

International Project on Innovative Nuclear Reactors and Fuel Cycles: Introduction and Education and Training Activity

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Abstract. The IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) was established in 2000 through IAEA General Conference resolution with aim to ensure that sustainable nuclear energy is available to help meet the energy needs of the 21st century. INPRO seeks to bring together technology holders, users and newcomers to consider jointly the international and national actions required for achieving desired innovations in nuclear reactors and fuel cycles, with a particular focus on sustainability and needs of developing countries. It is a mechanism for INPRO Members to collaborate on topics of joint interest. INPRO activities are undertaken in close cooperation with Member States in the following main areas: Global Scenarios, Innovations, Sustainability Assessment and Strategies, Policy and Dialogue. The paper presents short introduction in INPRO and specifically the distant Education and Training INPRO activity on important topics of nuclear energy sustainability to audiences in different Member States. These activities can support capacity building and national human resource development in the nuclear energy sector. The main benefit of such training courses and workshops is that it is not only targeted to students, but also to lecturers of technical and nuclear universities. Moreover, young professionals working at nuclear energy departments, electric utilities, energy ministries and R&D institutions can participate in such training and benefit from it.

Keywords: nuclear energy sustainability, nuclear education, distant learning, nuclear energy system assessment, educational resources

1 About INPRO

The IAEA's International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) was established in 2000 through IAEA General Conference resolution with aim to ensure that sustainable nuclear energy is available to help meet the energy needs of the 21st century. INPRO seeks to bring together technology holders, users and newcomers to consider jointly the international and national actions required for achieving desired innovations in nuclear reactors and fuel cycles, with a particular focus on sustainability and needs of developing countries.

INPRO is a membership-based project [1], currently consisting of 41 Members – 40 IAEA Member States and the European Commission (EC): Algeria, Argentina, Armenia, Bangladesh, Belarus, Belgium, Brazil, Bulgaria, Canada, Chile, China, Czech Republic, Egypt, France, Germany, India, Indonesia, Israel, Italy, Japan, Jordan, Kazakhstan, Kenya, Republic of Korea, Malaysia, Morocco, Netherlands, Pakistan, Poland, Romania, Russian Federation, Slovakia, South Africa, Spain, Switzerland, Thailand, Turkey, Ukraine, United States of America, Vietnam and the EC. Several other countries participate on a working level or as observers in INPRO meetings (Figure 1).

INPRO seeks to broaden the understanding among Member States of the challenges involved in achieving global nuclear energy sustainability. It is a mechanism for INPRO Members to collaborate on topics of joint interest. INPRO activities are undertaken in close cooperation with



Figure 1. History of INPRO membership [2].

Member States in the following main areas [2]:

Task 1: Global scenarios (provides long-term scenario evaluation using dynamic simulation of national, regional and global nuclear energy systems);

Task 2: Innovations (designs and convenes collaborative projects on topics crucial to future nuclear sustainability and technological and infrastructure innovations);

Task 3: Sustainability Assessment and Strategies (assists Member States to build strategies for sustainable development of nuclear energy systems and plans through Nuclear Energy System Assessments (NESAs), using the INPRO Methodology);

Task 4: Policy and Dialogue (encourages and organizes

topical Dialogue Forums on cross-cutting subjects of interest to INPRO members and to the larger nuclear energy community).

Within Task 3 INPRO has developed a methodology to assess present and future nuclear energy systems against criteria for sustainability [3] – an internationally recognized tool for that are presently part of the integrated services provided by the IAEA’s Department of Nuclear Energy to Member States. INPRO methodology developed of a quantitative metric characterizing development of NES towards sustainability. A hierarchical set of Basic principles (BP), User requirements (UR), and Criteria (CR) were defined with more than one hundred criteria, each consisting of an indicator and an acceptance limit (Figure 2).



Figure 2. Structure of the INPRO methodology.

After determining the values of the indicator and its relationship with the corresponding acceptance limit, a judgement be made on whether or not the assessed NES complied with the criteria or not. It was assumed that, if all the criteria are fulfilled, the NES is sustainable. This approach was further developed as Nuclear Energy System Assessment (NESA) method and applied in several IAEA Member States with the use of a package of supporting tools

Activity within Task 1 has undertaken studies of global and regional scenarios of collaborative transition to sustainable nuclear energy systems. The study on Global Architecture of Innovative Nuclear Energy Systems with Thermal and Fast Reactors and a Closed Nuclear Fuel Cycle (GAINS) [4] addressed technical and highlighted some institutional issues to develop a global architecture for sustainable nuclear energy in the 21st century. It also outlined plausible transitions to such architecture. The GAINS study made next major step in development of a quantitative metric characterizing transition of the global NES towards sustainability. The purpose in the GAINS framework was to provide a main basis for comparing the different options and results of transition scenarios towards a more sustainable NES on a global basis. The approach developed in GAINS used the concept of the ‘Key Indicators’ (KIs) introduced in the INPRO methodology [3]. KIs were defined in the INPRO assessment areas. They had a distinctive capability for capturing the essence of a given area, and provided a means to establish targets in a specific area to be reached via improving technical or infrastructural characteristics of the NES or via

