INTERNATIONAL PROJECT ON INNOVATIVE NUCLEAR REACTORS AND FUEL CYCLES (INPRO) AND ITS POTENTIAL SYNERGY WITH GIF

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Abstract – The IAEA's project INPRO was established in 2001 by bringing together technology holders, users and potential users to consider jointly the international and national actions required for achieving desired innovations in nuclear reactors and fuel cycles. After completing development of evaluation methodology of innovative nuclear system in the area of Economics, Environment, Fuel Cycle and Waste, Safety, Proliferation Resistance and Infrastructure, the project moved to phase II that has four areas: Methodology development and its use by members, Future nuclear energy vision and scenario, Innovative technologies, and Innovation in institutional arrangement. Ten Collaborative Projects were started to address technical issues. The complementary relationship between INPRO and GIF has been defined by both groups and joint action plan was defined in 2008 April. Further areas of cooperation to create synergetic effect by utilizing unique added value of INPRO is considered and proposed in this paper.

I. INTRODUCTION

The IAEA has programmatic activities to stimulate technology development in order to assure the benefit from the use of NE for sustainable development by the use of innovative nuclear systems by paying attention to the needs of users and developing countries.

The IAEA's project INPRO is mostly funded by extra-budgetary contribution of its members. It was initiated in 2001 in order to provide a forum for discussion of experts and policy makers on all aspects of nuclear energy planning as well as on the development and deployment of innovative nuclear energy systems (INS). It brings together technology holders, users and potential users to consider jointly the international and national actions required for achieving desired innovations in nuclear reactors and fuel cycles, but INPRO pays particular attention to the needs of developing countries. Currently there are 30 INPRO members (Figure 1) including five countries, which have not yet experienced operation of commercial nuclear reactors.

Figure 1: Current members of INPRO

II. STATUS OF THE PROJECT

The initial phase (2001-2006 summer) of INPRO has defined basic principles, user requirements and criteria in the area of Economics, Environment, Fuel Cycle and Waste, Safety, Proliferation Resistance and Infra–structure. After establishing a methodology usable by Member States in their evaluation and selection of INS, INPRO moved to the new

phase (Phase 2) in the summer of 2006, which includes collaborative projects on technological issues that need to be addressed for improved economics, safety, proliferation-resistance and other topics. The current tasks in programme 2008-9 include the following and its progress as of the end of 2008 is reported in INPRO progress report: [1]

Task 1: INPRO Methodology.

Task 2: Application of Methodology by Members.

Task 3: Vision and scenarios on the use of INS for sustainable development

Task 4: Infrastructure needs and support framework for INS development and deployment.

Task 5: Common User Considerations by Developing Countries.

Task 6: Collaborative Projects.

Task 7: Communication & publications.

Since the early part of 2009, it was determined to streamline the project's task into the following four areas with a forum for dialogue by members as a cross-cutting vehicle for communication:

- Methodology development and its use by members.
- Future nuclear energy vision and scenario, Innovative technologies.
- Innovation in institutional arrangement.

II.A. Assessment methodology and its use

INPRO methodology published as TECDOC1434 [2] is consisting of a set of *Basic Principles*, *User Requirements*, and *Criteria* in a hierarchical manner as a basis for the assessment of INS in the areas of economics, safety, environment, waste management, proliferation resistance, physical protection and infrastructure.

Associated User Manual [3] has been made available to users in 2009.

Seven assessments of INS using this methodology have been completed by the end of 2008 and will be published soon as working material:

- Joint assessment based on a closed fuel cycle with fast reactors (Canada, China, India, Japan, Republic of Korea, Russia, Ukraine).
- Assessment of INS based on high temperature reactors (India).
- Assessment of additional nuclear generation capacity in the country for the period 2010-2025 (Argentina).
- Assessment of INS options for a country with small energy demands (Armenia).
- Assessment of the DUPIC fuel cycle with respect to proliferation resistance (Republic of Korea).
- Two independent assessment studies on IRIS and FBNR reactors (Brazil).
- Assessment of national INS (Ukraine).

These assessments also contributed to identifying the needs for R&D and also to provide valuable feedback for further improvements to INPRO methodology.

