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

2009 Progress Report

IAEA

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Innovative Nuclear Reactors
and Fuel Cycles

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Foreword

The world, and in particular the nuclear world, has substantially changed since the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) was established in 2000. The first few years of the 21st century have brought an increased awareness of the importance of balancing the standard of living among all countries in the world, with the added constraints of continuous growth in world population and increased pressure to minimize environmental impacts. It seems clear then that the common goal of achieving economic and social development in a sustainable manner results in a rising demand for energy, and in particular low carbon emitting energy sources. In that sense, nuclear power has moved to the top of the list of potential energy sources that countries may choose to power their development. This has led the IAEA to add to its better known role as enforcer of safeguards, safety and security standards the role of providing assistance in developing and deploying new nuclear power programmes or expanding existing ones.

However, these fast and substantial changes in the nuclear world are probably just the beginning. The nuclear landscape may look rather different in 2020. Given the inherent long term nature associated with nuclear matters, it is more important than ever to be strategic and to plan ahead.

The IAEA supports Member States in long term strategic planning and decision making on nuclear energy programmes and is in the unique position to offer — through INPRO — a global forum for cooperation on innovative nuclear energy systems and innovative deployment strategies. International studies and collaborative projects are a mechanism for meeting INPRO's objective of fostering innovation and sustainable nuclear energy development. They enable groups of Member States to collaborate closely on assessing the sustainability of existing or planned nuclear energy systems with the INPRO Methodology, formulating and harmonizing scenarios and providing visions for global nuclear power development, and considering technological and institutional innovations that are the backbone for long term nuclear energy deployment.

Last year, 2009, was a year in which INPRO made a major step forward in all its activities, as documented in this report. As a membership based and multilateral project, INPRO benefits from the contributions of 30 IAEA Member States, the European Commission and all relevant IAEA programmes. International cooperation and collaboration are instrumental to the project and INPRO also works in synergy with other international initiatives such as the Generation IV International Forum. The results of INPRO's activities are available to all IAEA Member States, for example, through publications, web sites and presentations at international meetings. It should be noted that INPRO is funded mainly from extrabudgetary resources, i.e. from voluntary contributions by INPRO members.

This year, 2010, will be another important year for the project, as it marks its 10th anniversary and continues to work on issues related to innovations in nuclear technologies and fuel cycles for deployment in the 21st century, in close collaboration with Member States. Several studies and collaborative projects will be concluded and the results published by the IAEA.

As Project Manager of INPRO, I am pleased to present this progress report on INPRO activities in 2009, highlighting joint achievements by the IAEA Secretariat and INPRO Member States. I invite you to support INPRO activities in the coming years and to join us for the 10th anniversary events in September 2010 during the 54th General Conference of the IAEA.

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INPRO – 2009 Highlights

A Partnership for Dialogue and Innovation in a Changing Nuclear World Adds Value for Member States

An integrated approach for long term planning and strategic decision making on existing and planned nuclear energy programmes is offered to Member States through IAEA energy planning models and Nuclear Energy System Assessments (NESAs) using the INPRO Methodology.

A NESA support package — including documentation of the INPRO Methodology (IAEA-TECDOC-1575), a user's guide on how to perform a NESA, training courses and support materials, on-line access to reactor and nuclear fuel cycle data, and available expertise in Member States and at the IAEA — supports Member States in verifying the sustainability of their existing or planned nuclear energy system.

A NESA in Belarus was initiated, with strong support from the Russian Federation as a strategic partner, and with IAEA assistance. This is a reference assessment which will provide guidance and specific examples to Member States wishing to assess their nuclear energy system in the future.

Member States can engage in a Dialogue Forum on Nuclear Energy Innovations where technology holders, technology users and other stakeholders discuss issues of deploying technology innovations. Candidate topics for this key objective, developed by INPRO in 2009, were identified in close consultation with the INPRO Steering Committee.

Member States have built a consensus in scientific–technical studies on the possible global scenarios for nuclear energy growth. Consensus is the key, as these scenarios constitute the background against which all national programmes can consider actions which will aid in their nuclear energy programme development. For the first time, a common reference framework for global nuclear energy growth and fissile material flow has been prepared and through Member State consultations will be finalized in the near future.

Member States have joined forces under the INPRO umbrella to study a global architecture of innovative nuclear systems based on thermal (TRs) and fast reactors (FRs) including closed fuel cycles. Scenarios based on synergy between different types of approach to nuclear energy deployment illustrate the contribution that FRs can make to world energy supply. A larger fleet of FRs, and developing them in synergy with TRs, would decrease the consumption of natural uranium and result in considerable uranium savings.

The role of thorium as a supplement to the uranium–plutonium fuel cycle was investigated in a scenario envisaging a significant increase in nuclear energy use in the world. The thorium fuel cycle was considered to be potentially more proliferation resistant since it may eliminate enrichment and make spent fuel reprocessing more sophisticated. Member States and INPRO identified three possible groups of fuel cycle options suitable for a short to medium term application.

When an FR shuts down, the removal of decay heat is one of the most important safety functions and requires a very high degree of reliability. Research institutions in several Member States are investigating decay heat removal systems through a number of case studies and will compare results to identify the most robust one.

Within INPRO's programme, Member States discuss issues associated with institutional innovations and unique institutional frameworks which need to be addressed to accommodate innovative reactor approaches. An example includes transportable nuclear power plants (TNPPs), which are of potential interest to Member States considering niche applications of nuclear energy, such as in areas with limited infrastructure, countries with small electrical grids, remote or isolated areas, and non-electrical applications, e.g. desalination of sea water and hydrogen production. Although no operating TNPP currently exists, several countries are designing new technologies or constructing transportable plants.

Nuclear energy has a relatively low burden on the atmosphere and on water and land use. Nevertheless, assessing the environmental impacts of nuclear power plants (under normal operation) is of interest to many Member States. The release of environmental stressors (radionuclides) through the atmosphere or water, and the impacts on human health through inhalation or ingestion via the food chain are investigated by Member States and INPRO. The result will help Member States to determine which radionuclides have the highest health related impacts on people.

INPRO 2009 in Numbers

3	new INPRO members: Algeria, Italy, Kazakhstan
5	technical reports published
6	new INPRO Programme Areas
11	INPRO Collaborative Projects
12	cost free experts at INPRO/IAEA Secretariat in the course of 2009
13	international conferences attended by INPRO Group members
25	meetings held at IAEA headquarters and 5 meetings hosted by Member States
31	INPRO members at the end of 2009
543	participants from Member States at all INPRO meetings in 2009

I. INPRO

Concerns over energy resource availability, climate change and energy security suggest an important role for nuclear power in supplying energy in the 21st century. Any major future increase in the use of nuclear power will be fostered by innovation in reactor and fuel cycle technologies, along with innovation in institutional arrangements and deployment, while meeting criteria for sustainable development. International cooperation is important to facilitate such innovation, both technical (involving R&D) and institutional. Dialogue between today's technology developers and holders, and current and prospective technology users contributes to developing a joint understanding of the challenges and opportunities of nuclear technology to meet future energy needs in a sustainable manner.

The IAEA is in a unique position to provide a global forum for such cooperation on innovative nuclear energy systems and innovative deployment strategies. In response to related Member State requests, INPRO was established in 2000 to help ensure that nuclear energy is available to contribute to meeting the energy needs of the 21st century in a sustainable manner. It is a mechanism to enable IAEA Member States that have joined the project to collaborate on innovations in nuclear energy systems.

INPRO provides a forum in which technology holders and users jointly consider innovations that would support the sustainable development of nuclear energy. The project brings together experts and policy makers from industrialized and developing countries to discuss and cooperate on sustainable nuclear energy planning, development and deployment. INPRO also offers Member States support in long term strategic planning and decision making on nuclear energy development and deployment, and enhances awareness of technology innovation options for the future.

INPRO is implemented with contributions from INPRO members and all relevant IAEA programmes and in synergy with other international initiatives, such as the Generation IV International Forum (GIF) and the Sustainable Nuclear Energy Technology Platform (SNETP). The results of INPRO's activities are made available to all IAEA Member States.

Since its establishment, INPRO has found continued strong support from Member States through resolutions[1] of the IAEA General Conference and from world leaders, for example the G8.

> "The development of innovative nuclear power systems is considered an important element for efficient and safe nuclear energy development. In this respect, we acknowledge the efforts made in the complementary frameworks of the INPRO project and the Generation IV International Forum."
>
> G8 Summit, Global Energy Security, St. Petersburg 2006

Membership

IAEA Member States and recognized international organizations can become members of INPRO provided they make a contribution to the project. Contributions can be made by donating extrabudgetary funds, providing cost free experts, performing assessment studies using the INPRO Methodology or participating in INPRO Collaborative Projects.

INPRO is mainly funded by extrabudgetary contributions from Member States. In 2009, the Russian Federation made a five-year commitment to support INPRO which has given the project more stability and continuity and allowed longer term planning. Since 2001, when INPRO started its operations, 38 cost free experts from 16 Member States have contributed to the project's achievements.

By the end of 2009, INPRO had 31 members, representing 75 per cent of the world's gross domestic product and 65 per cent of the world population. The members are: Algeria, Argentina, Armenia, Belarus, Belgium,

[1] GC Resolutions: 2000: GC(44)/RES/21; GC(44)/RES/22; 2001: GC(45)/RES/12; 2002: GC(46)/RES/11; 2003: GC(47)/RES/10; 2004: GC(48)/RES/13; 2005: GC(49)/RES/12; 2006: GC(50)/RES/13 ; 2007: GC(51)/RES/14 ; 2009: GC(53)/RES/13.

Brazil, Bulgaria, Canada, Chile, China, the Czech Republic, France, Germany, India, Indonesia, Italy, Japan, Kazakhstan, the Republic of Korea, Morocco, Netherlands, Pakistan, the Russian Federation, Slovakia, South Africa, Spain, Switzerland, Turkey, Ukraine, the United States of America and the European Commission. Ten other countries have observer status as they are either considering membership or are participating at a working level.

INPRO Steering Committee

A Steering Committee guides INPRO's activities. It consists of representatives from all INPRO members and observers who meet regularly to review progress and provide guidance on future activities. Every two years, the Committee endorses the INPRO Action Plan which defines programme areas, detailed tasks and priorities for implementing INPRO activities. In February and November 2009, the INPRO Steering Committee met at the IAEA for the 14th and 15th meetings, respectively.

FIG. 1. 15th Meeting of the INPRO Steering Committee, IAEA, 9–11 November 2009.

Project Management

The INPRO Project Manager is Yury Sokolov, IAEA Deputy Director General and Head of the Department of Nuclear Energy. He is supported by the INPRO Policy Coordinator, the Director of the Division of Nuclear Power. The INPRO Group Leader, with support from the INPRO Programme Liaison Officer, manages the work of the INPRO group at the Secretariat, which consists of regular IAEA staff, cost free experts provided by INPRO members and consultants. The involvement of senior representatives from other IAEA programmes, the Area Coordinators, ensures effective coordination within the IAEA Secretariat.

Cooperation within the IAEA

Owing to the cross-cutting nature of INPRO, close cooperation within the IAEA is key to ensuring synergy with the IAEA's programmes related to all aspects of innovative nuclear reactors and fuel cycles. Involvement of other IAEA programmes in INPRO activities, and vice versa, and regular meetings with Area Coordinators

ensure exchange of information, identify topics of common interest and foster effective cooperation on INPRO activities. Cooperation on individual studies and collaborative projects is highlighted throughout this report.

International Collaboration

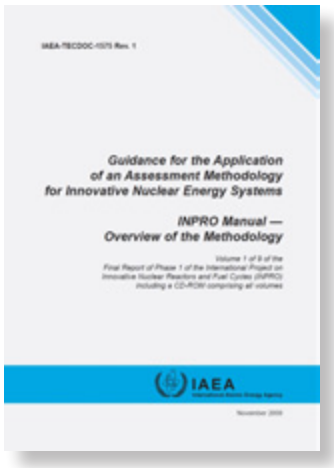
INPRO is collaborating with other international initiatives to ensure good synergy of activities and avoid duplication of efforts, including GIF and SNETP.

GIF[2] was established to lead the collaborative efforts of the world's leading nuclear technology nations to develop next generation nuclear energy systems to meet future energy needs. Recognizing the complementary nature of their programmes, and the potential for creating synergies in nuclear technology development, INPRO and GIF hold regular interface meetings. INPRO experts attend meetings of the GIF Policy Group and GIF Working Groups on Risk and Safety, Proliferation Resistance and Physical Protection, and Economic Evaluation Modelling, while GIF experts participate in meetings of the INPRO Steering Committee.

Similar to INPRO, SNETP[3] seeks to formulate long term visions for nuclear development. This European platform promotes R&D on innovative nuclear fission technologies and long term nuclear waste management. Working contacts between SNETP and INPRO have been established to ensure sharing of information and coordination of activities. Strengthening relations and cooperation with other international organizations and initiatives will be a focus of attention in 2010.

History of INPRO's Activities

During phase 1 of INPRO (2001–2006), activities focused mainly on developing an evaluation method — the **INPRO Methodology** — that can be used to assess whether or not a given nuclear energy system will contribute to meeting a country's energy needs in a sustainable manner, or will require follow-up actions including R&D studies to achieve a sustainable nuclear contribution. Developed with contributions from 300 international experts, the INPRO Methodology is a tool to assess nuclear energy systems and innovative technologies, including all nuclear fuel cycle facilities during their lifetime, in seven assessment areas: (i) economics, (ii) infrastructure (institutional arrangements), (iii) waste management, (iv) proliferation resistance, (v) physical protection, (vi) environment (impact of stressors and resource depletion) and (vii) safety of reactors and nuclear fuel cycle facilities.



Three IAEA publications documented the INPRO Methodology:

(1) *Guidance for the Evaluation of Innovative Nuclear Reactors and Fuel Cycles*, IAEA-TECDOC-1362 (2003);

(2) *Methodology for the Assessment of Innovative Nuclear Reactors and Fuel Cycles*, IAEA-TECDOC-1434 (2004);

(3) *Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems: INPRO Manual — Overview of the Methodology*, IAEA-TECDOC-1575-Rev.1 (2008).

This third, nine-volume publication, including an accompanying CD-ROM that describes the application of the INPRO Methodology in all assessment areas, represents the final report of phase 1 of INPRO.

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2 The current members of the GIF are: Argentina, Brazil, Canada, China, France, Japan, the Republic of Korea, the Russian Federation, South Africa, Switzerland, the United Kingdom, the USA and Euratom.

3 SNETP gathers about 70 European stakeholders from industry, research and academia, technical safety organizations, non-governmental organizations and national representatives.

At the beginning of the phase 2 of INPRO in 2006, the project's work was focused on three main activities: (i) methodology improvement, (ii) infrastructure/institutional aspects and (iii) collaborative projects. Within these main directions, six topical tasks were implemented in the INPRO Action Plan for 2008–2009: Task 1: INPRO Methodology; Task 2: Assessment Studies; Task 3: Nuclear Energy Visions for the 21st Century; Task 4: Infrastructure and Institutional Innovation; Task 5: Common User Considerations by Developing Countries for Future Nuclear Energy Systems; Task 6: INPRO Collaborative Projects. Two additional tasks — INPRO communications and convening of Steering Committee meetings — provided support to the project as a whole. The 11 INPRO Collaborative Projects, covering different issues of innovative nuclear reactors and fuel cycles, were selected from over 90 projects proposed by INPRO members. Initiated between 2007 and 2009, these projects support national and international R&D activities and contribute to INPRO's main programme areas. The collaborative projects are carried out with the participation of INPRO members, and most will be concluded in 2010 or 2011.

Six countries (Argentina, Armenia, Brazil, India, the Republic of Korea and Ukraine) conducted assessments of existing or planned national nuclear energy systems using the INPRO Methodology. A group of eight countries (Canada, China, France, India, Japan, the Republic of Korea, the Russian Federation and Ukraine) completed a similar joint study of the closed fuel cycle using FRs. The results and lessons learned are used to update and improve the INPRO Methodology.

A two year effort developed common user considerations (CUC) to identify commonalities in the expectations held by developing countries considering the introduction of nuclear power. The work, concluded in 2008, was documented in an IAEA publication: *Common User Considerations (CUC) by Developing Countries for Future Nuclear Energy Systems: Report of Stage 1* (IAEA Nuclear Energy Series No. NP-T-2.1).

In 2008, the organizational structure for INPRO activities at the IAEA was reorganized and positions for an INPRO Group Leader and an INPRO Programme Liaison Officer were introduced to ensure stability of the project management.