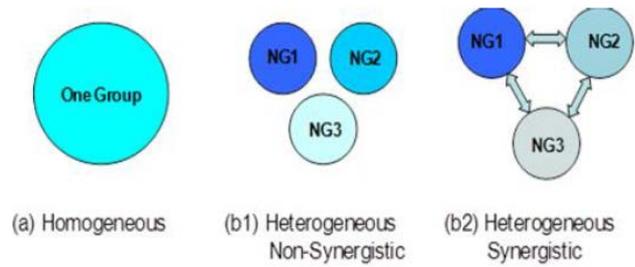


Figure 3. Possible world models for fuel cycle analysis.

collaboration among technology holders and users. GAINS project has introduced a model of the heterogeneous world comprising different nuclear strategy groups of countries non-personified, non-geographical (NGs) based on the spent nuclear fuel management strategy being pursued for the back-end of the nuclear fuel cycle (Figure 3).

INPRO Task 2 focuses on specific innovations, recommended by Member States as well as on subjects that are complementary to activities in the areas of Global Scenarios and Sustainability Assessment and Strategies. INPRO Task 2 “Innovations” has an objective to investigate innovative nuclear energy technologies and institutional arrangements to be deployed in the 21st century, supporting Member States pursuing those innovations [5]. Institutional arrangements are also an important part of the nuclear energy system, including agreements, treaties, legal frameworks or regimes, and conventions. Deploying of innovative nuclear energy systems (NES) may require innovative approaches to institutional measures, in particular for non-stationary, small and medium sized reactors. INPRO fosters collaboration in this area and supports countries in developing and implementing innovative arrangements.

The utilization of innovative fuels and fuel cycles also contribute directly to the development of sustainable NESs, for technical reasons as well as in terms of enhancing public acceptance. Innovations in the back end of nuclear fuel cycle have the potential to make a significant contribution to the growth of nuclear power. The sustainability of NESs at the regional and at global levels requires cooperation in the fuel cycle, particularly for issues involving the back end, including the end point for high level waste (HLW). Therefore INPRO is running a number of projects in the area of NFC back end.

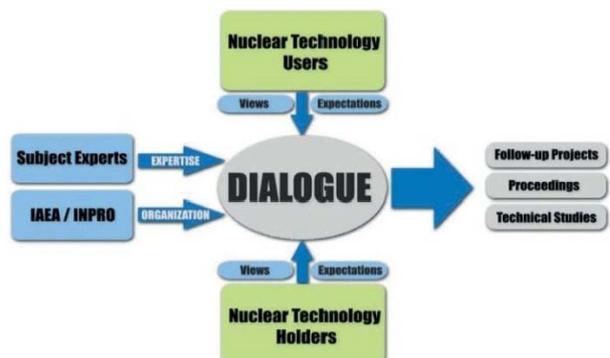


Figure 4. Schematic illustration of the INPRO dialogue forum.

INPRO Task 4 is effectively addressing urgent topics of institutional and technological innovations and has developed a dialogue forum among technology holders, technology users and newcomers to jointly define the desired innovations for future nuclear energy systems. Thereby, technology holders can better understand the needs and concerns of technology users and technology users can better understand the possibilities and limitations of technology holders (Figure 4). INPRO coordinates its activities with other international organizations and initiatives, the organization of meetings of the INPRO Steering Committee and INPRO's communication and outreach activities.

The INPRO Dialogue Forum [6] is open to all IAEA Member States and involves a variety of stakeholders, including governments, national and international organizations, regulators, vendors, operators and researchers. In 2015, the 10th forum focused on cooperative approaches to the back end of the nuclear fuel cycle including drivers and legal, institutional and financial impediments.

Task 4 also includes the education and training activity focussed on national experts, young nuclear professionals and students in Member States who wish to build awareness and gain an understanding of all issues related to a sustainable nuclear power programme.

2 Education and Training Activity

INPRO plays an important role in training and capacity building in support of nuclear energy system assessments for sustainability and strategic planning. Common interests of Member States in certain regions has led to the organization of a regional training that can further extend outreach to more experts in different fields of expertise relevant INPRO areas and also to decision makers in Member States. INPRO provides one regional INPRO workshop per year focussed on new comers and done in coordination between Tasks 1&3 and Planning and Economic Studies Section (PESS).

In 2014, INPRO conducted Regional Training (Latin America) on Nuclear Energy System Modelling and Assessment Using the INPRO Methodology (Figure 5).