II.B. Common User Considerations by Developing Countries

IAEA General Conference Resolution in 2006 [GC(50)/RES/13B] required Agency to sets of common characteristics needed and desired by potential users of new nuclear power plants (NPP) in developing countries. In response to this, the INPRO started study by dialogue with experts in 54 developing countries, which included visit to the countries and workshops. The resultant expectations are reported as a NE Series document [4] and are characterized by:

- Competitiveness with alternative supported by comprehensive and reliable cost information.
- Suppliers role in financing.

- Supplier's role in establishing international mechanism for AOS of FC services, spare part pool.
- Proven by operation, standardized and licensed in the country of origin.
- Plant size distributed with 1GWe peak (Figure 2).
- Technology transfer, transfer of database of operational experiences of similar plants, local participation (some targets), support to (soft) infrastructure building.

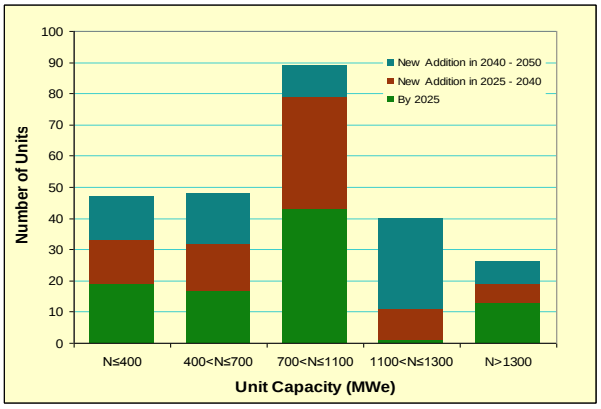

Figure 2: Plant size distribution

[Note] This distribution is based on the collective expectation by 31 experts in prospective user countries. It must be noted that assuming a rule of thumb (10% of grid, no interconnection with neighbors), among 54 prospective user countries, 20 countries have limitation to less than 300 MWe, and 12 countries to less than 700 MWe (larger than 300 MWe) as of today.

II.C. Collaborative Projects (CP)

INPRO members are identifying the needs of international collaborative projects or studies on a variety of topics that may be of common interest for countries expecting an increased role to be played by INS in the future. Three options are available to execute such projects;

- Coordinated Research Projects (CRP)
- Technical Cooperation projects (TCP)
- Joint Initiative (INPRO members establish a group and ask the IAEA for coordination)

Currently 12 CP have been planned and in various stage of implementation as is shown below on thematic basis. 10 of them are active by now.

- System analysis and fuel cycle: Thorium FC, GAINS (Global scenario analysis), RMI (Study of nuclear power programme under raw material limitation), FINITE (Fuel Cycle for INS), SMALL (issues of nuclear power and Fuel Cycle in small countries).
- Proliferation-resistance: PRADA (Acquisition/Diversion pathway analysis).
- Technology overview: AWR (Advanced water reactor thermal hydraulics), DHR (Benchmarking of code for analysis of decay heat removal from LMR), COOL (Coolant property and issues at elevated temperature).
- Safety: HTR H2 (Safety issues for advanced HTR for production of H2), PGAP (reliability of passive safety system), ENV (Benchmarking of environmental impact assessment code).

GAINS (Global scenario analysis) may deserve further elaboration here. GAINS assumes higher scenario, nuclear capacities reach 1 500 GW(e) by the mid-century and 5 000 GW(e) by 2100 and low scenario – 1 000 GW(e) and 2 500 GW(e), respectively. GAINS also assumes nuclear deployment scenario by three models; a 'homogeneous' model assuming that the whole world moves technically as one homogeneous group and "heterogeneous" with separate or synergistic cases.

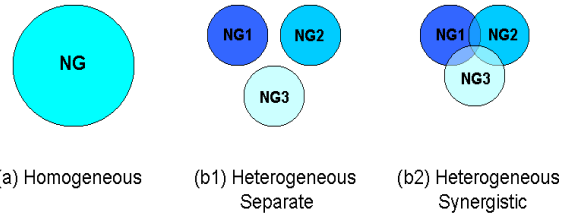

Figure 3: GAINS deployment models

Under GAINS, the non-geographical groups are defined as follows:

NG1: Countries which are most involved in the development and deployment of the INS and, consequently, would be able to incorporate them as soon as commercially available.

NG2: Countries with significant experience in the use of nuclear energy and most of the necessary infrastructure, but which are not quite ready to incorporate the most advanced nuclear energy system.

NG3: Countries supposed to incorporate nuclear energy in their energy mix, as newcomers.