II. Progress of INPRO in 2009

Overview

Last year, 2009, was the year in which INPRO made a major leap forward in fulfilling its vision of fostering sustainability and technological innovation so that nuclear energy can make a significant contribution to meeting global energy demand in a sustainable manner. The INPRO Action Plan for the next biennium (2010–2011), first drafted and discussed at the 14th meeting of the INPRO Steering Committee meeting in February 2009, was finalized and approved at the 15th meeting of the INPRO Steering Committee in November 2009. The new Action Plan serves to address the need for sustainable and affordable nuclear energy, charts the way forward for INPRO's activities in the next biennium and includes a new structure for the project's work. This programmatic structure was already implemented in 2009, following the 14th Steering Committee meeting, to achieve a smooth transition and effective implementation of activities during the coming years.

The main results for 2009 in the six new programme areas are summarized in the following section, including topical studies and collaborative projects. Most of them were already initiated in previous years and are undertaken with active participation of INPRO members. Although the focus is on activities pursued in 2009, a brief overview of each area is given as background to put the work undertaken into perspective. More details on the technical aspects of the work described may be found in the publications and articles listed in the bibliography at the end of this report and on the INPRO web site: *www.iaea.org/INPRO*

Programme Area A: Nuclear Energy System Assessments (NESAs) using the INPRO Methodology

Through activities in this programme area, INPRO assists Member States in assessing existing or future nuclear energy systems in a holistic way to determine if such systems meet national sustainable development criteria. A NESA using an internationally validated tool, the INPRO Methodology, aids Member States in strategic planning and decision making on long term nuclear energy deployment. A NESA can be undertaken by countries with established nuclear programmes, for example, to assess the transition from the current fleet of reactors to a nuclear energy system with innovative technologies, by countries developing new technology and by those considering or embarking on new nuclear energy programmes.

FIG. 2. Structure of the INPRO Methodology.

Collaborative Projects in Programme Area A concentrated their research studies in 2009 on two of the seven assessment areas of the INPRO Methodology, i.e. proliferation resistance and environment:

(1) *Proliferation Resistance: Acquisition/Diversion Pathway Analysis* (PRADA);

(2) *Environmental Impact Benchmarking Applicable for Nuclear Energy Systems under Normal Operation* (ENV).

Programme Area B: Global Vision, Scenarios and Pathways to Sustainable Nuclear Development

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

INPRO Collaborative Projects in this area include:

- *Global Architecture of Innovative Nuclear Systems based on Thermal and Fast Reactors including Closed Fuel Cycles* (GAINS);
- *Fuel Cycles for Innovative Nuclear Systems through Integration of Technologies* (FINITE);
- *Meeting Energy Needs in the Period of Raw Materials Insufficiency during the 21st Century* (RMI);
- *Further Investigations of the* ^{233}*U/Th Fuel Cycle* (ThFC).

Programme Area C: Innovations in Nuclear Technology

An important objective of performing assessments of nuclear energy systems is to identify gaps in the various technologies and corresponding R&D needs. This programme area fosters collaboration among INPRO members on selected innovative nuclear technologies to bridge technology gaps. Collaborative projects have been selected so that they complement other national and international R&D activities and address the following topics:

- *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);
- *Decay Heat Removal System for Liquid Metal Cooled Reactors* (DHR);
- *Advanced Water Cooled Reactors* (AWCR);
- *Performance Assessment of Passive Gaseous Provisions* (PGAP).

Programme Area D: Innovations in Institutional Arrangements

Institutional arrangements are also an important part of the nuclear energy system, including agreements, treaties, 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.

One INPRO Collaborative Project contributes to activities in this area:

- *Implementation Issues for the Use of Nuclear Power in Small Countries* (SMALL).

Programme Area E: INPRO Dialogue Forum on Nuclear Energy Innovations

This cross-cutting programme area, implemented in close conjunction with the IAEA's technical cooperation programme and thematically with other programmes, 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 long term sustainability. The forum also addresses national long term nuclear energy planning and the global nuclear energy system.

Programme Area F: Policy Coordination, Communication and INPRO Management

Programme Area F encompasses the project management of INPRO, including strategic programme planning, organization of meetings of the Steering Committee and policy coordination with other international initiatives. Effective and targeted communication with INPRO stakeholders focuses on outreach activities such as dissemination of INPRO results through publications and the web site, and participation in international conferences and other events.

A. NESAs Using the INPRO Methodology

A.1. Introduction

The IAEA supports Member States in strategic planning and decision making on nuclear power programmes. NESAs are an integral part of national nuclear power development, along with IAEA energy system planning models and the IAEA 'milestones'[4] approach for developing nuclear infrastructure for a country's first nuclear power plant.

Nuclear energy systems are characterized by complex infrastructures and longevity easily extending over several generations. Also, developing or expanding nuclear energy systems requires extensive lead times and resources, especially for the design and commercialization of new and innovative components. It is therefore prudent to assess nuclear energy systems holistically by considering all possible factors that influence them long term, including the dimensions of sustainable development[5].

A NESA helps energy planners in Member States make informed decisions on the choice of the most appropriate nuclear system and to determine whether their strategic deployment plan is sustainable. The IAEA offers Member States support in the application of a NESA using the INPRO Methodology.

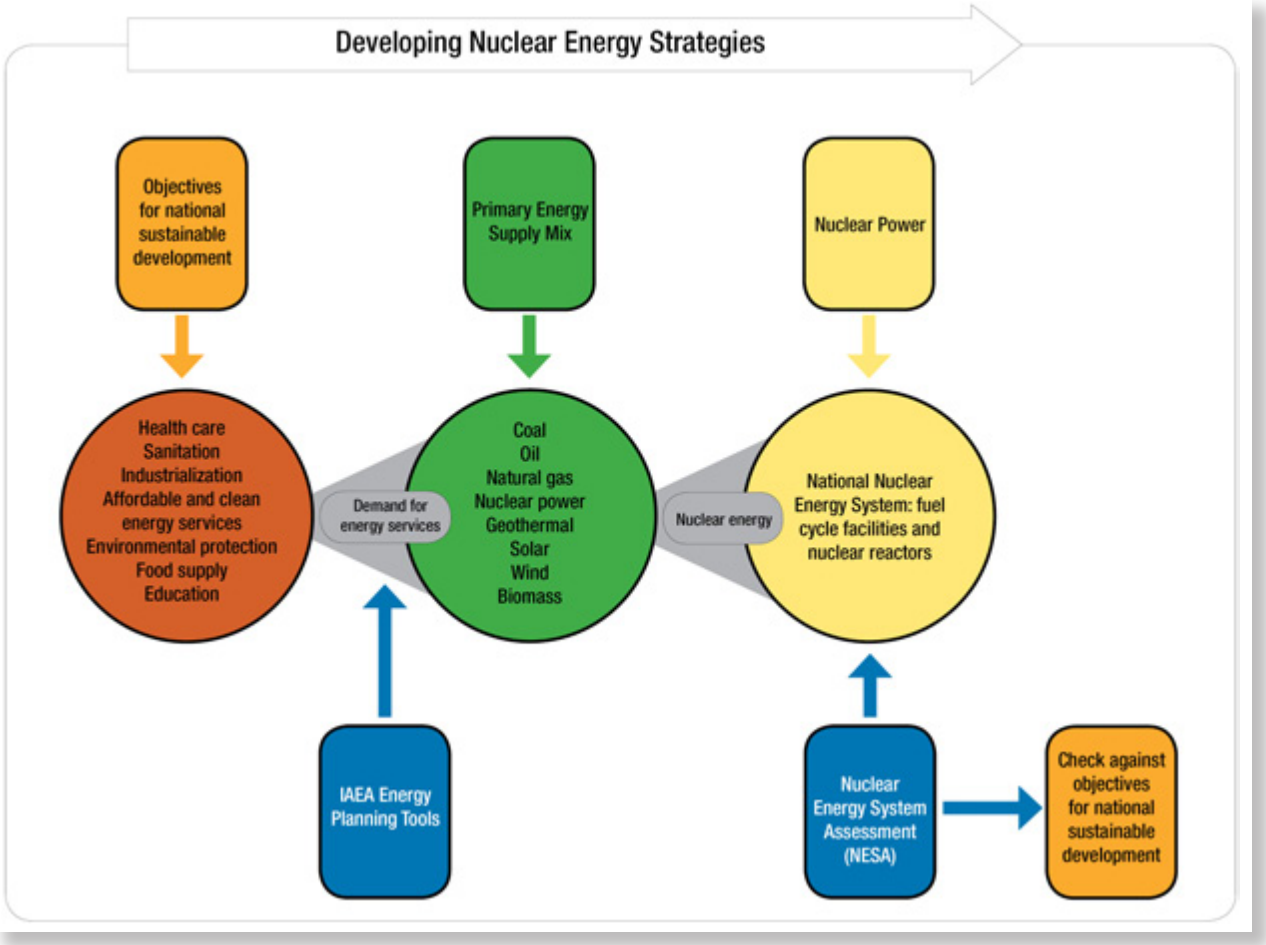


FIG. 3. IAEA energy planning tools and methodologies to support national sustainable (nuclear) energy planning.

[4] Milestones in the Development of a National Infrastructure for Nuclear Power (IAEA Nuclear Energy Series No. NG-G-3.1).

[5] The World Commission on Environment and Development (1987) defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" and identified four essential dimensions: economic, social, environmental and institutional.

Using NESA for Long Range Strategic Planning of Nuclear Energy Programmes

NESAs are of benefit to countries with established nuclear programmes, to countries developing new technology and for those considering or embarking on new nuclear programmes, to assess if their current or future nuclear systems will contribute to meeting the sustainable development criteria of a country. In particular, a NESA evaluates:

- *All nuclear facilities in a given nuclear energy system, from mining through to final end states for all wastes and permanent disposal of high level waste, and all related institutional measures such as legal framework, regulatory bodies, etc.*
- *The complete life cycle of the facility ('cradle to grave'), i.e. design, construction, operation and decommissioning.*
- *All assessment areas defined in the INPRO Methodology.*

Given its comprehensive nature, a NESA with the INPRO Methodology is targeted at:

- *Nuclear technology developers, to identify possible gaps in R&D and associated actions to fill those gaps;*
- *Experienced nuclear technology users, to assist with strategic planning and decision making concerning the development or expansion of a nuclear energy system;*
- *Prospective first time nuclear technology users, to identify issues that need to be considered when deciding on the step by step development of a nuclear energy system (i.e. building a first nuclear power plant and developing the necessary infrastructure with support from the IAEA infrastructure team) for long term energy supply, and to assist such users in their planning and decision making.*

The INPRO Methodology — A Tool for NESAs

The INPRO Methodology (see p. 7) comprises a three tier hierarchy of basic principles, user requirements and criteria with indicators and acceptance limits to assess a nuclear energy system in seven areas, which together encompass the dimensions of sustainable development:

(i) Economics;

(ii) Infrastructure (institutional arrangements);

(iii) Waste management;

(iv) Proliferation resistance;

(v) Physical protection;

(vi) Environment (impact of stressors and resource depletion);

(vii) Safety of reactors and nuclear fuel cycle facilities.

If all criteria, user requirements and basic principles are met in the assessment areas, the nuclear energy system represents a source of energy consistent with a country's sustainable development criteria. If not all components are met, a given nuclear energy system may still represent an excellent interim energy supply system, 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.

The INPRO Methodology is documented in a nine volume publication: *Guidance for the Application of an Assessment Methodology for Innovative Nuclear Energy Systems: INPRO Manual — Overview of the Methodology* (IAEA-TECDOC-1575 Rev. 1 (2008)).

A.2. Lessons Learned from NESAs

Six countries (Argentina, Armenia, Brazil, India, the Republic of Korea and Ukraine) conducted assessments of existing or planned national nuclear energy systems using the INPRO Methodology from 2005 to 2008. Eight countries (Canada, China, France, India, Japan, the Republic of Korea, the Russian Federation and Ukraine) completed a similar joint study of the closed fuel cycle with FRs. The national assessment studies included recommendations for enhancing the INPRO Methodology and simplifying its application, for example through a set of support materials and targeted activities, later defined as a NESA support package.

The results of these NESAs, lessons learned and recommended follow-up actions were discussed at a workshop in February 2009. The meeting, sponsored by the IAEA (*INT/4/142: Promoting Technology Development and Application of Future Nuclear Energy Systems in Developing Countries*), brought together representatives from ten INPRO members, i.e. Argentina, Armenia, Brazil, Canada, China, India, Japan, the Republic of Korea, the Russian Federation and Ukraine. All participants confirmed that the INPRO Methodology was a useful tool to assess how innovative nuclear energy systems can contribute to sustainable nuclear energy development and deployment, and to identify gaps to be bridged by further R&D studies.

In 2009, the IAEA published experiences gained in all NESAs in: *Lessons Learned from Nuclear Energy System Assessment (NESA) using the INPRO Methodology* (IAEA-TECDOC-1636). The complete reports of all seven assessment studies were compiled in a working document (plus CD-ROM) for limited distribution. Another technical document, which summarizes the results of the joint study and includes the study's full report on CD-ROM, was prepared for publication with the title: *Assessment of Nuclear Energy Systems Based on a Closed Nuclear Fuel Cycle with Fast Reactors (CNFC–FR)* (IAEA-TECDOC-1639).

Nuclear Energy System Assessments							
Assessment areas of the INPRO Methodology	**Argentina (NFC)**	**Armenia**	**Brazil (IRIS, FBNR)**	**India (HTR)**	**Republic of Korea (DUPIC)**	**Ukraine**	**Joint Study (CNFC–FR)**
Economics	x	x	x			x	x
Infrastructure	x	x				x	x
Waste management	x	x				x	x
Proliferation resistance	x	x	x		x	x	x
Physical protection	x	x					
Environment	x	x				x	x
Safety of reactors		x	x	x		x	x
Safety of fuel cycle facilities	x					x	x

TABLE 1. Assessment areas covered in NESAs (IAEA-TECDOC-1636).

A.3. NESA Support Package

In response to the workshop's recommendations, presented at the 14th meeting of the INPRO Steering Committee, a NESA support package was developed in 2009. It includes a user's guide on how to perform a NESA, differentiating between three types of assessors: (i) a nuclear technology developer, (ii) an experienced user of nuclear technology and (iii) a prospective first time user of nuclear power. A draft version of this user's guide was finalized in 2009.

The package offers comprehensive assistance from the IAEA, including identifying the required national technical expertise to perform a NESA, full documentation of the INPRO Methodology, specifying input data necessary for a NESA and providing links to sample data, convening workshops in the country where a NESA is to be performed, and continuous access to IAEA expertise in all assessment areas. An Excel spreadsheet named NEST (NESA economics support tool) was designed, which facilitates calculations of all economic parameters of the methodology. Additional features of the NESA support package will be developed next year, such as on-line access to reactor data and nuclear fuel cycle facilities required for assessment.

A.4. NESA in Belarus

At the 14th INPRO Steering Committee meeting in February 2009, several countries, including Belarus, expressed an interest in conducting a national NESA. Subsequently, Belarus embarked on performing a full scope comprehensive assessment with support from the Russian Federation. The terms of reference for this project were determined at a 'kick off' meeting at the end of July in Minsk. INPRO also organized a training workshop in Belarus in September 2009 to familiarize the national NESA team with the methodology.

FIG. 4. NESA training workshop, 28 September to 2 October 2009, Joint Institute for Power and Nuclear Research (SOSNY), Minsk, Belarus.

The assessed nuclear energy system consists of the first two nuclear power plants to be built in Belarus by 2016 and 2018, respectively, together with associated waste management facilities. In view of the holistic approach of the INPRO Methodology, all other nuclear fuel cycle facilities located outside the country will also be evaluated with support from the Russian Federation. The assessment of the nuclear energy system of Belarus will be finalized in 2010.

A.5. Workshop on Assisting Member States in Long Term Energy Planning and Development

In July 2009, 50 representatives from over 40 Member States came together at the IAEA for a *Workshop on IAEA Tools for Nuclear Energy System Assessment for Long Term Planning and Development* to learn about the integrated use of these tools and methods for national energy and nuclear energy planning and development.

The meeting also enabled participants to establish a network for the exchange of information of developing countries between themselves and with technology suppliers.

The workshop was jointly organized by the INPRO Group and IAEA experts on energy planning and economics and supported by the IAEA's technical cooperation programme. It benefited from contributions of INPRO Area Coordinators and experts from the IAEA's programmes on nuclear science and applications, safety and security, safeguards, fuel cycle and waste technology and nuclear power engineering.