Figure 5. Regional training (Latin America) on nuclear energy system modelling and assessment using the INPRO methodology.

In 2015, INPRO provided Regional Training on Nuclear Energy System Modelling and Assessment using the INPRO Methodology.

The objectives of the trainings were:

- to deliver lectures on the modelling of nuclear energy system and the use of INPRO methodology as a tool to perform sustainability assessment of nuclear energy system, in order to assist Member States in their long range and strategic planning of nuclear energy program as part of each country's energy mix.
- to develop understanding of sustainability issues in a planned nuclear energy system and ability to perform assessment of selected INPRO methodology criteria.
- Training participants mastered the ideas of nuclear energy system modelling and INPRO methodology in the four areas, fulfilled the quizzes and exercises, and demonstrated awareness in their areas of expertise. All participants presented statements on the results of modelling and assessment exercises performed during work sessions.
- Unique feature of INPRO training is a holistic approach for NES assessment including components of NES and areas assumed to be relevant to the assessment of long-term NES sustainability: economics, safety, infrastructure, waste management, proliferation resistance, physical protection and the environment.
- INPRO has complimentary its training services with the introduction of specially designed web oriented e-learning training package titled "An Interactive Online Training Course (NESA-ITC) on Performing a Nuclear Energy System Assessment". The objective of NESA-ITC is to familiarize Member States with the INPRO Methodology and assist them in using the INPRO Methodology in a NESA [7].
- INPRO also provides distant training on important topics of nuclear energy sustainability to undergraduate, graduate and PhD students and teaching and research staff of nuclear universities and research centres around the world.
- State-of-the art conferencing services provide excellent opportunities to deliver training on important topics of nuclear energy sustainability to undergraduate, graduate and PhD students and teaching and research staff of nuclear universities and research centres in many countries. Such distance training helps increase capabilities in Member States to develop and deploy innovative NESs and to make a collaborative transition to globally sustainable nuclear energy.

In 2014, INPRO provided two distant learning lecture courses and a series of workshops for students of Obninsk



Figure 6. Students of INPE-MePhI attending an INPRO online lecture.

Institute for Nuclear Power Engineering of National Research Nuclear University “MEPhI” (INPE NRNU MEPhI) in Spring Semester [8] (Figure 6) and for students and teachers of nuclear specialties State Engineering University of Armenia in Autumn Semester. The main objective of these lecture courses was to familiarize groups of undergraduate, graduate and PhD students as well as teaching and research staff with INPRO’s activities through direct communications with the IAEA leading experts having extensive experience in this field. The lectures covered (1) an overview of the INPRO’s activities; (2) the INPRO methodology for nuclear energy system assessment as a whole and for specific areas; (3) a nuclear energy system analysis using the INPRO/GAINS analytical framework; and (4) findings of the INPRO activities on small modular reactors, including transportable nuclear power plants.

This activity was organized within the framework of the Practical Agreements between the IAEA and NRNU MEPhI signed in September 2012 during the 56th General Conference in Vienna, aimed at implementation the initiatives and efforts related to education and training in the nuclear field.

Participants got familiarized with the INPRO activities, analytical framework for analysis and assessment of nuclear energy system evolution scenarios and with several aspects of MSRs including the areas of safety and economics. Topics covered during the lectures included the following:

- Overview of International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO)
- Nuclear energy system analysis using the INPRO/GAINS analytical framework;
- Findings of INPRO activities on small modular reactors, including transportable nuclear power plants.

The recently completed INPRO Collaborative Project GAINS (Global Architecture of Innovative Nuclear Energy Systems) has developed a framework for the analysis and assessment of transition scenarios to future sustainable nuclear energy systems (NES) and suggested a sustainable global architecture of innovative NES. The GAINS framework includes a heterogeneous world model which takes

into account differences in the countries’ policies regarding nuclear fuel cycle and enables to define attractive solutions for collaboration among technology holders and users in nuclear fuel cycle, enabling a transition to regionally or globally sustainable NES. Several scenarios were analysed including dynamic transition from the existing fleet of reactors and nuclear fuel cycles to the future sustainable NES.

It is essential that lectures were delivered to young professionals and lecturers and students of technical universities who will further be engaged in development and deployment of sustainable solutions for nuclear systems in IAEA Member States. The course will help improve professional and educational activities in the field of analysis and assessment of nuclear energy systems in support of developing solutions toward future sustainable nuclear energy.

The Web-conferencing was used as software so far as it is an easy, efficient and effective way for providing distance training courses.

Such training course targets students and lecturers from technical and nuclear universities as well as young professionals working at nuclear energy departments, electric utilities, energy ministries and/or R&D institutions. The training course supports capacity building in the area of national human resources in nuclear energy sector. Educating the lecturers, students and young professionals in IAEA Member States based on the INPRO framework and methodology will help to improve State’s ability to make professional and responsible long-term decisions with respect to sustainable nuclear power development.

