Sustainable Nuclear Energy

by Y. Sokolov and R. Beatty

Assessment tools developed by the IAEA assist Member States in strategic planning and decision making on sustainable nuclear energy development and deployment.

Long-range and strategic planning for energy system evolution and the potential role of nuclear energy therein requires a sound understanding of the dynamics of technology change and innovation. Careful consideration of energy related infrastructures, social preferences, economic development directions and environmental constraints must be part of national nuclear energy deployment. Nuclear Energy System Assessment (NESA) is an integral part of national nuclear power development along with energy planning and nuclear infrastructure development using the IAEA 'Milestones' approach for first nuclear power plants. In particular, adopting a nuclear power programme has intergenerational implications and obligations extending well beyond 100 years.

Energy planning aims at ensuring that decisions on energy demand and supply infrastructures involve all stakeholders, consider all possible energy supply and demand side options, and are consistent with overall goals of national sustainable development. The decision that nuclear energy will be part of a diverse energy mix should include reactor technology selection, infrastructure development required for first plants, and an understanding of the entire range of impacts and considerations related to deploying a sustainable nuclear energy system. This must include innovations in nuclear technology and institutional arrangements that contribute to, and are caused by, global evolution.

A nuclear energy system encompasses the complete spectrum of the nuclear fuel cycle, i.e. from mining to final end states for all wastes, and associated institutional arrangements. Nuclear energy systems are characterized by complex infrastructures and long life, easily extending over several generations. In addition, developing or expanding nuclear energy requires extensive lead times and resources, especially for the design and commercialization of new and innovative components. Nuclear energy systems must be assessed holistically, i.e., from all possible angles of sustainable development, which includes three interdependent and mutually reinforcing pillars: social development, economic development and environmental protection, all linked by effective government institutions.

Nuclear Energy System Assessment using the INPRO Methodology

To assist Member States in assessing their long range strategic planning for existing or future nuclear energy systems, the IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) developed the 'INPRO Methodology' with contributions from 300 international experts including some from the Generation IV International Forum (GIF). The Nuclear Energy System Assessment is a holistic approach that uses this internationally validated tool — the INPRO methodology — to support long-term planning and strategic decision making on nuclear energy development and deployment in Member States.

A prerequisite for a NESA is an energy planning study in case of newcomers — or a national energy strategy for countries with a mature nuclear power programme — that defines the potential role of nuclear in a mix of energy supply at the national level, however with due regard to regional and global trends. IAEA energy planning models assist energy planners in undertaking such studies. National authorities in charge of energy policy or nuclear energy system planning can initiate a full assessment or a scoping NESA.

A NESA with the INPRO methodology evaluates all nuclear facilities in a given nuclear energy system, from mining through to final end states for all

INPRO: A Partnership for Dialogue and Innovation

The IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) plays an important role in understanding the future development of nuclear energy systems from a national, regional and global perspective, and innovations in technologies and institutional arrangements in support of this development.

Established as a commitment of IAEA Member States to help ensure that nuclear energy is available to contribute to meeting the energy needs of the 21st century in a sustainable manner, INPRO brings together technology holders and users to consider jointly international and national actions that would result in required innovations in nuclear reactors and fuel cycles.

INPRO provides a forum for discussion and cooperation of experts and policy makers from industrialized and developing countries on all aspects of sustainable nuclear energy planning, development and deployment. It promotes a mutually beneficial dialogue between countries with nuclear technology and countries considering these technologies to develop new nuclear energy capacity. It also offers Member States support in national strategic planning and decision making on nuclear energy development and deployment, and enhances awareness of technology innovation options for the future.

IAEA Member States and recognized international organizations can become members of INPRO provided they make a contribution to the project. Contributions can be in the form of donating extra-budgetary funds, providing cost-free experts, performing assessment studies using the INPRO methodology or participating in INPRO collaborative projects.

Since its establishment in 2001, membership in INPRO has grown to 31 members. These countries represent 75% of the world's GDP and 65% of the world population.

Ten other countries have observer status as they consider membership or are participating on a working level. In addition, INPRO is collaborating with other international initiatives including the Generation IV International Forum (GIF) and the European Sustainable Nuclear Energy Platform (SNETP) to ensure good synergy and avoid duplication of effort.