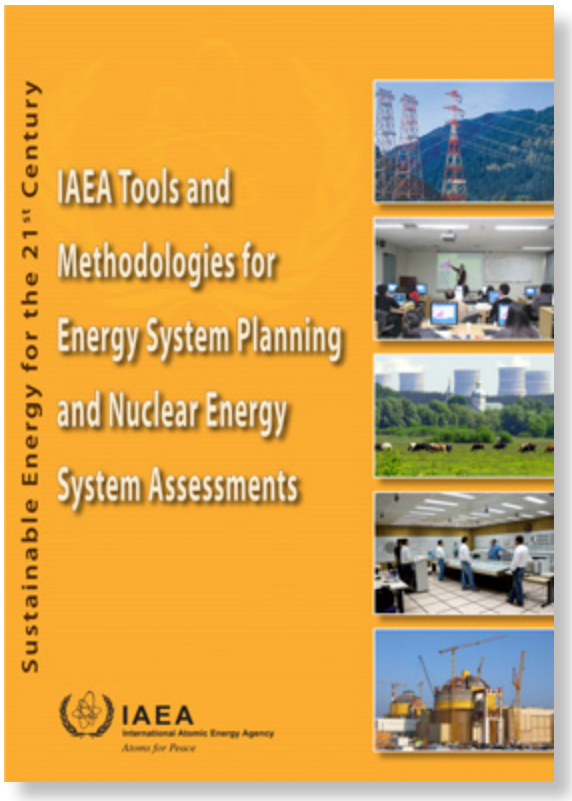
IAEA analytical tools for energy planning, presented and discussed at the meeting, included the model for the analysis of energy demand (MAED), the Wien automatic system planning package (WASP), the model for energy supply system alternatives and their general environmental impacts (MESSAGE), a financial analysis of electric sector expansion plans (FINPLAN), a simplified approach for estimating impacts of electricity generation (SIMPACTS) and indicators for sustainable energy development (ISED), all assessment areas of the INPRO Methodology as a tool to undertake nuclear energy system assessments, as well as additional tools that support the deployment of nuclear energy, i.e. the DESAE[6] code and the NFCSS[7] code.

FIG. 5. An exhibition during the workshop offered opportunities for networking and communication.

Representatives from developing countries, especially those that are not INPRO members, were able to familiarize themselves with the large range of aspects that have to be taken into account when establishing modern nuclear energy systems. The approach of coupling the assessments for an optimal energy mix and evaluating a planned nuclear energy system was considered to be very useful. Participants emphasized the need to organize similar workshops in Member States, since this would enable many national decision makers to participate. All participants also highlighted the value of direct feedback from the representatives of Brazil, Ghana, India, Ukraine and Vietnam as users of energy planning tools or NESAs. Continuous dialogue with Member States to support their needs and taking into account the challenges of implementing the models and tools offered by the IAEA were also considered a key aspect for future action. All presentations and workshop documents are available at: *http://www.iaea.org/INPRO/2009-Jul-WS.html*

6 Dynamics of energy system of atomic energy.

7 Nuclear fuel cycle simulation system.



A brochure on *Sustainable Energy for the 21st Century: IAEA Tools and Methodologies for Energy System Planning and Nuclear Energy System Assessment* was prepared as a background document for the meeting and was subsequently distributed widely at other meetings, including the IAEA General Conference. The brochure presented IAEA computer models devoted to energy system analysis and planning, indicators for sustainable energy development and the INPRO Methodology as a tool for NESAs. An electronic copy can be downloaded at *http://www.iaea.org/NuclearPower/Downloads/INPRO/Files/INPROPESS-brochure.pdf*

A.6. INPRO Collaborative Projects in Programme Area A

Two INPRO Collaborative Projects within this programme area aim at further developing and enhancing the assessment areas of 'proliferation resistance' and 'environment' of the INPRO Methodology: PRADA and ENV.

PRADA (Proliferation Resistance: Acquisition/Diversion Pathway Analysis)

The overall objective of the Collaborative Project on PRADA is to provide guidance on enhancing proliferation resistance of innovative nuclear energy systems and contribute to strengthening the assessment area of proliferation resistance of the INPRO Methodology. The basic principle for this area requires that intrinsic features and extrinsic measures of proliferation resistance be implemented throughout the full life cycle of an innovative nuclear energy system to help ensure that the system will continue to be an unattractive means of acquiring fissile material for a nuclear weapons programme. A key user requirement demands that innovative nuclear systems should incorporate multiple proliferation resistance features and measures.

The PRADA project focuses on identifying and analysing high level pathways for the acquisition or diversion of fissile material for a nuclear weapons programme, using the DUPIC (direct use of spent PWR fuel in CANDU reactors) fuel cycle as a case study with an assumed diversion scenario. The project will also make recommendations for assessing the multiplicity and robustness of barriers against proliferation, including institutional, material and technical barriers as well as barriers resulting from the implementation of international safeguards.

Initiated in 2008 and led by the Republic of Korea, which is conducting the DUPIC case study, Canada, China, the USA and the European Commission are also participating in the project. The PRADA project is being run in close cooperation with the IAEA safeguards programmes. Also, progress and results of the study are being harmonized with an assessment methodology for proliferation resistance and physical protection developed by GIF for Generation IV nuclear energy systems.

In 2009, the study progressed, concluding stage 2 and moving into its third stage. Two consultants meetings were held, one hosted by the Republic of Korea in Jeju-city in June and another held at the IAEA in December. Stage 1 of PRADA, in 2008, focused on the selection of prospective acquisition or diversion pathways. In 2009, achievements included an initial pathway analysis, the selection of an example pathway involving the diversion of fresh DUPIC fuel with a detailed description of diversion targets, and the identification of safeguards measures able to detect the diversion. On the basis of detailed facility information, fault and success trees[8] were modelled, describing plausible acquisition paths. A multipurpose document, the system notebook, was

[8] A success tree identifies what a proliferator must do to be successful; a fault tree identifies potential activities that must occur for a successful diversion to be undetected.

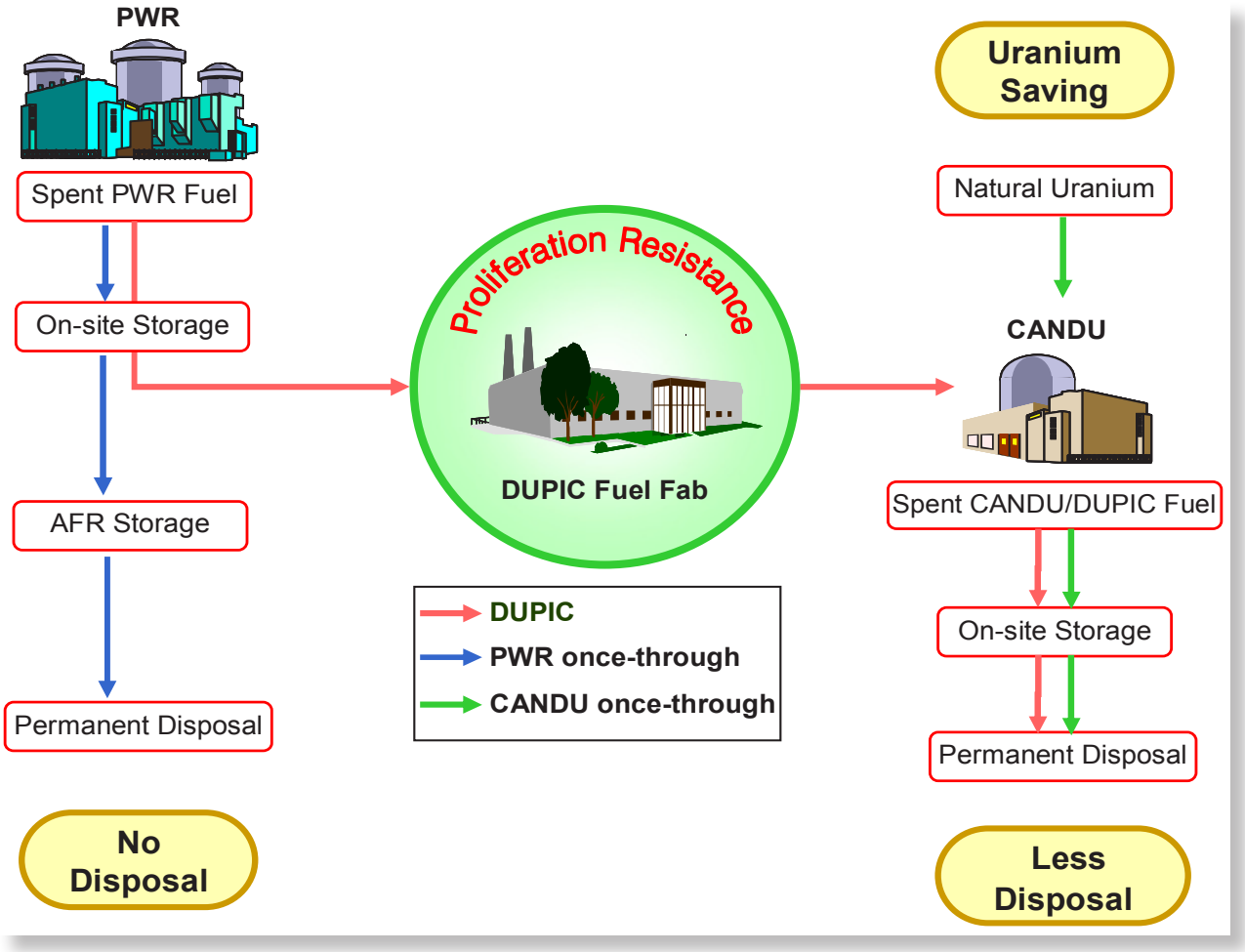


FIG. 6. Concept of the DUPIC fuel cycle.

developed to facilitate the presentation of information and analytical results. The project team also developed an evaluation checklist to support a structured approach to the pathway analysis. During stage 3 of the PRADA project, launched at the December meeting, the project team will investigate the multiplicity and robustness of barriers for preventing diversion of fissile material from the example DUPIC system.

The project team also produced a scientific paper on the current status of the INPRO Methodology for evaluating proliferation resistance and on harmonization with the GIF assessment method in the area of proliferation resistance, which was presented at the 50th Annual Meeting of the Institute of Nuclear Materials Management in Tucson, USA, in July 2009.

See also: INPRO Collaborative Project PRADA at *http://www.iaea.org/INPRO/prada.html*

ENV (Environmental Impact Benchmarking Applicable for Nuclear Energy Systems under Normal Operation)

Protection of the environment is a major consideration in industrial activities in many countries and a central theme within the concept of sustainable development. Nuclear energy supports sustainable development by providing energy that has a relatively low burden on the atmosphere, water and land use. Many predictive tools exist to assess the environmental impact of different nuclear facilities. As issues of environmental protection move to the forefront, a review of current approaches and predictive tools is considered timely.

The objective of ENV is to compare existing methodologies available for assessing the environmental impacts of nuclear energy systems under normal operation and to provide feedback for the practical application of the INPRO Methodology in the area of environment.

FIG. 7. INPRO consultants meeting on ENV, held at the IAEA, 15–16 October 2009.

Initiated by France, and with the participation of Belarus, Brazil, the Czech Republic, India, Kazakhstan, the Republic of Korea, the Russian Federation, Slovakia and Ukraine, the project started in 2009. Within the IAEA, the Agency's Laboratories at Seibersdorf are cooperating in this project.

In October 2009, a kick off workshop was held at the IAEA which redefined the terms of reference and established a work plan. Although several scenarios and pathways could have been considered, it was decided that in its first stage, the project will consider only radionuclide stressors from nuclear energy systems under normal operation. It is expected that two source terms will be developed (one for a nuclear power plant and one for reprocessing). The aim is for participants in the Collaborative Project to compare radionuclide ranking methodologies, based on the scenario definition, with the appropriate developments necessary to reach this objective, such as databases and radionuclide transfer codes. Thus, the project partners decided to change the initial title of this project, "Environmental Impact Benchmarking Relative to an INS Component" to one that better reflects the activities within this collaborative project, i.e. "Environmental Impact Benchmarking Applicable for Nuclear Energy Systems Under Normal Operation"(ENV).

The results expected of this project, which will end in 2011, include a benchmark on an assessment methodology to rank radionuclides according to their degree of health related impact on humans, a comparison of the most important radionuclides in terms of environmental impact for a given source term, reference scenarios for the INPRO Methodology in the area of environment and feedback on the practical application of the INPRO Methodology for environmental protection.

See also: INPRO Collaborative Project ENV at *http://www.iaea.org/INPRO/env.html*

B. Global Vision, Scenarios and Pathways to Sustainable Nuclear Development

B.1. Introduction

A long range and global analysis of possible future nuclear energy development scenarios has become an important element in the discussion of future nuclear prospects on a global level. By formulating scenarios and harmonizing visions for long term global nuclear development and deployment, INPRO aids newcomers and 'mature' nuclear countries alike to understand the potential of technical innovations and new institutional approaches for developing and building a sustainable nuclear 'architecture' in the 21st century, including possible transition scenarios. The studies aim at supporting capacity building in scenario/vision analysis in Member States, and establishing and analysing reference scenarios for large scale global nuclear energy development. This analysis should assist Member States in defining actions that have to be taken today in institutional and technology development areas to facilitate global nuclear energy use in the medium term.

Activities include defining different options and scenarios for the global and regional development of nuclear energy over the next 50 years, identifying the corresponding type of nuclear fuel cycle, reactor technologies and fissile materials, and the modalities for spent fuel recycling, storage and disposal. Institutional arrangements for the implementation of nuclear energy systems in developing countries are also addressed, including leasing of nuclear fuel, trade of fissile material and multinational approaches to enrichment, reprocessing and disposal. This programme area also includes four INPRO Collaborative Projects: (i) GAINS, (ii) ThFC, (iii) FINITE and (iv) RMI.

B.2. Global Scenarios and Regional Trends of Nuclear Energy Development in the 21st Century: Studies of Nuclear Capacity Growth and Material Flow

As worldwide primary energy consumption is growing, there is an increased urgency for reducing CO_2 emissions and for promoting sustainable energy technologies. Today, 85% of the energy supply depends on fossil fuels. In addition to affordability, stability and security of supply, energy must also be produced in an environmentally sustainable way. The future energy mix will be determined by the availability of technologies, total cost, environmental impact of energy generation, security of supply and societal acceptance. A future energy mix must also take into account the attributes of the different energy systems. An important feature of nuclear energy is that it provides a very stable base load energy supply and therefore complements the non-hydro renewable energies whose main drawback is their intermittency. Nuclear energy is the only low CO_2 emitting electricity generation technology deployed on a large scale today and which can also be significantly expanded.

The study on *Global Scenarios and Regional Trends of Nuclear Energy Development in the 21st Century* was launched in January 2009 and concluded with a final draft report at the end of the year. It analysed the global perspective for long term sustainable nuclear energy development, based on scientific–technical calculations of possible growth scenarios, which detailed interregional links in industrial capacity, resources and flows of nuclear fuel and other nuclear materials between regions.

Experts from China, the Czech Republic, India, Italy, the Russian Federation, Slovakia and the European Commission collaborated with five additional Member States that participated as observers: Canada, France, Japan, Ukraine and the USA. The study also uses IAEA expertise on energy planning and economics, and on nuclear power technology development.

In particular, the study's objectives were to:

(1) Illustrate the potential contribution that innovative nuclear energy systems employing FRs and closed fuel cycles can make in meeting the global and regional demand for nuclear energy, for a range of possible demand scenarios and, in parallel, also illustrate the potential roles of different reactor types operating in combination in an evolving and growing global nuclear energy system;

(2) Illustrate, for a range of possible demand scenarios, how nuclear materials might flow between different regions of the world;

(3) Identify some of the issues that would need to be addressed to realize the global vision of nuclear energy development presented in the study and, in particular, the visions for two higher demand scenarios.

The study built upon a system of a few reactor and fuel cycle types that are available today (TRs, FRs, liquid fuel reactors and molten salt reactors), and others likely to be developed in the future (e.g. fusion neutron sources), to illustrate the strength of a modelling approach that would demonstrate the role of an interregional transfer of nuclear fuel resources in support of a global growth of nuclear energy. Dynamic simulation using the DESAE code was applied in modelling nuclear power development. Using low, moderate and high energy growth scenarios, the development of nuclear energy was modelled in eight world regions, i.e. Africa (AF), Eurasia (EA), Europe (EU), Far East and the Pacific (FE), Latin America (LA), Middle East (ME), South Asia (SA) and North America (NA) (Fig. 8).

