart from those generic emergency measures developed for any industrial facility used for similar purpose,' the requirements for licensing could possibly be simplified. In developing countries, and amongst them countries that do not have a highly developed nuclear knowledge base and infrastructure, the development of regional or international licensing and regulatory mechanisms and organizations could play an important role.

Such considerations have lead INPRO to define a basic principle for infrastructure:

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.

The associated user requirements (in total four) recognize the need for establishing a national legal framework, that the industrial and economic infrastructure of a country planning to install an INS be adequate, that measures are taken to secure public acceptance, and that adequate human resources are available for safe operations. Globalization brings with it the opportunity to draw on a much broader pool of resources rather than striving to maintain a complete domestic capability across the many disciplines of science and engineering that constitute the range of technologies on which nuclear energy systems depend. It is recognized that in adopting nuclear technology for the supply of energy requires some investment in national capability – at the very least to position a country to be a knowledgeable purchaser – but the idea is that a country has options concerning the upfront investment required because of the wide range of services and products available internationally, including operating and even regulatory services.

10. MODELLING

In performing an INPRO assessment, the assessor must take into account a reference energy scenario or scenarios. For example, if the assessor were focussed on energy supply in his state he would take into account a national energy scenario (or perhaps a more localized scenario based on a region within his country). Such a national scenario would also be expected to take into account global and/or regional considerations such as the global demand for uranium, reprocessing capacity, etc., and so would also have to use some elements of a regional or global scenario. If the assessor were interested in global energy supply as a component of sustainable development, he would necessarily utilize a broadly based scenario that takes into account various regions and country groupings to arrive at a global scenario. Such scenarios will use modelling tools, including existing tools that have been developed by the IAEA and those under development by INPRO, in particular the DESAE code.

The DESAE code, as currently developed, calculates the resources, both financial and material, required for a given combination of reactors to meet a specified supply of nuclear energy as a function of time. Thus the user can study the practicality of a proposed system and material balances such as uranium demand as function of time, waste arisings, plutonium re-cycling, etc. The code is at an early stage of development. Future developments will extend its use to include other sources of energy supply and to couple it with IAEA codes such as MESSAGE.

In general the use of such modelling tools is seen to be an important part of energy planning and of INPRO and the use of such tools will be integrated into the INPRO methodology as it is further developed.

11. ONGOING ACTIVITIES

In the ongoing Phase 1B (2nd part) the INPRO methodology is ready to be applied for the assessment of INS in national and multinational studies. Several INPRO members have indicated their interest to perform such studies. Examples are:

a) 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.

b) Transition from LWRs to Generation IV with fast neutrons in France.

c) Introduction of a bloc of 700 MWe of nuclear electricity power production based on either ACR700 or CAREM300 in Argentina.

d) Assessment of hydrogen generating innovative nuclear systems in Indian national energy mix.

e) Assessment of proliferation resistance of the whole DUPIC fuel cycle regarding proliferation resistance.

In addition to the assessment studies being performed, the INPRO manual with a detailed description of the methods of assessment in the different INPRO areas is being completed.

In parallel, the INPRO modelling tools, e.g. the computer code DESAE, are to be improved further based primarily on feedback received from the studies performed.

All these activities will lead to a continuous improvement of the INPRO methodology and are expected to identify possible frameworks and options for collaborative RD&D for INS to be performed in later phases of INPRO, as described in the next section.

12. OUTLOOK

Upon successful completion of Phase 1 in 2006, a second phase of INPRO, Phase 2, is planned to be initiated as per the decision of the INPRO steering committee, which represents the participated Member States. While some Member States may still require IAEA assistance in assessment of various INS options, the main objective of Phase 2, which is foreseen now, is to encourage and support IAEA Member States to cooperate in the research and development of safe, competitive, environmentally clean, and proliferation resistant INSs for sustainable development. This will/could be achieved by RD&D, institutional/infrastructure and methodology oriented activities:

RD&D oriented activities include the provision of a forum to enable identification and prioritization of RD&D needed as defined in Phase 1B, the facilitation of assessments of INSs, the identification of specific RD&D to be performed under IAEA/INPRO auspices, the assistance in assessing RD&D progress and reorientation and the preparation of country profiles on RD&D programs for innovative nuclear technologies.

Institutional/infrastructure oriented activities include the undertaking of relevant studies to evaluate the potential role of INS for sustainable development, the effort to promote the use of INS for electricity production and non-electrical applications, the identification of options for multi national fuel cycle facilities, the assistance for harmonization of licensing and industrial codes and standards, the facilitation of international design certification and the support of the analysis of fuel cycle strategies to determine best-suited solutions.

Methodology oriented activities include the further development of the INPRO methodology and the refinement of the assessment method.

Within Phase 2, INPRO activities will address the needs of both technology users and technology holders among the members with especial emphasis on the needs of developing countries.

INPRO will seek continued cooperation from other international initiatives like GIF.

12. CONCLUSIONS

The IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles is addressing the identification of a full spectrum of requirements for innovative technologies as well as the development of methodologies and guidelines for the comparison of different innovative approaches taking into account variations in potential demands across countries. INPRO can make major contributions by focusing on economic aspects, societal acceptability issues and those areas where IAEA can make unique contributions such as proliferation resistance, nuclear safety, waste management, sustainability issues and providing assistance to the user community.

In the area of safety risk based approach for the assessment of innovative nuclear power plants should be used in conjunction with the INPRO basic principles and user requirements. The risk based approach can provide an alternative view of the relative risk of fundamentally different designs, all of which may, in their own manner, satisfy the basic principles.

To enhance the potential for the deployment of innovative technologies, some changes in the infrastructure under which nuclear energy is developed and used, should be envisaged.

The final result of INPRO Phase 1B (first part) is a tested and validated methodology for assessing innovative nuclear energy systems to ascertain whether they are sustainable. Thus, Phase 1B (first part) was a decisive step toward INPRO's first objective of "*ensuring the availability of nuclear energy in a sustainable manner in the 21st century*".

In the ongoing Phase 1B (second part) the holistic assessments of complete INSs ("cradle to grave") will represent an important step towards fulfilling INPRO's second objective "*bringing together all Member States, to consider jointly the international and national actions required to achieve desired innovations*".

The work in the second part of Phase 1B and in the following Phase 2 will include all stakeholders in nuclear energy. In this way INPRO will meet its third objective "*to create 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 research, development and deployment of Innovative Nuclear Energy Systems in the 21st century.

ACKNOWLEDGEMENTS

The IAEA highly appreciates the guidance and advice given by INPRO Member States during Steering Committee meetings, and contributions from international experts participating in the consultancies and workshops to complete the INPRO Phase 1B (1st part) timely and successfully.

NOMENCLATURE

GIF	Generation IV International Forum
INS	innovative nuclear energy system
NGO	non government organization
RD&D	research, development and demonstration

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY; Guidance for the evaluation of innovative nuclear reactors and fuel cycles, Report of Phase 1A of the International Project on Innovative Nuclear Reactors and Fuel Cycles, TECDOC-1362, IAEA, Vienna (2003).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY; Methodology for the assessment of innovative nuclear reactors and fuel cycles, Report of Phase 1B (first part) of the International Project on Innovative Nuclear Reactors and Fuel Cycles, TECDOC-1434, IAEA, Vienna (2004).

[3] L. LANGLOIS, I. FACER, I. JALAL, Cost effectiveness of Plant Modification. The benefits of Risk Reduction. Presented at 2nd International Workshop "Communication on Risk Reduction" 7-9 June 2004, Moscow, Russia