From January to May 2015, INPRO continued this activity by providing joint lecture course on “State-of-the-art methods and tools for sustainability assessment of nuclear energy systems” [9] (Figure 7). The course was oriented to groups of under-graduate, graduate and PhD students, as well as national experts involved in the development and application of the methods and tools for sustainability and performance assessments of innovative nuclear energy systems, related nuclear fuel cycles and reactor technologies and corresponding issues by means of distant conferencing.

The course was delivered on a joint basis for students of the NRNU MEPhI and a number of higher educational universities, an nuclear industry organizations (Belarusian State University and Republican Unitary Enterprise “Belarusian Nuclear Power Plant”) (Belarus), Nuclear Technology Safety Center and Kazakhstan Institute for Strategic Studies under the President of Kazakhstan (Kazakhstan)), expressed their interest to participate in the lecture course.

This joint successful experience on nuclear education related cooperation between the INPRO section and NRNU MEPhI has demonstrated the possibility of:

- ensuring effective integration of fundamental and applied research in the nuclear engineering area with the educational process, including the use of research results in the lecture courses and practical training, laboratory and research activities, production and pre-diploma practice under the guidance of research staff and experts;

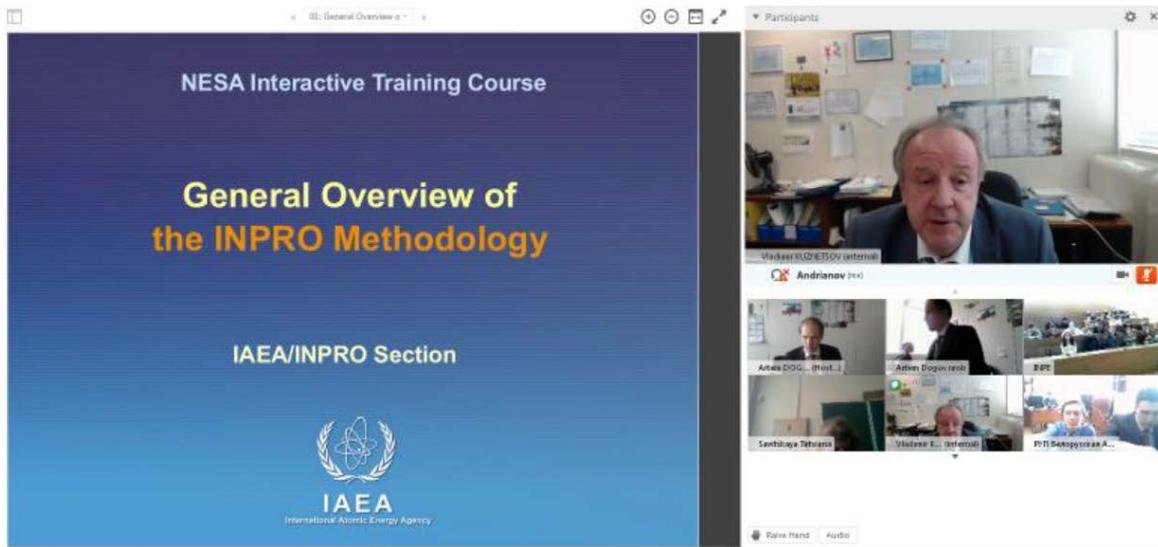


Figure 7. Online lecture on ‘General overview of INPRO methodology’.

- improving the quality of educational and methodological activities by creating new syllabuses, disciplines, tutorials, textbooks and other education resources both in hardcopy and electronic forms;
- realizing effective international cooperation in the nuclear education, overcoming isolationist trends, and providing conditions for international exchange of university staff, students and young scientists.

These activities can support capacity building and national human resource development in the nuclear energy sector. The main benefit of such training courses and workshops is that they are targeting not only students, but also lecturers of technical and nuclear universities. Moreover, young professionals working at nuclear energy departments, electric utilities, energy ministries and R&D institutions can participate in such training and benefit from it.

Educating lecturers, students and young professionals in IAEA Member States on the INPRO section and other relevant activities will help to improve the Member States’ abilities to take knowledgeable and responsible long term decisions with respect to a sustainable nuclear power development.

3 Conclusion

INPRO activities combined seek to develop a structured, holistic approach to support sustainable nuclear energy development in all interested countries. This approach includes sustainability definition and assessment, dynamic analysis of nuclear energy systems, studies of innovations in technology and institutional arrangements, and a continued dialogue among technology holders, users and newcomers on issues relevant for long-term sustainability and affordability of nuclear energy

The successful cooperation between the INPRO Section and nuclear education institutions in several Member

States demonstrated that fundamental and applied research in nuclear engineering can be effectively integrated in the education process. Research results are used in lecture courses, practical training, laboratory and research activities, and for pre-diploma practice.

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