The low growth rate scenario assumed that the nuclear share in total energy consumption remains at its current (2007) level for electricity generation. The moderate scenario was consistent with nuclear energy increasing its share of electricity generation, for example, by replacing fossil fuels, while the high growth rate scenario assumed a large scale development of nuclear energy for both electricity generation and non-electrical applications, such as the production of artificial motor fuels and heat for industrial processes. The three growth scenarios were quite similar until 2030 and diverged at an increasing rate, particular after 2050 (see Table 2).

	Installed capacity (GW(e))		
Year	**Low growth**	**Moderate growth**	**High growth**
2007	371.64	371.64	371.64
2030	500	600	700
2050	1000	1500	2000
2100	2500	5000	10 000

TABLE 2. Global installed nuclear capacity as a function of time used in the study.

The study revealed that closing the fuel cycle and deploying FRs in combination with the continued deployment of TRs will reduce the need for uranium resources while accommodating a large expansion of the role of nuclear power in meeting the growing long term energy demand. This can be achieved using technologies that could be commercialized within the foreseeable future. Thus, a shortage of fissile material would not be a limiting factor for the sustainability of nuclear power.

The study showed possible and plausible evolutions of the global reactor fleet, comprising TRs and FRs and provided examples of transition scenarios for moving from a global nuclear energy system based largely on a once through fuel cycle to one based on a closed fuel cycle. The use of a closed fuel cycle and FRs would also reduce the demand for uranium enrichment and if multinational fuel cycle centres are established under an appropriate international framework, proliferation resistance should be enhanced globally. Also, closing the fuel cycle opens up new options for waste management. The study recommended that a comprehensive assessment, addressing all areas of the INPRO Methodology, be carried out on one of the TR and FR systems addressed in the study[9].

The findings emphasized the need to think beyond national and regional planning, and to adopt a global view, which takes advantage of synergies in energy supply systems. Developments in one region may well be constrained by those in other areas. Thus a shared understanding of strategic objectives, planned developments

[9] IAEA experts on nuclear fuel cycle and waste management, in cooperation with INPRO, have studied waste management opportunities and challenges.

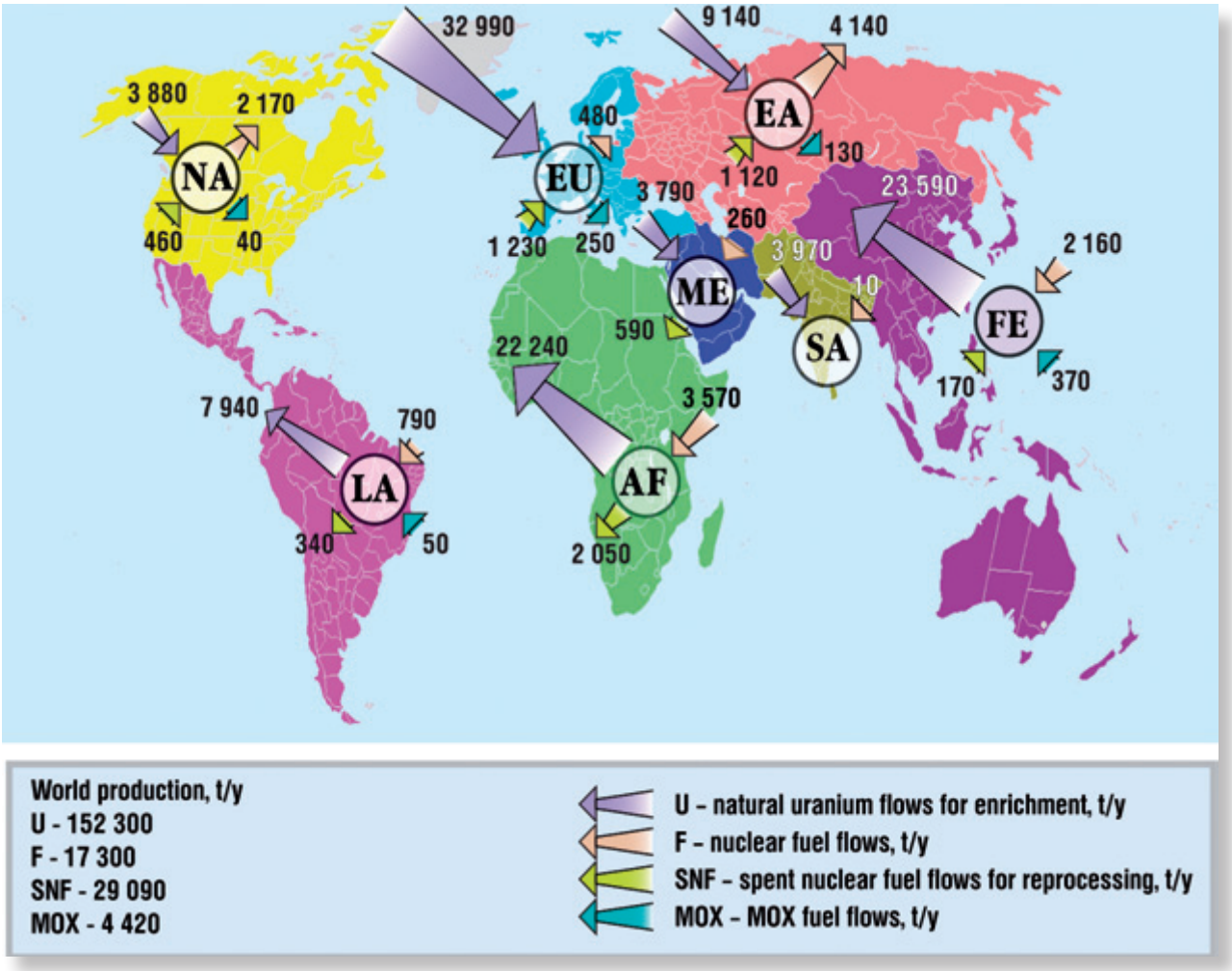


FIG. 8. Flows of uranium, fresh, spent and MOX fuels in the eight world regions under the high growth scenario (2050).

and progress made by different countries and regions is highly desirable. INPRO provides a mechanism for such international cooperation.

It should be noted that the findings represent neither a forecast of regional nuclear power development nor global projections. Rather, they represent an integrated view of possible and plausible nuclear energy development pathways that might be followed as nuclear energy is utilized to contribute to meeting the global demand for energy in the 21st century.

The report on *Global Scenarios and Regional Trends of Nuclear Energy Development in the 21st Century: Studies of Nuclear Capacity Growth and Material Flow* will be published by the IAEA in 2010. The results of this study will feed into a new activity on "INPRO Vision on Sustainable Nuclear Energy Development Scenarios in the 21st Century", which will also take into account the results of several INPRO Collaborative Projects, including RMI, ThFC and FINITE, and is planned to be completed in 2012.

B.3. INPRO Integrated Computer Simulation Model: DESAE Code — A Tool for Global and National Scenario Building

The DESAE code is a system research model designed for developing nuclear energy scenarios on a regional or global scale and analysing a detailed material flow. The DESAE code is also a comprehensive tool for a NESA, since it allows qualified users to obtain, in an interactive manner, data on key indicators for several INPRO assessment areas.

Linking DESAE with the MESSAGE model permits projecting nuclear power development. DESAE takes aggregate results of MESSAGE and calculates the nuclear material flows, generated waste and detailed

information on nuclear infrastructure needs. The outputs from DESAE, fed back into MESSAGE, establish consistent assumptions on nuclear power development.

In 2009, the DESAE 2.2 code, developed by the Russian Research Centre Kurchatov Institute, was used and disseminated by INPRO. The code was applied in the study on *Global Scenarios and Regional Trends of Nuclear Energy Development in the 21st Century* to calculate nuclear fuel cycle requirements, material balances and economic parameters for developing nuclear energy scenarios with a given combination of nuclear reactors during a specified period. Combining data from eight world regions and employing a plausible regional distribution of nuclear energy consumption provided a global picture. The regional distribution was based on extrapolations of current technologies available in the regions, geographic and climatic conditions and the fact that nuclear technology development in different regions or countries within a region would depend on the existing status of nuclear energy development. The aim was not to predict the development of nuclear power region by region, but to identify issues that might affect such a development.

An additional module of the simulation model, the DESAE TRANSPORT code, was also developed in 2009, specifically for this study. It allowed the calculation of interregional supplies against given resource production and consumption data for each region, as well as establishing a matrix of interregional exchange priorities for resources, i.e. natural uranium, fresh nuclear fuel, including MOX fuel, and spent nuclear fuel.

In cooperation with INPRO, a DESAE users' manual was developed jointly by the DESAE developers' team at the Russian Research Centre Kurchatov Institute and the users' team at the Indira Gandhi Centre for Atomic Research (IGCAR) in India, which applied the DESAE code in a study on *A Methodology for the Assessment of Nuclear Power Development Scenarios*.

Two INPRO Collaborative Projects (RMI and FINITE) used the DESAE code in 2009. The modelling results were presented at progress meetings on both projects in Liblice, Czech Republic (RMI) and Dimitrovgrad, Russian Federation (FINITE).

B.4. INPRO Collaborative Projects in Programme Area B

Four INPRO Collaborative Projects contribute to establishing a global vision, scenarios and pathways for sustainable nuclear development: (i) GAINS, (ii) ThFC, (iii) FINITE and (iv) RMI.

GAINS (Global Architecture of Innovative Nuclear Systems based on Thermal and Fast Reactors including Closed Fuel Cycles)

A coherent vision for the evolution of a global nuclear energy system requires unification of a methodological platform, including assumptions, boundary conditions and tools, and validation of the simulation results through sample analyses of transition strategies from the present to future nuclear power systems with reduced financial, environmental and proliferation risks.

Performance of these tasks is the focus of the INPRO Collaborative Project on GAINS, implemented by Argentina, Belgium, Canada, China, the Czech Republic, France, India, Italy, Japan, the Republic of Korea, the Russian Federation, Slovakia, Ukraine, the USA and the European Commission. IAEA experts on nuclear fuel cycle and waste technology, and on energy planning and economics are contributing to this Collaborative Project.

In 2009, significant progress was made in implementing the GAINS working plan. The targets achieved and future steps were discussed in the third and fourth consultants meetings held in Vienna in May and in Brussels in October, respectively. An optimal balance between national efforts and multilateral cooperation was discussed at a meeting in Kiev in April. Interim results of GAINS were presented at two international conferences, at the IAEA Standing Advisory Group on Nuclear Energy and at several internal IAEA meetings and workshops. The work done and findings to date were summarized in an interim report.

One of the principal tasks in 2009 was developing a framework to examine the potential synergy between current and innovative nuclear energy systems, and synergy between groups of countries with different preferences in reactor types and fuel cycle options. A homogeneous model of global nuclear power that assumes no differences in nuclear development strategy was not considered suitable to achieve this objective. Further

development and use of a heterogeneous model of the 'nuclear world', as put forward in the GAINS Terms of Reference remained an important direction of activities.

For this heterogeneous model, three non-geographical groups (NG 1, NG 2 and NG 3[10]) had been identified earlier in the study by their strategy for used fuel management on the back end of the fuel cycle. These three groups can operate separately from, or synergistically with, each other to create the architecture of a global nuclear energy system (see Fig. 4). The group approach, however, is flexible and other group configurations can also be used.

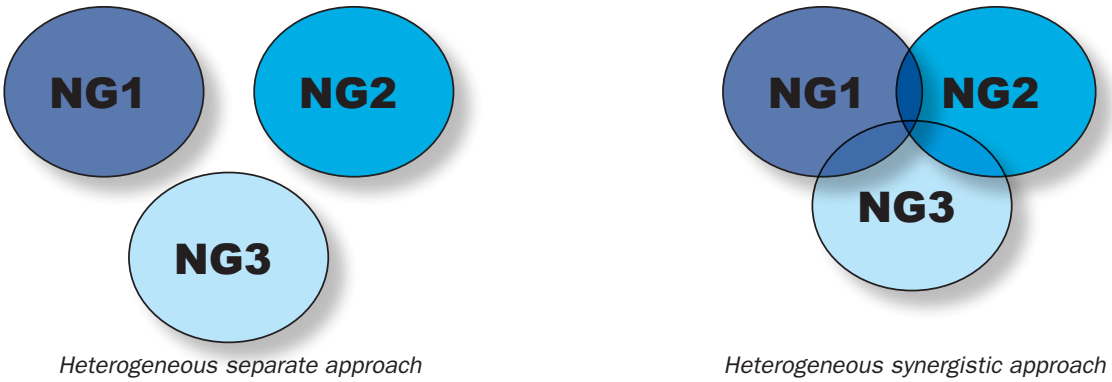


FIG. 9. GAINS heterogeneous model: Grouping of non-geographical countries (NG).

Development and use of a heterogeneous model of the nuclear world was the backbone that linked and consolidated the different items of the GAINS working plan in 2009:

- Extension of the GAINS reference database by including characteristics of several advanced reactor systems provided by Member States within an agreed template;
- Estimation of global nuclear power demand profiles during the 21st century in non-geographic groups;
- Simulation and analysis of global and group nuclear demand scenarios (moderate and high) using fuel cycle modelling codes available at the national or common level;
- Cross-checking of analytical and computational tools, assessing the potential needs of participants and assisting interested countries in the use of IAEA tools for analysing national long term nuclear programmes within a global context.

A special internal procedure was developed in close cooperation with IAEA experts on energy planning and economics to estimate global nuclear power demand profiles in non-geographical groups. It included composing a list of (potential) nuclear users in the 21st century; splitting current/future nuclear countries into non-geographic groups; analysing long term projections of nuclear deployment in each country of the world; consolidating the countries' projections in the three groups and defining a nominal case by summing up the countries' scenarios inside the groups, as well as variations of nuclear demand scenarios for sensitivity analysis. Since there is a large degree of uncertainty associated with long term estimates, the profiles received should be considered only as an illustrative case based on expert opinion.

[10] NG1: The group plans to build, operate and manage used fuel recycling facilities and permanent geological disposal facilities for highly radioactive waste (recycling group).

NG2: The group plans to build, operate and manage permanent geological disposal facilities for highly radioactive waste (once through fuel cycle group).

NG3: This group has no plans to build, operate and manage used fuel recycling facilities or permanent geological disposal facilities for highly radioactive waste (minimal fuel cycle infrastructure).

The nuclear power demand estimated for each non-geographical group is supposed to be met with energy production from nuclear energy systems that are exploited in a given group. In 2009, nuclear energy systems of three types were analysed:

(1) Business as usual (BAU) based on PWRs (94%) and HWRs (6%) operated in a once through fuel cycle;

(2) BAU plus advanced PWR (BAU+);

(3) A system based on current and advanced PWRs, HWRs including FRs and a closed nuclear fuel cycle (BAU+FR).

Input data for operating PWRs and HWRs (from the IAEA NFCSS code) and input data for advanced PWRs, HWRs and FRs (provided by project participants) were included in the reference database.

Moderate and high scenarios of nuclear energy demand were simulated and analysed using several national fuel cycle modelling codes such as COSI (France), TAPS (India), FAMILY (Japan), VISION (USA), and DESAE (Russian Federation), or those disseminated by the IAEA, such as MESSAGE and NFCSS. The following indicators were evaluated in the analysis: cumulative amount and rate of natural uranium consumption, fuel material balance and inventory, amount of discharged spent fuel, fissile material inventory and balance at the main sections of the nuclear fuel cycle, separative work units for uranium enrichment, investments, fuel cost and electricity generation cost.

The analysis of simulation results revealed the sensitivity of selected indicators to different configurations of the global nuclear architecture. Introducing FRs with a closed nuclear fuel cycle (CNFC–FR) into the global nuclear energy system has positive effects on many indicators. However, the deployment rate of FRs is limited in the long term by the availability of plutonium. It was assumed in the GAINS scenarios that until 2050, FRs will be deployed in NG1 and will deliver 10 GW(e) by 2030 in both moderate and high scenarios. In 2050, the fleet of FRs is expected to increase up to 200 GW(e) in the moderate scenario, and 400 GW(e) in the high scenario. Thereafter, the deployment of FRs will depend on the available plutonium. The remaining nuclear demand could be covered by a TR fleet where the ratio between LWR and HWR remains at the present level. In the case of groups operating separately, the reprocessed plutonium for FRs of the NG1 group is provided by TRs from the same group. In the synergistic case, spent fuel is supplied from all groups and reprocessed in NG1.