Funded mainly by extra-budgetary contributions, the project now benefits from a recent commitment of the Russian Federation to provide resources for five years; this has added stability to the project and allows longer term planning. Recently, INPRO activities were consolidated into five main areas which also form the basis of the project's action plan for 2010 and 2011. Twelve collaborative projects sup-

wastes including permanent disposal of high-level waste, and all related institutional measures. It considers the complete lifecycle of nuclear facilities ('cradle to grave'), i.e. design, construction, operation and decommissioning, and evaluates a nuclear system in the seven areas identified by the methodology developers, which together encompass the dimensions of sustainable development: economics, infrastructure (institutional arrangements), waste management, proliferation resistance, physical protection, environment (impact of stressors, and resource depletion), and safety of reactors and of nuclear fuel cycle facilities.

Countries with established nuclear programmes, as well as nuclear 'newcomers' who are considering embarking on new nuclear programmes can conduct a NESA to identify possible gaps in their nuclear programme and associated actions to fill the gaps. This is targeted at:

❶ Nuclear technology developers, to assess their long-term development and deployment strategy to confirm that it is sustainable and that it has the correct balance of nuclear facilities;

❷ Experienced nuclear technology users, to increase the awareness of key stakeholders and assist with strategic planning and decision making concerning the expansion of their nuclear energy system;

❸ Prospective first time technology users, to identify issues that need to be considered when deciding the step by step development of a nuclear energy system, i.e. developing the necessary nuclear infrastructure and building a first nuclear power plant.

National Assessments

Recently, several countries performed a series of national NESAs: Argentina, Armenia, Brazil, India, Republic of Korea, and Ukraine. In addition, eight countries, i.e. Canada, China, France, India, Japan, Republic of Korea, Russian Federation, and Ukraine, port the activities with active participation of INPRO Members.

INPRO Programme Areas

Nuclear Energy System Assessments (NESAs) Using the INPRO Methodology
INPRO recently passed a milestone with the development and application of the INPRO methodology that can help countries assess existing and future nuclear energy systems in a holistic way and supports long-term strategic planning and decision making. After a first series of successful studies, eight additional countries have expressed interest in assessing existing or future nuclear energy systems to determine if they meet national sustainable development criteria.

Global Vision on Sustainable Nuclear Energy
By formulating potential scenarios and harmonizing visions for long-term global nuclear development and deployment, INPRO helps newcomers and 'mature' nuclear countries alike to understand the potential of technical innovations and of new institutional and legal approaches for developing and building a sustainable nuclear 'architecture' in the 21st century, including possible transition scenarios.

Promotion of Innovations in Nuclear Technology
Fostering collaboration among INPRO members on selected innovative nuclear technologies and related R&D, which contribute to sustainable nuclear energy, are key activities in this area.

Promotion of Innovations in Institutional Arrangements
In addition to the complete spectrum of the nuclear fuel cycle, institutional arrangements are also part of the nuclear energy system. Such arrangements include agreements, treaties, national and international legal frameworks or regimes, and conventions. Deploying new reactor designs may require innovative approaches to institutional measures, in particular for non-stationary, small and medium-sized reactors. INPRO fosters collaboration in this area and supports countries in developing and implementing innovative arrangements.

The INPRO Dialogue Forum
This cross-cutting area aims at fostering the information exchange between nuclear technology holders and technology users to ensure that future technical and institutional innovations meet the expectations of both.

INPRO members are Algeria, Argentina, Armenia, Belarus, Belgium, Brazil, Bulgaria, Canada, Chile, China, the Czech Republic, France, Germany, India, Indonesia, Italy, Japan, The Republic of Korea, Kazakhstan, Morocco, the Netherlands, Pakistan, the Russian Federation, Slovakia, South Africa, Spain, Switzerland, Turkey, Ukraine, the United States of America and the European Commission.
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jointly investigated a nuclear energy system consisting of sodium cooled fast reactors with a closed fuel cycle (see box "Closed Fuel Cycle With Fast Reactors").

The national NESA studies were conducted by countries of both technology users and developers and included different scales of assessments. Argentina and Ukraine evaluated the sustainability of their planned national nuclear energy systems by assessing all facilities of the nuclear fuel cycle. Brazil, India and the Republic of Korea assessed specific reactor designs and associated fuel cycles in selected areas of the INPRO methodology. The Brazil team chose the IRIS reactor design and assessed it in the areas of safety and economics. In addition, the Fixed Bed Nuclear Reactor (FBNR) design was assessed for sustainability in the areas of safety and proliferation resistance. The Indian study investigated the replacement of fossil fuel by hydrogen in the transportation sector. The prime objective of the Korean study was to develop a qualitative analysis to determine the level of proliferation resistance of the DUPIC fuel cycle, where spent PWR fuel is transformed into new fuel for CANDU reactors. Armenia performed a NESA primarily to familiarize national decision makers with all issues of the planned nuclear power programme of replacing the existing reactor by a larger unit around 2025.