Figure 10 (a) illustrates the potential of FR deployment in these two cases. The synergistic model demonstrates that the fleet of FRs could be doubled. Also, a larger fleet of FRs will decrease cumulative consumption of natural uranium. Both would considerably enhance the sustainability of the global nuclear energy system. In the BAU+ option, the relatively cheap uranium (<130 $/kg[11]) will be exhausted by around 2070 in the high nuclear demand scenario (1500 GW(e) in 2050, 5000 GW(e) in 2100) and by around 2090 in the moderate demand scenario (1000 GW(e), 2500 GW(e)).

Introducing FRs with a break even conversion ratio (~1) into NG1 and full utilization of plutonium from TRs of this group could save about 20% of the uranium necessary to realize the BAU+ option. A synergistic approach would about double the uranium savings. FRs with higher breeding ratios (>1) can make the total uranium savings even more significant.

Assurances of nuclear fuel supply services through multilateral nuclear approaches could result in synergies that would be crucial in addressing issues in the areas of waste management and proliferation resistance. Figure 10 (b) shows that in the high nuclear demand scenario, the global accumulation of plutonium in spent fuel inventories can be decreased drastically by using FRs in NG1 (red curve) compared with the BAU once through option (blue curve). In a synergistic case (green curve), the accumulation of plutonium is expected to decrease further to meet minimum operation needs. The synergistic approach substantially decreases waste management requirements in NG3. The multilateral nuclear approach presents an option for a global nuclear architecture that would provide for a more secure and manageable growth of nuclear power. However, other

[11] IAEA–OECD/NEA, Uranium 2007: Resources, Production and Demand, OECD, Paris (2008).

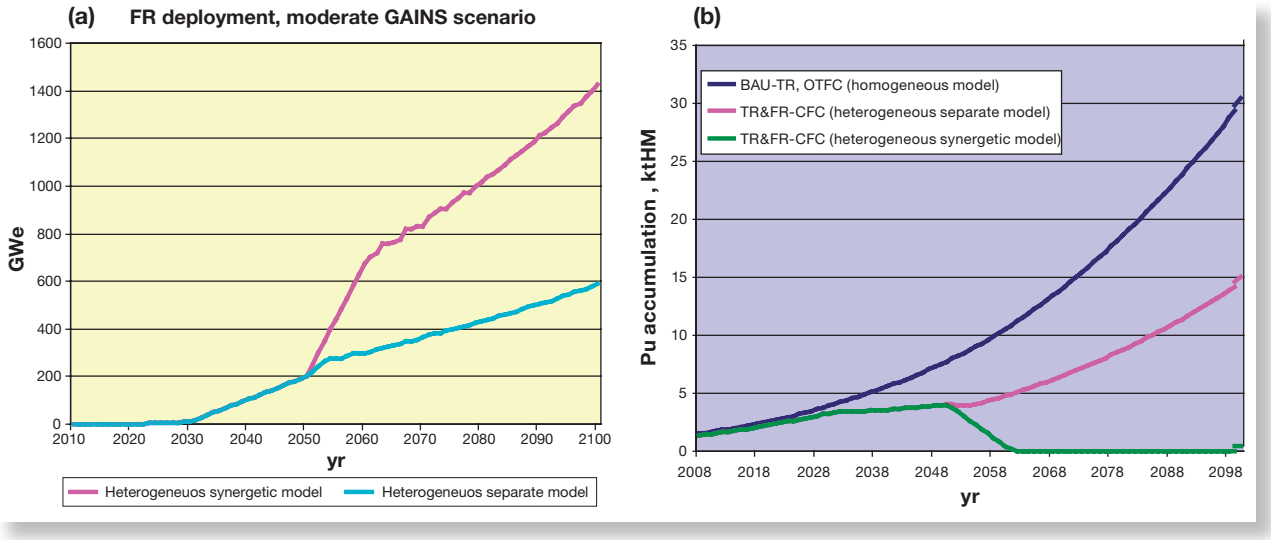


FIG. 10. (a) Potential for FR deployment, (b) plutonium accumulation in GAINS separate and synergistic cases.

factors with their benefits and challenges, such as transportation and demand for fuel cycle services in other groups need to be further assessed.

In 2009, some economic indicators were also assessed such as the role of pre-commercial investments (transition costs) that are required for transition from the current nuclear energy system mainly based on the once through nuclear fuel cycle with TRs, to a system which includes the CNFC–FR. The cost of uranium fuel under different global nuclear architecture configurations was another economic indicator of interest in 2009, and the linkage between measures on natural uranium savings and the cost of uranium fuel was quantitatively evaluated.

The 2010 GAINS implementation plan is focused on further development of a framework for analysis of global architectures and conducting sample analyses to illustrate the usefulness of the framework in assessing benefits and challenges of the fuel cycle system. Additional innovative nuclear energy system options such as accelerator driven systems, molten salt reactor systems and thorium fuel cycles may also be explored in conjunction with developing the framework.

See also: INPRO Collaborative Project GAINS at *http://www.iaea.org/INPRO/gains.html*

ThFC (Further Investigations of the ^{233}U/Th Fuel Cycle)

Thorium, like uranium, is a 'fertile' material that can be used to produce fissile material, which in turn could be used as fuel in a nuclear reactor. Re-examining the potential of thorium based fuel cycles to support future large scale deployment of nuclear energy systems and enhance the sustainability of nuclear power is being explored in the INPRO Collaborative Project on Further Investigations of the Thorium Fuel Cycle, which was launched in 2007 and will end in 2010.

Unlike studies of thorium conducted by the IAEA in the past (e.g. IAEA-TECDOC-1450), the INPRO ThFC study includes consideration of the role of thorium to supplement the uranium–plutonium fuel cycle in a scenario envisaging a significant increase in the global use of nuclear energy in the world. In this scenario, the most important advantage of the thorium fuel cycle is that it is considered to be potentially more proliferation resistant compared with the uranium–plutonium fuel cycle, since the thorium fuel cycle potentially eliminates enrichment and makes the process of spent fuel reprocessing more sophisticated.

INPRO members participating in the project include Canada, China, India, the Republic of Korea, the Russian Federation, Slovakia, Ukraine and the European Commission. In addition, institutions such as Thorium Power (USA), Thor Energy (Norway) and the Institute of Energy Research at Jülich, Germany, are involved as observers. The IAEA's nuclear security and safety programme is contributing to the ThFC project, which also uses IAEA expertise on nuclear fuel cycle and waste technology.

During an INPRO consultants meeting in January 2009, a number of thorium based fuel cycle options were identified for consideration by INPRO members. The following three groups of fuel cycle options suitable for short term to medium term application were identified:

(1) Once through uranium–thorium fuel cycle in HWRs, PWRs, BWRs and HTGRs. This includes the conventional once through and fuel shuffling and recycling of mechanical reconfigured fuel.

(2) Once through plutonium–thorium fuel cycle in HWRs, PWRs, BWRs and HTGRs. This is similar to the first option except existing ^{239}Pu, instead of ^{235}U, is used to start the fission process prior to sufficient creation of ^{233}U in the reactor core. A special variation of this are designs for the purpose of reducing the plutonium as a potential weapons material.

(3) Synergism between FRs and TRs, in which a number of FRs are operated as factories for converting ^{232}Th into ^{233}U to feed other reactors.

A web based information system on thorium utilization was constructed in 2009 and some two hundred available publications were classified and included in this system which is accessible to all project participants. Also, material flow data in the nuclear fuel cycle were prepared and parameters of reactors consuming thorium and ^{233}U, and producing ^{233}U needed to model scenarios of thorium introduction were established. Scenario drafts were developed and selected and calculations necessary for their optimization were completed. An article on *Exploring Fuel Alternatives*, related to this collaborative project, was published in the September issue of IAEA Bulletin, Vol. **51**(1).

A follow-up coordinated research project on thorium was prepared and this will be undertaken in 2010–2011 and will further study the utilization of thorium as a supplementary nuclear fuel resource.

See also: INPRO Collaborative Project ThFC at *http://www.iaea.org/INPRO/thfc.html*

FINITE (Fuel Cycles for Innovative Nuclear Systems through Integration of Technologies)

This Collaborative Project provides an overview of technically feasible and economically sound advanced and innovative nuclear fuel and fuel cycle options (AINFCO). Existing national technologies for the fuel cycle back end, planned evolution, and corresponding databases will be evaluated and a set of them will be selected for application to an expected realistic scenario of nuclear energy demand. This includes both existing and advanced aqueous and non-aqueous reprocessing methods for obtaining oxide and metallic fuels, respectively. Sustainability of the options considered will be assessed with the INPRO Methodology suitably adapted to the purpose of this project. Special emphasis is given to the INPRO assessment areas of economics, environment, proliferation resistance, safety and waste management. The project also identifies medium and long term institutional measures necessary to deploy the selected AINFCO in order to help meet the sustainability objectives of long term nuclear energy development.

In 2009, the project consolidated its membership and scope definition. China, the Czech Republic, India and the Russian Federation are contributing to this study as participants, and some other countries are following the project's developments as observers. However, it was decided to implement this collaborative project only during 2010–2011. The selection of parameters, assessment key indicators and acceptance limits required for the INPRO Methodology began in 2008 and continued in 2009. The terms of reference will be reconsidered when the project is launched at the beginning of 2010.

See also: INPRO Collaborative Project FINITE at *http://www.iaea.org/INPRO/finite.html*

RMI (Meeting Energy Needs in the Period of Raw Materials Insufficiency during the 21st Century)

In times of significant fossil fuel price rises, society's life can be greatly impacted by the ways in which energy is produced. Investments are essential and time is needed to provide new capacities. R&D and optimizations, together with considerations of technology maturity, political and social stability, and other factors are required.

The INPRO Collaborative Project on RMI identifies demand trends in energy markets and opportunities to meet those demands. Modelling is used to evaluate the most effective solutions for selected EU countries, i.e. Bulgaria, the Czech Republic, Hungary, Lithuania, Poland, Romania and Slovakia, as well as for Ukraine and Belarus. Special attention is given to the role of nuclear energy.

The project is implemented by experts from Armenia, Belarus, Bulgaria, the Czech Republic, France, Hungary, Lithuania, Poland, the Russian Federation, Slovakia, Ukraine and the European Commission (Joint Research Centre/Institute for Energy, Petten).

In 2009, progress was made in meeting the project's objectives, which are to:

- Recommend a strategic plan on developing energy production for selected countries, taking into account the existing trends in consumption of world energy resources and growth of energy production in different regions of the world and globally;

- Prepare an overview of asymptotic energy needs for the selected countries and their sustainable raw material supply;

- Investigate sustainable options of energy supply in the central European region and estimate required basic investments in waste management and non-electrical applications.

In 2009, the Dynamic Energy System (DES) code was further developed to allow looking beyond the present capabilities of the INPRO Methodology and extending its basic principles and criteria for assessing non-nuclear energy sources. DES is an extension of the DESAE code and was tested in case studies in Nigeria and the Russian Federation. Data for global scenarios, assumptions and available energy sources were collected and possible energy solutions were modelled. They were presented at the 2nd RMI project meeting in Liblice, Czech Republic. Solving emerging energy supply problems in the selected countries was also addressed, in view of decreasing fossil fuel resources and their possible substitution by alternative energy sources.

An analysis of the available data indicated that crude oil supply to the world market could peak around 2015, and then would decrease between 2020 and 2030 by about 12.5%, instead of a currently expected increase of about 50%. Gas supply is expected to be stable up to 2050. A review of current consumption of electricity, crude oil and nuclear electricity indicated that there is a large gap in energy supply in the selected European region. However, any long term projections of energy demand require caution and taking into account boundary conditions of external oil and gas supplies.

In early 2010, the RMI project participants will meet to discuss progress made and further work. A final report, including recommendations for a strategy of energy production in the selected countries, taking into account trends in the region and in neighbouring countries, will be issued in 2011.

See also: RMI *http://www.iaea.org/INPRO/rmi.html*

C. Innovations in Nuclear Technology

C.1. Introduction

Ensuring the sustainability of nuclear energy might necessitate technology innovations and new and innovative institutional approaches. Technical innovations are being pursued nationally and through international initiatives such as the GIF and SNETP. INPRO contributes and complements these efforts.

An important objective of performing assessments of nuclear energy systems using the INPRO Methodology is to identify gaps in technologies and corresponding R&D needs. This area of work fosters collaboration among INPRO members on selected innovative nuclear technologies to bridge such technology gaps. The collaborative projects in this programme area have been selected so that they complement other national and international R&D activities.

C.2. Status and Trends of Nuclear Technologies

In 2009, a new INPRO publication on *Status and Trends of Nuclear Technologies* (IAEA-TECDOC-1622) provided an overview of the history, current situation and future perspectives of nuclear fuel cycle technologies. It summarized knowledge accumulated in IAEA Member States in the area of advanced and innovative nuclear reactors and fuel cycle technologies. While this overview focused on technical issues, nevertheless, the aspects of economics, environment, safety and proliferation resistance were important background issues for this study. The report covered all different types of reactor and nuclear fuel cycle options with special emphasis on innovative nuclear fuel cycle technologies and summarized technological approaches. It also recommended future INPRO activities regarding nuclear fuel cycle options and specifically addressed the needs of developing countries. The publication includes a CD with the full report and two separate studies, i.e. one by the Russian Federation on a sustainable global nuclear energy system and another one on initiatives regarding multilateral nuclear fuel cycle centres. The report can be downloaded at *http://www.iaea.org/INPRO/publications.html*

C.3. INPRO Collaborative Projects in Programme Area C

Five INPRO Collaborative Projects are the backbone of this programme area. The studies undertaken jointly with INPRO members address different aspects of technology innovations and cover in the following areas: COOL, DHR, AWCR and PGAP.

COOL (Investigation of Technological Challenges related to the Removal of Heat by Liquid Metal and Molten Salt Coolants from Reactor Cores Operating at High Temperatures)

Next generation reactors, to be used for hydrogen production and other applications, will need to incorporate innovative approaches to further enhance their reliability and safety for large scale deployment in different regions of the world. An important feature of these reactors will be the use of coolants at temperatures that are much higher than those in current generation reactors. This involves addressing a wide range of issues concerning the design and safety of these reactors.

The INPRO Collaborative Project on COOL investigates the technological challenges of cooling reactor cores that operate at temperatures of up to 1000°C in advanced FRs, high temperature reactors and accelerator driven systems by using liquid metals and molten salts as coolants. The project was initiated by the Czech Republic and India and also includes other participating INPRO members, i.e. Brazil, China, Germany, Hungary, Italy and the Republic of Korea. IAEA expertise on nuclear power technology development is supporting this project.

In 2009, experts from these countries met at the IAEA in June to chart the way forward by presenting their experience in this field and interest in the project, defining national contributions and finalizing, adopting and signing new terms of reference for research work to be undertaken. India has played a key role as COOL project

leader and will continue to do so in the future. The Czech Republic's experience lies in the area of molten salt coolants. Germany has investigated the area of materials and the development of barriers for protection. China and Italy have been researching thermohydraulic correlations for liquid metal coolants and computational fluid dynamics (CFD), while Brazil has been contributing with research on neutronics and CFD. Hungary has focused on CFD studies on liquid metals and molten salts, and the Republic of Korea has been participating with studies on molten salts for various geometries, since there is no R&D project at a national level.

In 2010, these studies will be continued by the respective INPRO members and interim results will be shared at a consultancy meeting in June 2010. In addition, the data generated by the COOL project will be included in the IAEA Thermophysical Properties Database of Light Water Reactors and Heavy Water Reactors (THERPRO). The results of the investigation will be documented in progress reports and a final report, to be published by the IAEA in 2011.

See also: INPRO Collaborative Project COOL at *www.iaea.org/INPRO/cool.html*

DHR (Decay Heat Removal System for Liquid Metal Cooled Reactors)

Decay heat removal (DHR) after reactor shutdown of an FR is one of the most important safety functions which must be accomplished with a very high degree of reliability. For a typical pool or loop type sodium cooled FR, one DHR system design is based on the heat transferred to the atmospheric air, as an ultimate heat sink from the reactor pool system via an intermediate loop having sodium as coolant.

This Collaborative Project investigates multidimensional thermohydraulic phenomena in the primary sodium circuit of an FR with a core under natural convection conditions, and specifically the performance of the safety grade DHR system when the secondary loop has lost its heat removal function. It addresses methodologies for analysing pool hydraulics and heat transfer in sodium–sodium and sodium–air heat exchangers, also taking into account thermohydraulic effects of the elements of the core contributing to heat production and removal.

The data used in the analyses were provided by India and correspond to a 1250 MW(th), 500 MW(e), pool type fast breeder reactor which consists of a primary sodium circuit, two secondary sodium circuits and a steam water circuit. The primary sodium circuit includes the core, control plug, hot pool, cold pool, two primary sodium pumps, four intermediate heat exchangers (IHX), DHR system, etc. The DHR system has four redundant and totally independent circuits capable of removing decay heat from the hot pool through natural convection in the primary and intermediate sodium sides as well as in the air side (stack). Each circuit consists of a sodium–sodium heat exchanger (DHX) and a sodium–air heat exchanger (AHX) connected by an intermediate sodium circuit. A tall air stack provides the driving force for the natural convection air flow through the AHX, when the dampers are opened.

Institutions in China, India, the Republic of Korea and the Russian Federation and the European Commission's JRC Institute for Energy are implementing this project with the objective of comparing results of a candidate robust DHR system. Six case studies representing different transient conditions are calculated; opening time of the air stack dampers (cooling air entrance), type of coolant in the intermediate circuit (Na or NaK), air inlet temperature entering the stack (nominal or lower) and consideration or not of the interwrapper flow (IWF) are the variable parameters modified in the different case studies.

In 2009, the project participants presented their results and findings at a consultancy meeting held in Obninsk, Russian Federation, in September 2009.

The **Korea Atomic Energy Research Institute** (KAERI**,** Daejon) used the MARS–LMR code (1-D, transient, two fluid model for two-phase flows), which is based on the original MARS code used for water cooled reactor analyses. Additional models were incorporated to this code to be adapted to the analyses of transients for sodium cooled FR systems, such as liquid metal coolant properties, wall heat transfer coefficients related to liquid metal and friction factor correlations associated with wire spacers of fuel rod. The elements of the reactor vessel, primary circuit and DHR were modelled, connecting the nodes to simulate the thermohydraulic phenomena occurring in the system in an integrated manner.

Null transient was calculated at full power for 5000 s to obtain the steady state conditions. Then the loss of offsite power transient was calculated for the conditions of the case study where no IWF is considered.

The **European Commission's** JRC Institute for Energy (JRC–IE, Petten) performed its studies using the ANSYS CFX12 code, which is a general commercial CFD code. The code has many turbulence models, such as

the common RANS models as well as scale resolving LES and DES models. It required long computing times even though the full geometry was not modelled. However, it includes the necessary physical models. The user made no changes to the code for the calculations. A model representing a quarter of the primary pool was used with nearly 4 million cells. The most central subassemblies were modelled individually with the IWF taken into account. The outer regions of the core, the IHX and the DHX were considered as porous regions. Steady state calculations were performed at two power levels. At each power level one calculation included IWF and the second calculation disregarded it. The primary outcome from these analyses was the calculation of the DHR from the hottest SA when the IWF is taken into account.

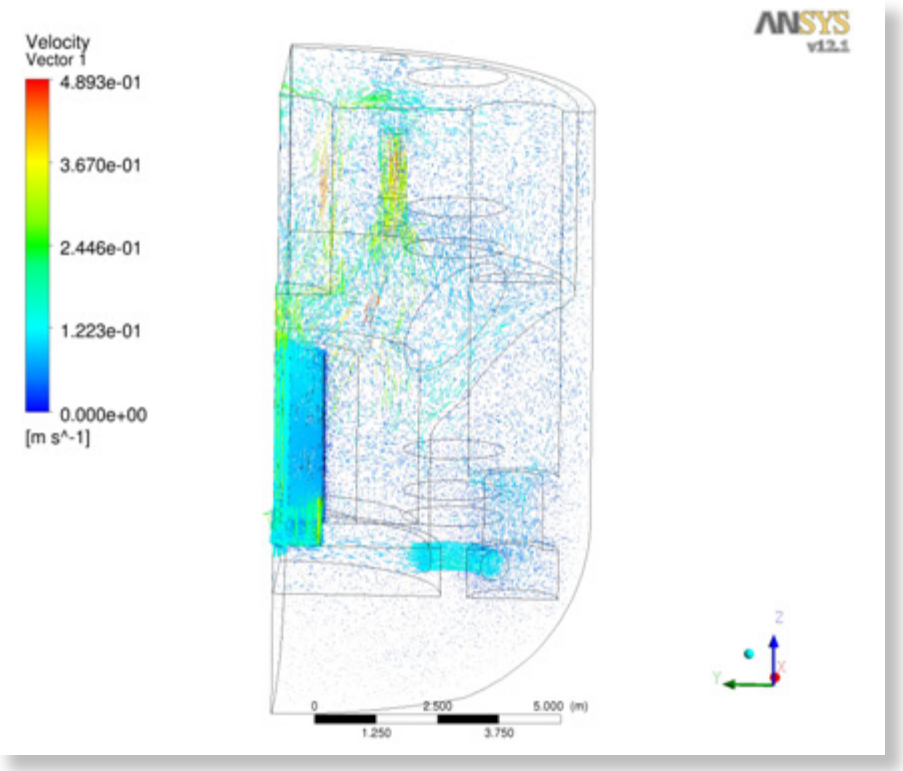


FIG. 11. Vector field during steady state calculation at 2.82% nominal power with IWF.

The **Russian Institute of Physics and Power Engineering** *(IPPE, Obninsk)* carried out all six case studies covered by the project using the GRIF code which incorporates a 3-D thermohydraulic model for calculating sodium velocity, pressure and temperature in the primary circuit and a 3-D model for simulating interwrapper sodium thermohydraulics. Other models simulated the primary pump, wrapper, IHX, DHX, fuel/absorber pins, reactivity coefficients and neutron kinetics. One fourth of the reactor core was modelled simulating the steam generator as a single-phase heat exchanger.

A base case study was analysed and used as reference to five additional case studies representing different conditions in the primary circuit or in the DHR system. In all cases, the conservative condition of having available two of the four DHR systems of the reactor was assumed. Results from transient analysis performed for a base case were then compared with those obtained from the other five cases.

The **China Institute of Atomic Energy** (CIAE, Beijing) modelled five of the six case studies. For all of the cases, full power operation and a primary sodium pump operated at low regime were used as initial conditions. Station blackout was also considered the initiating event in one case, and off-site power failure for the others.

The analyses were carried out using OASIS 3.2, a French code to model transient analysis of liquid metal fast breeder reactors. OASIS is a 1-D, single pin, multiple channel code. It contains detailed, mechanistic models for fuel element heat transfer, oxide fuel pin and cladding mechanics, single-phase coolant fluid dynamics, primary/secondary/balance-of-plant thermohydraulics, and plant control systems. The geometric idealization was based on a 1-D model to simulate the DHR. In the primary circuit, the IWF flow path and other sodium volumes were also modelled as 1-D and the components such as IHX, DHX, AHX, sodium pump, main vessel cooling system, etc., were also represented. Empirical correlations were adopted to calculate the heat transfer coefficient in IHX/

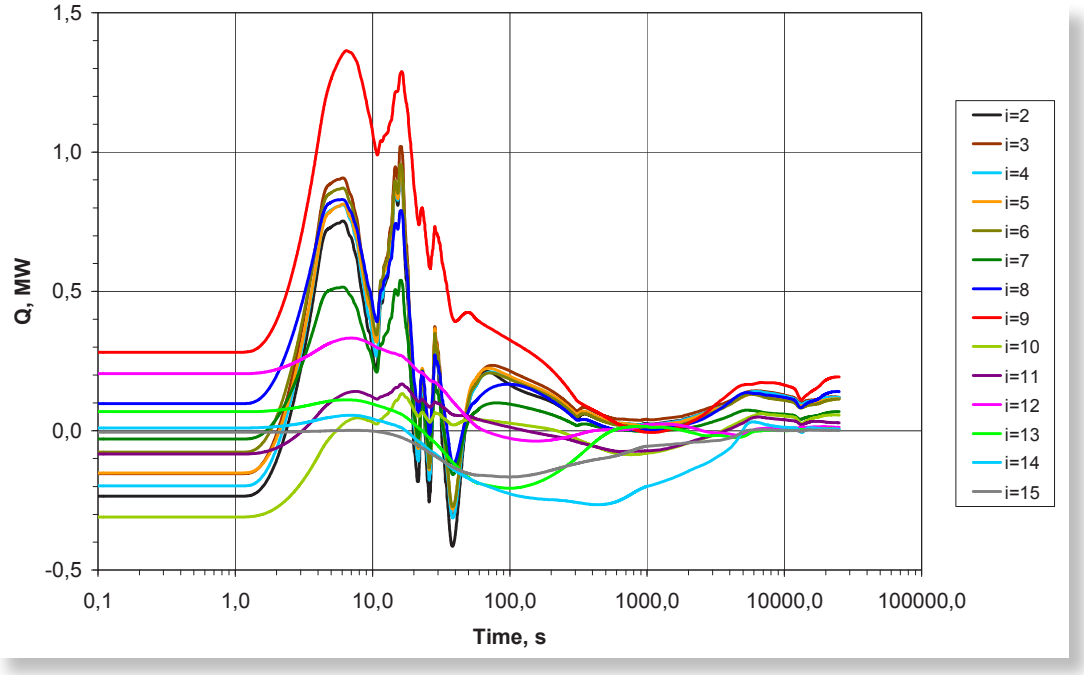


FIG. 12. Heat transfer by IWF in various channels for one of the transients.

DHX and in AHX. No empirical correlations were available for IWF. Hot spot factors were used only to extract the pick cladding/coolant temperature.

Results for loss of off-site power with and without IWF were obtained although the IWF was not modelled accurately in the analysis. A sensitivity study to the variation of the safety grade DHR system initial logics on the maximum cladding temperatures was also performed.

The **Indira Gandhi Centre for Atomic Research** (IGCAR, Kalpakkam) performed the analyses with the commercial CFD code, whose main characteristics were described above. The complete core sector (360°) was modelled, representing explicitly each subassembly and providing detailed attention to the interwrapper space and phenomena. All other elements of the reactor vessel were modelled as porous bodies. Heat removed by the DHX was evaluated independently using the 1-D code as a function of the hot pool temperature. Temperature distribution and flow velocities were analysed in nominal conditions for all areas and elements inside the reactor

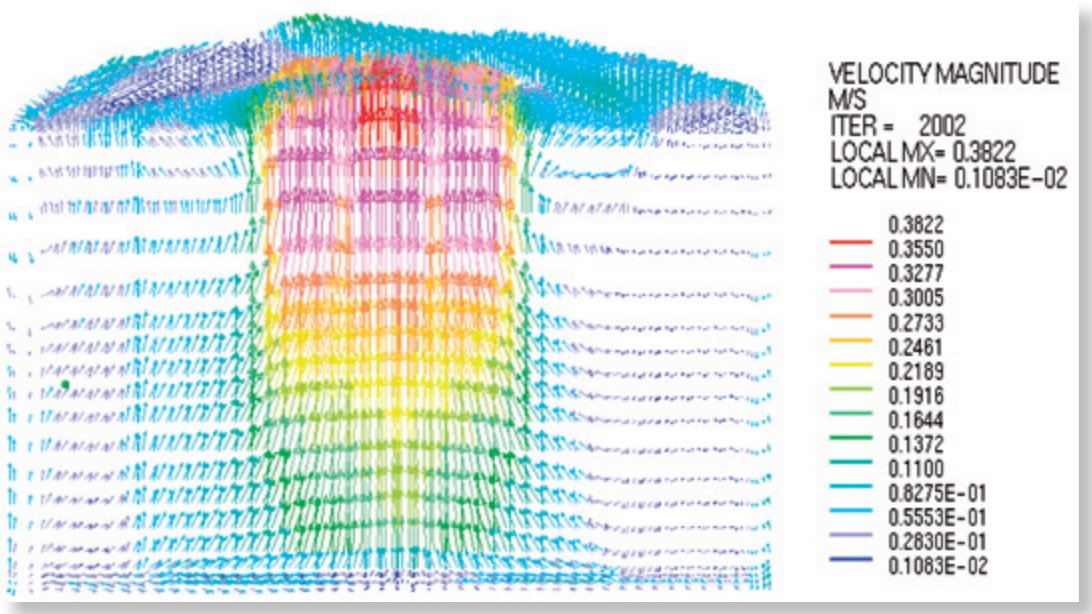


FIG. 13. Velocity distribution at the interwrapper space 10 min after event initiation.

vessel. Next, the behaviour of these parameters was evaluated through transient analyses carried out for three of the six case studies and only within 200 s after shutdown, owing to the large computational time required. Hence, quasi-steady-state analyses were performed 10 min and 5 h after event initiation. The quantification of flow and the temperature reduction across the core due to the consideration of the IWF were some of the most relevant results obtained.

Some preliminary specific conclusions indicate that temperature distribution at the core outlet for decay heat evacuation is not essentially affected by some delay in dampers opening, by the replacement of sodium coolant in DHX loop by NaK, or by moderate changes in air inlet temperature in the AHX. The general preliminary conclusion is that the reactor can be safely shut down and the residual heat can be removed by natural convection of DHR in the loss of off-site power/station blackout event.

In 2010, the results obtained by all the participants will be compared and assessed. A summary report will be prepared in the second half of 2010.

See also: INPRO Collaborative Project DHR at *http://www.iaea.org/INPRO/dhr.html*

AWCR (Advanced Water Cooled Reactors)

This INPRO Collaborative Project investigates natural circulation and thermal stratification phenomena relevant to AWCRs. Several phenomena, such as stability, startup, flashing induced oscillations, self-pressurization, thermal stratification and condensation in the vapour dome are investigated extensively for a wide range of operating conditions. In particular, case studies on passive safety investigate natural circulation phenomena of selected AWCR systems including startup and stability of single-phase natural circulation reactor systems (CAREM, AHWR), and theoretical and experimental studies on mixing and stratification in large water pools with immersed heat exchangers (AHWR, APR+) in a two-phase natural circulation.

The AWCR project was initiated by Argentina and India in 2008. The Republic of Korea joined the study in late 2009, since it is developing an APR. IAEA experts on nuclear power technology development are contributing to this Collaborative Project.

In 2009, experts from Argentina and India made significant progress in implementing the project's working plan. In the area of the single-phase natural circulated reactor system, the startup procedure for the AHWR was set up and an integral test loop for the AHWR was completed. The results of an experimental demonstration of the startup procedure were used as benchmarking data for an RELAP5 analysis. Two cold startup options, i.e. a pressurized startup and a startup with self-pressurization, were studied and revealed that self-pressurization appears to be feasible as it avoids power oscillations. For another single-phase natural circulated reactor system, CAREM, a special thermohydraulic code was developed and used in sensitivity studies to determine critical parameters for system stability.

In the area of two-phase natural circulation with immersed heat exchangers, the effect of thermal stratification was measured using an integral test loop for the AHWR and a system code developed for this purpose. Also, the passive auxiliary feedwater system (PAFS), one of the passive safety features, has been adopted for the APR+. A basic design and preliminary analysis of the PAFS were carried out; a test plan was designed for measuring the heat removal rate, pressure loss at system, system instability, etc., of the PAFS, using separate effect tests and integral effect tests. The advantages of using a system code or a CFD to solve thermal stratification in the large pool immersed heat exchanger were also considered and will be explored in further experiments.

At a technical meeting in October 2009, project participants presented the status of their R&D activities, shared experiences and discussed milestones to be achieved in project implementation in 2010, which will focus on further tests and compilation of test results concerning simulation of thermal stratification (India), stability of natural circulation (Argentina) and detailed design and integral effect tests (Republic of Korea). The results of these research activities will be presented at an AWCR project meeting in late 2010.

See also: INPRO Collaborative Project AWCR at *http://www.iaea.org/INPRO/AWCR.html*

PGAP (Performance Assessment of Passive Gaseous Provisions)

Innovative reactors are expected to increase the use of passive systems to enhance safety. The lack of operating experience and data covering relevant phenomena over a wide range of operating conditions may

cause challenges to the designers of such systems. This is particularly true of a certain class of passive systems that involve a moving fluid under natural circulation. In these systems, the driving forces and uncertainties associated with important parameters that affect natural circulation raise questions regarding their performance and reliability. Several methodologies have been developed to assess the performance and reliability of such systems. These methodologies have different features and employ different definitions for reliability.

The objective of the INPRO Collaborative Project on PGAP is to contribute to an international consensus in two areas: (i) a unified definition of the reliability of a passive system that involves natural circulation and (ii) a unified methodology to assess this reliability. This new methodology will be based on existing methodologies developed in Europe, i.e. reliability methods for passive systems, and in India, i.e. assessment of passive systems reliability, and will use the results of a benchmark exercise that models decay heat removal transients for the Commissariat à l'énergie atomique (CEA) gas cooled fast reactor design (Fig. 14). The benchmark will comprise two phases: deterministic calculations and reliability calculations. For each phase, two transients will be simulated to assess the performance of the DHR system. These transients include a station blackout event and a 76 mm diameter loss of coolant accident event.