The Joint Study explored several possible scenarios through modelling of how different nuclear technologies could contribute to fulfilling the expanded role of nuclear energy and what kinds of problems and approaches might be considered to allow an easy transition to a closed nuclear fuel cycle with fast reactors.

INPRO methodology

The INPRO Methodology is organized in a three-tier hierarchy of Basic Principles, User Requirements and Criteria, consisting of indicators and acceptance limits. These elements are used in the seven INPRO assessment areas. An assessed nuclear energy sys-

Closed Fuel Cycle with Fast Reactors

Over a period of two years, eight countries joined forces to assess a nuclear energy system based on a closed fuel cycle with fast reactors (CNFC-FR) with the INPRO methodology. The objective of this "Joint Study" was to determine whether a CNFC-FR would meet criteria of sustainable development, to define milestones for deploying nuclear energy and to establish areas which would require future collaborative R&D work. The countries were Canada, China, France, India, Japan, the Republic of Korea, the Russian Federation, and Ukraine. A near-term CNFC–FR system based on proven technologies, such as sodium coolant, MOX pellet fuel and aqueous reprocessing technology was used as a reference system.

A general observation was made that an optimized future for nuclear energy deployment may not be entirely consistent with current national planning. With the goal of making the CNFC-FR a viable alternative to conventional sources of power, the Joint Study identified some weak points in current national approaches that must be resolved. This refers specifically to economics and safety, where further research is necessary to achieve a lower level of risk of severe accidents.

The design of currently operating nuclear energy systems with CNFC–FR may not meet economic competition requirements. Simplifying the design, increasing the fuel burn up and reducing costs through targeted R&D, along with small series constructions, could make the costs of nuclear power plants with fast reactors comparable to those of thermal reactor and fossil fuelled power plants.

In some countries, the introduction of fast reactors might contribute to an efficient use of nuclear fuel resources by increasing the use of plutonium fuels and denaturated uranium fuel, to be generated in the fast reactor blankets, if needed.

By developing and introducing novel technologies for an optimal management of nuclear fission products and minor actinides, the CNFC–FR system would have the potential for a 'breakthrough' in meeting all of today's requirements of waste management.

Due to the technological features of the CNFC–FR system, its proliferation resistance could be comparable to, or higher than that of a once-through fuel cycle. The CNFC–FR system is a key technology for the balanced use of fissile materials.

A CNFC–FR system requires a regional or multilateral approach to front and back end fuel cycle services and the transition to a global nuclear architecture.

Since the Joint Study conclusions also called for an inter-disciplinary approach and international collaborations wherever possible, as a follow-up, several INPRO collaborative projects were initiated which address the issues identified:

› Global architecture of nuclear energy systems based on thermal and fast reactors including a closed fuel cycle (GAINS);

› Integrated approach for the design of safety grade decay heat removal system for liquid metal cooled reactor (DHR);

› Assessment of advanced and innovative nuclear fuel cycles within large scale nuclear energy systems based on CNFC concept to satisfy principles of sustainability in the 21st century (FINITE); and

› Investigation of technological challenges related to the removal of heat by liquid metal and molten salt coolants from reactor cores operating at high temperatures (COOL).

tem represents a source of energy consistent with a country's sustainable development criteria, if all principles, requirements and criteria are met. If the assessment points to a gap, further R&D studies should be undertaken.

If not all components are met, a given nuclear energy system may still make a significant, interim contribution to meeting the energy needs of a country or region, but will need to change and evolve to become sustainable in the longer term. The results of a NESA can be used to guide this evolution.

An IAEA publication describes how to conduct a NESA using the INPRO methodology: *Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems: INPRO Manual — Overview of the Methodology (TECDOC 1575 Rev.1).*

Yuri Sokolov is IAEA Deputy Director General, Department of Nuclear Energy, and INPRO Project Manager. E-mail: Y.Sokolov@iaea.org.

Randy Beatty is the INPRO Group Leader at the IAEA. E-mail: R.Beatty@iaea.org.