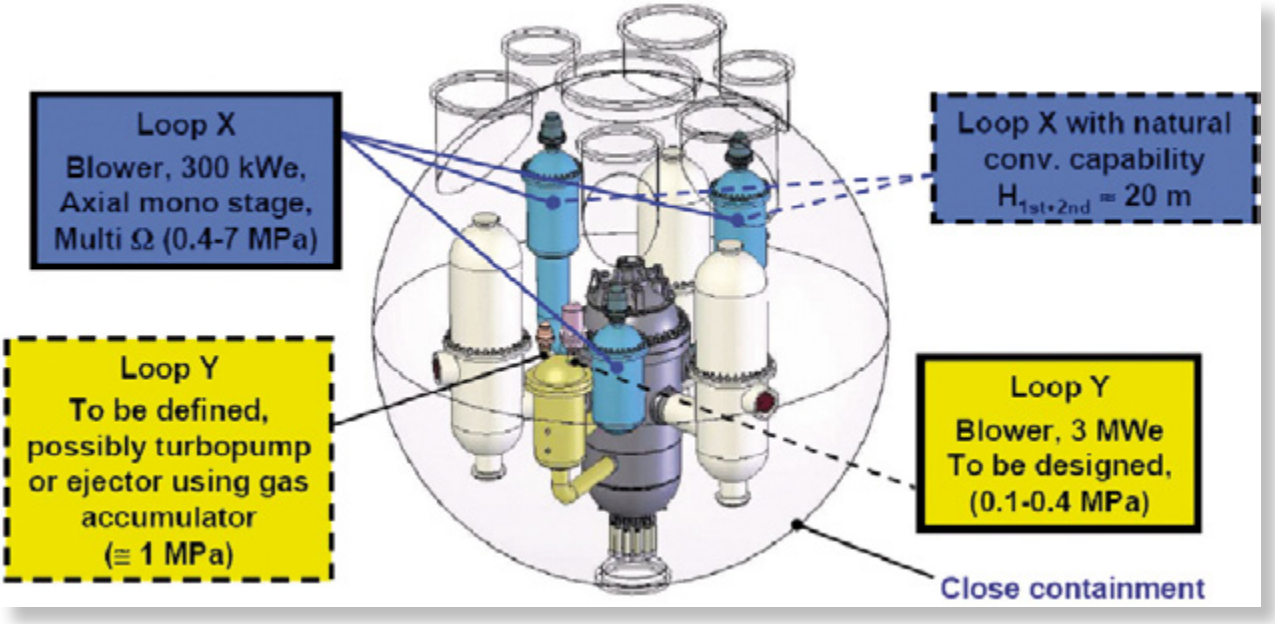


FIG. 14. Main features of the CEA gas cooled reactor design.

In addition to France (CEA), which initiated and is now leading the PGAP project, institutions in Belarus (SOSNY), Belgium (SCK-CEN), Czech Republic (NRI-Řež), Germany (FZK), India (BARC) and Algeria (COMENA) are contributing to this project.

In 2009, the analyses of transient 1 were carried out by several participants using two different computer codes (RELAP and CATHARE). Transient 1 consisted of a station blackout accident scenario where a loss of station service power was assumed to take place in combination with failure of the backup emergency diesel generators, and with only one DHR loop available. The purpose of the analyses was to predict the performance of the DHR loop and its effectiveness in keeping certain parameters such as the temperature of fuel and other components within design safety limits. The results were presented at a project meeting in June 2009, where the responses of various plant parameters (e.g. reactor core power, fuel temperature) were compared. Although the results appeared to be mainly consistent, some discrepancies, for example, variations in certain physical parameters as a function of time, suggested that the interpretation of the scenario and related assumptions were not always consistent. While not part of the project scope, this exercise provided insight into the effect of the use of different analysis tools (RELAP and CATHARE in this case) as well as the effect of code user on the results. Most discrepancies were resolved in a second round of calculations following further discussions of the transient specification.

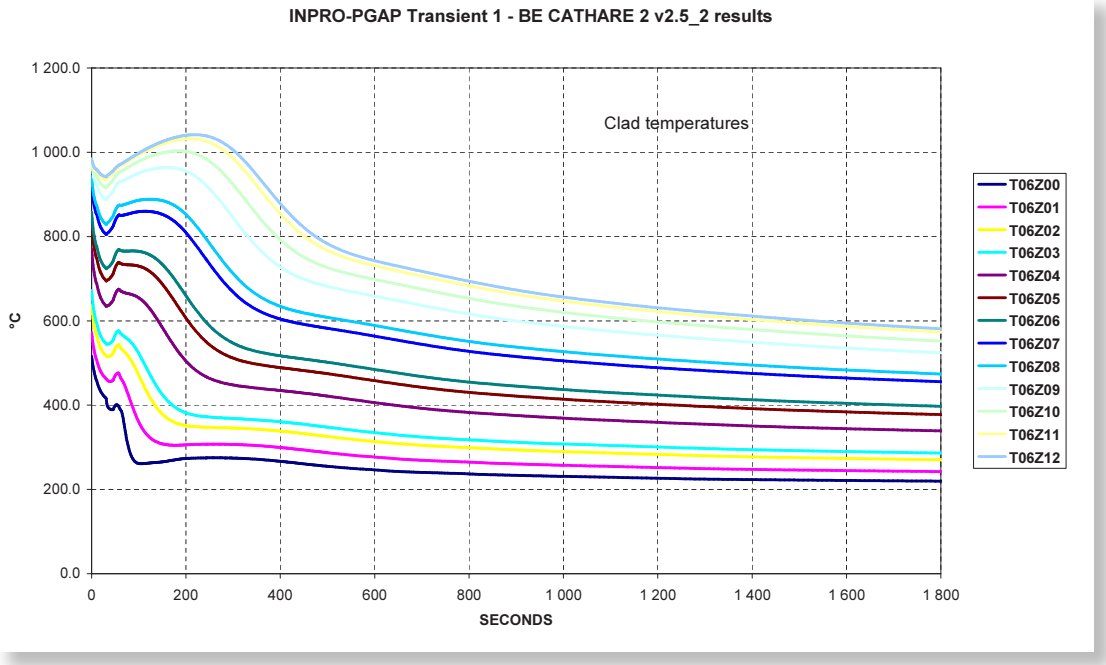


FIG. 15. Sample result from transient 1 (fuel clad temperature as a function of time at different core elevations).

The repeated results showed improved agreement in the prediction of important plant parameters between the participants. An example is given in Fig. 15, where the evolution of fuel clad temperature is shown as a function of time. The improved agreement between the different code predictions is a prerequisite for the start of the second phase of the calculations, namely, the reliability phase, where the effect of perturbations in certain input parameters will be investigated. This phase will be completed in early 2010 and the results will be discussed at the next project meeting in February 2010. The calculations for the second transient will be initiated and completed in 2010.

See also: INPRO Collaborative Project PGAP at *http://www.iaea.org/INPRO/pgap.html*

D: Innovations in Institutional Arrangements

D.1. Introduction

Institutional arrangements are an important part of the nuclear energy system, including bilateral or multilateral agreements, treaties, national nuclear legislation and regimes, safety standards, new regulatory and licensing approaches and international conventions. Deploying new reactor designs may require innovative approaches to such institutional measures, in particular for transportable, small- and medium-sized reactors. This programme area fosters collaboration and supports Member States in developing innovative institutional and legal arrangements for deploying innovative nuclear energy systems in the 21st century.

One INPRO Collaborative Project supporting activities in this area is SMALL.

D.2. INPRO Study on Legal and Institutional Issues of Transportable Nuclear Power Plants (TNPPs)

In 2009, a key study in the area of innovations in institutional arrangements addressed legal and institutional issues related to the introduction of TNPPs[12]. The main objective was to help developers learn about technologies that could simplify legal and infrastructure issues, and consider technical design scenarios and options of operation and ownership that might introduce additional problems.

Twenty experts from seven INPRO members (Chile, the Czech Republic, Egypt, Indonesia, Pakistan, the Russian Federation and the USA) contributed to the study which also benefits from IAEA legal expertise and cooperation of the IAEA nuclear safety and security programme, as well as programmes on nuclear power engineering and nuclear power technology development.

A TNPP is a non-stationary nuclear energy unit capable of producing final energy products. It includes the nuclear reactor, balance-of-plant, for example, steam generator or turbine and, if necessary, fuel storage facilities. The complete TNPP is factory fabricated and then moved to its location by rail, truck or ship. Fuel is either already loaded in the reactor core or transported separately and then loaded at the site. What all TNPP reference cases of the INPRO study had in common is that they are not designed for, and do not allow, operation during transport. The TNPPs can be designed for relocation after operation at a selected site, or for remaining at the original site until their final return to the factory.

FIG. 16. Model of a transportable nuclear reactor designed by SOSNY, Belarus.

[12] Previously named transportable nuclear installations.

TNPPs are of particular interest for niche applications, especially in areas with limited infrastructure, for countries with small electrical grids, and for use in remote or isolated areas. They can also be used for non-electrical applications, such as desalination of sea water and hydrogen production. No operating TNPP currently exists, although in several countries new technologies are being designed or TNPPs constructed. TNPPs will require innovative approaches to institutional and infrastructure arrangements. The IAEA publication *Milestones in the Development of a National Infrastructure for Nuclear Power* (IAEA Nuclear Energy Series No. NG-G-3.1) identifies 19 infrastructure issues that are also applicable to TNPPs.

In the INPRO study, special emphasis has been placed on:

- Technical, logistic and hard infrastructure implications of the use of a TNPP as a battery reactor, i.e. transport with or without loaded fuel, decommissioning or TNPP replacement and use at another site before the end of the core life.

- A minimum technological level required in the recipient country to deploy a TNPP. Infrastructural arrangements, such as a healthcare system, communication network, availability of regional assistance, local services and a conventional safety culture are not expected to require any special or significant development or adjustment.

- Quality assurance and quality control to meet licensing requirements in the supplier/recipient countries, i.e. access to the supplier factory for inspection.

- Available legislation and existing regimes for safety, security, safeguards and liability were also considered.

Three meetings were held in 2009 to exchange information on the work of the Russian team (May 2009), discuss infrastructure issues related to the deployment of TNPPs (July 2009) and prepare the final report (October 2009). The study results should also enable newcomer countries to recognize the potential advantages of introducing transportable plants, since users of TNPPs are not obliged to install facilities for the storage and management of fresh and spent nuclear fuels and waste management is also considerably reduced. Since reactors would be factory fabricated in the supplier country, a Member State installing a TNPP may need to develop only minor construction or maintenance capabilities depending on the type of TNPP.

The study report on *Legal and Institutional Issues of Transportable Nuclear Power Plants* will be published by the IAEA in 2010.

D.3. INPRO Collaborative Project in Programme Area D

SMALL (Implementation Issues for the Use of Nuclear Power in Small Grid Countries)

This Collaborative Project addresses issues faced by countries with electrical grids of limited capacity and stability in particular technology issues and related institutional measures. It investigates the deployment of nuclear power in countries with small grids as well as technical and economic options for managing spent fuel and radioactive waste applicable to the conditions of such countries.

In 2009, Armenia, France, the Russian Federation and the USA contributed to the project. Two consultancy meetings were held in April 2009 to chart the way forward and present and share relevant activities and agree on the content and structure of the project's report.

So far, Armenia has been the focus of the project and provided data for further investigation and extrapolation. Armenia was one of several countries which had conducted an assessment of its nuclear energy systems using the INPRO Methodology. The Armenian NESA specifically focused on the issues and requirements of a country with a small grid and identified further R&D to bridge technological and institutional gaps. The Armenian study analysed the potential demand for nuclear power with reference to gas price scenarios and examined two nuclear fuel cycle options suitable for small countries:

1. Storage of spent nuclear fuel in wet storage at the nuclear power plant site and transportation of spent nuclear fuel to an interim (up to 50 years) dry storage facility or disposal facility within the country. The feasibility of this first option depends on finding an adequate geological site for high level waste and spent fuel disposal.

2. Storage of spent nuclear fuel in a wet storage at the nuclear power plant site and transportation of spend nuclear fuel to the supplier. These options were evaluated and disposal facilities within the country or multiregional disposal facilities were also considered.

A calculation of the spent fuel isotope content as well as some economic considerations are foreseen for 2010 to support national decisions on a strategy for final disposal and spent fuel storage in terms of the volume, cost and type of storage facility. A consultancy meeting in 2010 will review the final report to be issued at the end of the year.

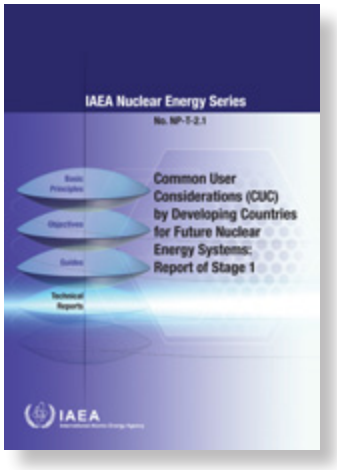
See also: INPRO Collaborative Project SMALL at *http://www.iaea.org/INPRO/small.html*

E. INPRO Dialogue Forum on Nuclear Energy Innovations

E.1. Introduction

The objective of the INPRO Dialogue Forum is to bring together technology users and technology holders from all interested Member States and facilitate discussion so that technology holders can better understand the needs and concerns of technology users, and users can better understand the possibilities and limitations of technology holders associated with the development and deployment of innovative nuclear energy systems. The Dialogue Forum addresses all concerned stakeholders, including governments, national and international organizations, regulators, vendors, operators and researchers. Open discussions between technology users and holders at an early stage of development of nuclear energy systems facilitate harmonization of practices, establishment of strategic partnerships between technology users and holders and future deployment of innovative nuclear energy systems in the technology user countries.

The main value of the Dialogue Forum lies in the opportunity to discuss and share information without necessarily reaching consensus or adopting joint policies. Correspondingly, the main product of the INPRO Dialogue Forum will be proceedings that document positions, questions and progress in discussions.



Preceding this new activity was a two year study, conducted in 2007 and 2008, which identified commonalities in the expectations of developing countries considering the introduction of nuclear power. The results were published in 2009 in *Common User Considerations (CUC) by Developing Countries for Future Nuclear Energy System: Report of Stage 1* (IAEA Nuclear Energy Series No. NP-T-2.1).

This publication promoted early and frequent dialogue between technology users and holders. It was prepared with input from some two hundred experts from participating developing countries that are considering the deployment of nuclear power plants in the near term, or are making projections for the deployment of nuclear power plants in the next 40 years (up to 2050). The countries addressed in this publication were selected using the World Bank's definition of developing economies.

The input by the experts reflected good knowledge of the currently available technologies; discussions and considerations of innovative technologies were, however, very limited. Expectations of the experts were more optimistic in terms of nuclear power plant deployment up to 2030 than the IAEA projections for the same time frame. The study recommended that additional refinements of the information by various methods, such as application of the INPRO Methodology to identify gaps, or the collection of larger scientific samples of country specific data would be required to analyse comprehensive trends and/or to quantify market demand. In particular, issues of grid capacity and likely available investment based on gross domestic product should be carefully considered in the future as they might affect near and long term nuclear expansion projections.

E.2. Organizing the Dialogue Forum

In November 2009, at a special session on the INPRO Dialogue Forum held in conjunction with the 15th meeting of the INPRO Steering Committee, delegates decided on Dialogue Forum operation, including stakeholders, meetings, dissemination of information, communication and interaction levels, and issues to be addressed in the next four years. The Dialogue Forum is open to all IAEA Member States and involves a variety of audiences.

The following areas were identified for further discussion through the Dialogue Forum in the course of the next four years:

- **Innovative nuclear systems**: Definition of innovation; approaches to safety for innovative systems; timescale for development and deployment of innovative systems; information exchange on innovative technologies, including degree of maturity; role of users in the development and deployment of innovative systems; lessons learned from current technology and the application of these lessons to innovative concepts; near term deployment technology as a bridge between current technology and future concepts; and demand driven innovative nuclear systems for electricity production, process heat, desalination and hydrogen production.

- **Institutional arrangements**: Innovations to support sustainable deployment of new technologies and to facilitate the implementation of radical changes in technologies and national, regional and international long term commitment to the nuclear option and sociopolitical issues.

- **Nuclear fuel cycles**: Future users' needs concerning the back end of the nuclear fuel cycle; multinational reprocessing plants; material flow as a result of a large use of nuclear energy and assurance of fuel supply for innovative concepts.

For each of these topics, the Dialogue Forum could contain discussion 'tracks', i.e. smaller meetings or information exchange through internet platforms and other channels to further elaborate these topics.

E.3. First Workshop of the Dialogue Forum

In preparing a workshop of the Dialogue Forum, the first activity in this INPRO programme area, the outcome of the Common User Considerations study (IAEA Nuclear Energy Series No. NP-T-2.1) and deliberations of the 15th INPRO Steering Committee meeting were reviewed. The workshop to be held in February 2010 focuses on:

1. **Socioeconomic and macroeconomic factors**: These are factors that influence decisions regarding deployment of nuclear systems, including: impact on environment/climate, behaviour of the national or local economy, psychological and 'quality of life' issues, perceptions, State–public relationships and national economic development.

2. **Proven technology**: Technology which is provided in an innovative nuclear energy system should be 'proven' or 'mature' before it is included in a proposed design. For technology to be considered mature, it must have been applied in a prototype article (a system, subsystem, or component), tested in a relevant or operational environment and found to have performed adequately for the intended application for a reasonable length of time, or be fully licensed and operated by a host country before export to another country. This implies a need for measuring or evaluating maturity and ensuring that only sufficiently mature technology is included by the technology holders in proposed plant designs.

3. **Safety approaches for innovative nuclear energy systems**: Safety is an essential consideration for the overall assessment of a given nuclear energy system. This initial discussion will focus on 'generic' regional approaches to safety that could be the first step in the establishment of (i) a process to assist technology users to perform independent assessments of the safety of innovative nuclear systems based on IAEA Safety Standards, and (ii) approaches to national and/or regional arrangements to assist in providing safety guidelines and assessments for future reactor systems while taking full advantage of the experiences of technology holders and their extensive safety analysis database.

The workshop is organized through the IAEA's technical cooperation programme (INT/4/142) and held in cooperation with IAEA experts on energy planning and economics, and on nuclear installation safety of the IAEA's nuclear safety and security programme.

In 2010, strategic partnerships of stakeholders will be established to secure full participation of, and benefits for, all interested organizations and Member States in this programme area.

F. Policy Coordination, Communication and INPRO Management

F.1. Introduction

The project management of INPRO, including strategic programme planning, organization of meetings of the Steering Committee and policy coordination with other international initiatives are the main activities in this cross-cutting programme area. It also focuses on effective and targeted communication with INPRO stakeholders in Member States and at the IAEA and includes outreach activities such as dissemination of INPRO results through publications, the web site and information material, participation in international conferences and meetings, and organization of special events and related exhibitions.

F.2. Communications

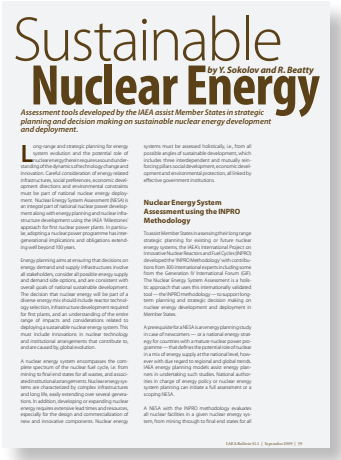
In 2009, INPRO's communication activities were intensified to enhance cooperation with INPRO's stakeholders in Member States and at the IAEA and to keep them abreast of ongoing activities, such as meetings and publications, and achievements and results from INPRO studies and projects. Using a variety of communication channels and newly produced communication tools contributed to increasing the information flow between the INPRO group at the Secretariat and Member States. This included articles in the IAEA Bulletin, fact sheets and brochures, regular contributions to the IAEA newsletters on nuclear power and on fuel cycle and waste, a section on INPRO in an IAEA audiovisual on-line show, four new displays and posters shown in several exhibitions, and the INPRO web site.

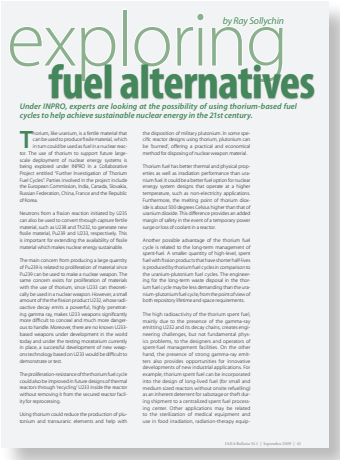
A major event in 2009 was a briefing session during the 53rd IAEA General Conference in September, entitled *INPRO: A Partnership for Dialogue and Innovation in a Changing Nuclear World*. Senior representatives from Member States, including Canada, India, Indonesia and the Russian Federation shared their perspectives and views on INPRO with an audience of some 70 delegates and emphasized the added value of INPRO for their countries' nuclear development and their expectations for the future. Delegates were also briefed on INPRO's recent developments and how the project helps Member States chart their way forward in choosing innovative technologies when developing sustainable nuclear energy systems.

See also: *http://www.iaea.org/NewsCenter/News/2009/inpro.html*

FIG. 17. INPRO briefing session for delegates of the 53rd IAEA General Conference, 17 September 2009.

Two articles were published in the IAEA Bulletin (Vol. **51** (1), September 2009), on *Sustainable Nuclear Energy* and on *Exploring Fuel Alternatives*, related to the Collaborative Project on Further Investigations of the ^{233}U/Th Fuel Cycle.





To enhance communications aspects of larger and smaller meetings, exhibitions were organized on activities of INPRO and other IAEA programmes, for example, during a workshop on IAEA Tools for Nuclear Energy System Assessment for Long Term Planning and Development (July 2009) and the 15th INPRO Steering Committee (November 2009). INPRO also participated in the exhibition during the IAEA General Conference in September 2009. In addition, work began on producing a short video that would mark the 10th anniversary of INPRO in 2010.

A main communications channel used to reach out to the INPRO community and other stakeholders is the INPRO web site *(www.iaea.org/INPRO)*. In 2009, it was revised, including a new layout, to reflect the programme structure as endorsed by the INPRO Steering Committee. Regular news items on results of meetings and workshops, new publications and other relevant information provide a comprehensive and timely overview of the latest developments in INPRO.

FIG. 18. INPRO web site: www.iaea.org/INPRO.

III. Outlook 2010

The INPRO Action Plan for the biennium 2010–2011 reinforces INPRO's role as an international initiative that is investigating nuclear energy innovation to achieve a comprehensive scientific and technological understanding of the institutional, legal, sociological, environmental and economic factors that will determine the success of nuclear energy development. The project will be on a firm basis, with strong support from Member States and the IAEA General Conference and will be active in four substantive and two cross-cutting programme areas: (i) nuclear energy system assessment with the INPRO Methodology; (ii) global vision, scenarios and pathways to sustainable nuclear development; (iii) innovations in nuclear technology; (iv) innovations in institutional arrangements; (v) INPRO Dialogue Forum on nuclear energy innovations; and (vi) policy coordination, communication and INPRO management.

The INPRO Dialogue Forum will be established as one of the project's key activities, and two major meetings will be convened in February and October 2010, bringing together technology holders and users to identify and discuss needs, concerns, possibilities and limitations related to deploying existing and innovative nuclear energy systems.

Increased emphasis will be on supporting Member States in their national long range planning, in particular through NESAs. A NESA which Belarus has been undertaking will be completed by the end of the year and will serve as a model for other countries. As part of the NESA support package, a brochure on *Introduction to a NESA* will be published. A new service tailored to nuclear newcomers will offer support and guidance in building and introducing national nuclear energy policies as part of their long term energy planning strategy, in conjunction with the IAEA 'milestones' approach and guidance on building a first nuclear power plant. INPRO will continue to assist Member States in strategy planning through a technical cooperation workshop on Long Range Nuclear Energy Programme Planning and Strategy Development in June 2010. Consideration of socioeconomic and macroeconomic factors to support Member States in strategic nuclear energy planning will also form a new activity in this biennium.

Several IAEA publications will be issued, documenting progress results of INPRO activities such as the INPRO Collaborative Projects GAINS, PRADA, ThFC, DHR, PGAP and SMALL, as well as two major studies on global scenarios for nuclear energy development in the 21st century, and legal and institutional issues of non-stationary reactors.

The results from four collaborative projects and the major study on Global Scenarios and Regional Trends of Nuclear Energy Development in the 21st Century will form an integrated analysis on sustainable nuclear energy development scenarios in the 21st century which describe the background of global nuclear power development against which national programmes will develop.

Coordination with other international initiatives such as GIF and SNETP will be strengthened. In early March 2010, representatives of GIF and IAEA–INPRO will meet at the IAEA for the 4th GIF–INPRO Interface Meeting to share information on the progress status and future plans of activities related to technology innovation of nuclear energy systems, to monitor the progress of cooperation as agreed in a Memorandum of Understanding of February 2008, and to develop a Joint Action Plan with new areas of expanded cooperation.

Finally, in 2010 INPRO will celebrate its tenth anniversary with an event during the 54th IAEA General Conference in September.

IV. Annex

INPRO Meetings in 2009

Date	Meeting	Location
12–13 January 2009	Consultants meeting on the INPRO CP "Further Investigations of the ^{233}U/Th Fuel Cycle (ThFC)"	IAEA
26–30 January 2009	Consultants meeting on the INPRO study "Global Scenarios and Regional Trends of Nuclear Energy Development in the 21st Century"	IAEA
16–20 Feb 2009	Workshop on "Lessons Learned from the INPRO Assessment Studies"	IAEA
25–27 Feb 2009	15th INPRO Steering Committee Meeting	IAEA
6–7 April 2009	Consultants meeting on the INPRO CP "Implementation Issues for the Use of Nuclear Power in Small Grid Countries (SMALL)"	IAEA
15–16 April 2009	Information exchange meeting on Ukraine's contribution to the INPRO CP "Global Architecture of Innovative Nuclear Energy Systems based on Thermal and Fast Reactors including Closed Fuel Cycle (GAINS)"	Ukraine
4–6 May 2009	Consultants meeting on the INPRO CP "Global Architecture of Innovative Nuclear Energy Systems based on Thermal and Fast Reactors including Closed Fuel Cycle (GAINS)"	IAEA
5–6 May 2009	Consultants meeting on "Planning of IAEA Activity on Fuel and Fuel Cycle Options for Small and Medium Sized Reactors with Long Core Life (SMLCLR)"	IAEA
14–15 May 2009	Information exchange meeting on the work of the Russian Team related to the INPRO study "Legal and Institutional Issues of Non-stationary NPPs"	IAEA
25–27 May 2009	Consultants meeting on the INPRO study "Global Scenarios and Regional Trends of Nuclear Energy Development in the 21st Century"	IAEA
9–11 June 2009	Consultants meeting on the INPRO CP "Proliferation Resistance: Acquisition/Diversion Pathway Analysis (PRADA)"	Rep. of Korea
11–12 June 2009	Consultants meeting on the INPRO CP "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)"	IAEA
16–17 June 2009	Consultants meeting on the INPRO CP "Performance Assessment of Passive Gaseous Provisions — PGAP"	IAEA
22–26 June 2009	Consultants meeting on "Planning Support to INPRO Activities in Programme Areas D and E"	IAEA
20–23 July 2009	Workshop on IAEA Tools for Nuclear Energy System Assessment for Long term Planning and Development	IAEA
22–24 July 2009	Consultants meeting on "Infrastructure Issues Related to Deployment of Transportable Nuclear Installations"	IAEA

Date	Meeting	Location
27–31 July 2009	Consultants meeting on "Comprehensive Full Scope Nuclear Energy System Assessment of Belarus"	Belarus
25–27 Aug 2009	Consultants meeting on the INPRO study on "Global Scenarios and Regional Trends of Nuclear Energy Development in the 21 Century"	IAEA
3–4 Sept 2009	Consultants meeting on the INPRO CP "Fuel Cycles for Innovative Nuclear Systems through Integration of Technologies (FINITE)"	IAEA
22–25 Sept -2009	Consultants meeting on the INPRO CP "Integrated Approach for the Modelling of Safety Grade Decay Heat Removal System for Liquid Metal Reactors (DHR)"	Russian Federation
28 Sept–2 Oct 2009	Consultants meeting on "Comprehensive Full Scope Nuclear Energy System Assessment of Belarus"	Belarus
5–7 Oct 2009	Consultants meeting to discuss final draft report of the INPRO study on "Legal and Institutional Issues of Transportable Nuclear Installations (TNIs)"	IAEA
15–16 Oct 2009	Kick-off meeting on the INPRO Collaborative Project "Environmental Impact Benchmarking Relative to Innovative Nuclear System Component (ENV)"	IAEA
19–23 Oct 2009	Consultants meeting on "Processing of Waste from Innovative Types of Reactors"	IAEA
26–29 Oct 2009	Consultants meeting on the INPRO CP "Global Architecture of Innovative Nuclear Energy Systems based on Thermal and Fast Reactors including Closed Fuel Cycle (GAINS)"	Belgium
29 Oct 2009	Consultants meeting on the INPRO CP "Advanced Water Cooled Reactors (AWCR)"	IAEA
9–11 Nov 2009	15th INPRO Steering Committee Meeting	IAEA
11 Nov 2009	Preparatory meeting for the INPRO Dialogue Forum	IAEA
9–13 Nov 2009	Consultants meeting on the INPRO CP "Planning Support to INPRO Activities in Programme Areas D and E"	IAEA
2–4 Dec 2009	Consultants meeting on the INPRO CP "Proliferation Resistance: Acquisition/Diversion Pathway Analysis (PRADA)"	IAEA
7–8 Dec 2009	Consultants meeting on "Global Scenarios and Regional Trends of Nuclear Energy Development in the 21st Century"	IAEA

Participation of the INPRO Group in International Conferences in 2009

Conference	Date and place
5th Annual Nuclear Energy Conference	12–13 February, Bethesda, Maryland, USA
Generation IV International Forum — Policy Group (GIF-PG)	4–5 March, San Diego, USA
31st ESARDA Annual Meeting	26–28 May, Vilnius, Lithuania

Conference	Date and place
6th International Scientific and Technical Conference "Safety Assurance of Nuclear Power Plants with WWERs"	26–29 May, Podolsk, Russian Federation
Platts 4th Annual European Nuclear Power Conference	29–30 June, Paris, France
7th European Commission Conference on Euratom Research and Training in Reactor Systems (FISA-2009)	22–24 June, Prague, the Czech Republic
International Conference on Nuclear Engineering — ICONE 17	12–16 July, Brussels, Belgium
50th Annual Meeting of the Institute of Nuclear Materials Management (INMM)	13–17 July 2009,Tucson, Arizona, USA
GLOBAL — 2009 "The Nuclear Fuel Cycle: Sustainable Options and Industrial Perspectives"	6–11 September, Paris, France
2009 GIF Symposium: "10 Years of Achievements and the Path Forward" & GIF Policy Group Meeting	9–11 September, Paris, France
11th International Conference on "Nuclear Power Plant Safety and Personnel Training"	29 September–2 October, Obninsk, Russian Federation
International Conference on "Fast Reactors and Related Fuel Cycles: Challenges and Opportunities (FR2009)"	7–11 December, Kyoto, Japan
"ISTC — The Way Forward", 15th Anniversary Conference	10–11 December, Moscow, Russian Federation

INPRO Publications

The following publications were issued in 2009:

Lessons Learned from Nuclear Energy System Assessments (NESA) using the INPRO Methodology, IAEA-TECDOC-1636

Status and Trends of Nuclear Technologies: Report of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), IAEA-TECDOC-1622

IAEA Tools and Methodologies for Energy System Planning and Nuclear Energy System Assessment, Brochure

Common User Considerations (CUC) by Developing Countries for Future Nuclear Energy Systems: Report of Stage 1, IAEA Nuclear Energy Series No. NP-T-2.1

International Project on Innovative Nuclear Reactors and Fuel Cycles, INPRO Progress Report 2008

Assessment of Nuclear Energy Systems Based on a Closed Nuclear Fuel Cycle with Fast Reactors. A report of the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), IAEA-TECDOC-1639 (2010)

Visit *http://www.iaea.org/INPRO/publications.html* to view all INPRO publications and conference papers.

IAEA publications can also be obtained at *http://www.iaea.org/Publications/index.html*

INPRO Members in 2009

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Kazakhstan
Republic of Korea
Morocco
Netherlands
Pakistan
Russian Federation
Slovakia
South Africa
Spain
Switzerland
Turkey
Ukraine
United States of America
European Commission

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