A representative set of reactor types and fuel cycle installations and their expected time for introduction were also assumed. The current reactor fleet was assumed to be replaced gradually by new reactors such as large advanced thermal reactors (TR) and fast reactors (FR), small and medium reactors, HTR, ADS, and molten salt reactors. Different fuels (UOX, MOX, high density fuels, etc.) and different fuel cycles (U, Th) are considered. A very preliminary result indicates that, from the comparison of two models, an intensive cooperation in fuel cycle (heterogeneous synergetic model) enables twice high growth of the MOX fuel FR fleet globally as compared with the case of completely heterogeneous development.

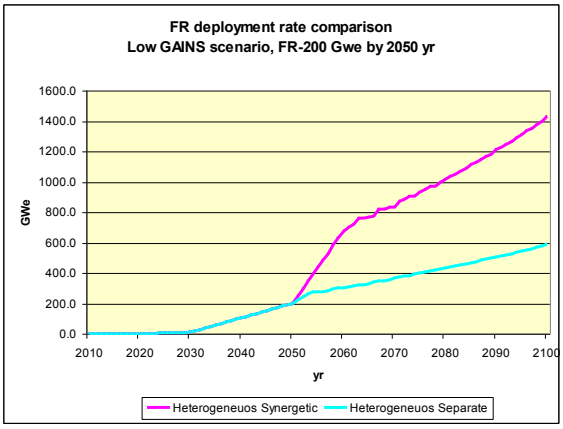

Figure 4: FR deployment rate comparison

In the 2010-11 programme and budget of the IAEA, two CRPs (Coordinated Research Projects) are being proposed: a) Simulation and modeling for development of technologies and b) innovative institutional approaches.

II.D. Publications

The results of INPRO activity is shared as public domain publications from the Agency.

INPRO has already published several documents with focus on methodology, namely 2008 Progress report [1], Assessment methodology (TECDOC-1434) [2] and accompanying manuals, [3] and Common User Considerations stage 1 report. [4] Further there are many soon-to-be published documents in 2009:

- Members' assessment results as working material (*Argentina, Armenia, Brazil, India, RoK, Ukraine, Joint Study)*.
- IAEA methodologies and tools for exploring long term energy development (including INPRO methodology).
- Lessons learned from Member's assessment.
- Legal and institutional aspect of non-stationary reactors.

III. FUTURE PERSPECTIVE

The generic direction of INPRO phase II activities is at this moment set for four areas as mentioned in section II.

One important point for discussion is that INPRO has initiated Vision/Scenario study intended for capacity building of MSs for their own long-term plan and to provide Member States with reference scenarios for consideration of maximizing the benefit from the use of NE for sustainable development. This activity is strongly linked with some CPs for global future nuclear energy system analysis such as GAINS and FINITE. If nuclear energy is deployed on a large scale in this century, the world would eventually have to consider recycling of spent fuel for better use of resources and other reasons.

INPRO will be able to provide a reference scenario and an opportunity for considering institutional and infrastructure issues jointly by technology holders and uses, to enabling conditions for the use innovative nuclear system using recycle of spent fuel.

IV. COLLABORATION WITH GIF

Relationship with GIF is a very often asked question. The web sites on each side have comprehensive information on this. [5][6] In essence, GIF is an international development activity by technology holders, whereas INPRO's has unique value as:

- A forum by both technology holders & users including countries not yet operating nuclear power plants.
- Addressing issues other than development.
- Having viewpoint from users.
- Paying attention to the needs of developing countries.

Their complementary relationship has been recognized in various occasions including G8 Summit in St. Petersburg in July 2006. [7]

Because the IAEA has a unique role (by statute) in safety and safeguard, the IAEA has been contributing GIF by sending experts to GIF working groups. INPRO has been participating in GIF Policy Group as observer. Occasionally interface meetings have been held and joint action plan has been established to create synergy by working together in such areas as use of IAEA Safety Standards for preliminary assessments of GIF systems, use of the GIF economic model ECONS by IAEA GCR group for cost estimates of GCRs, providing IAEA's HEEP code for non-electric application to GIF.

Future synergy could be developed, subject to discussion by both sides in interface meeting and INPRO Steering Committee (All the GIF members are members of INPRO. Through the national delegations to INPRO, GIF can express its expectations on synergy with GIF in the INPRO Steering Committee). In the author's view, this synergy could be created by utilizing unique value and activities by the IAEA and INPRO in the following areas, but not limited to:

1) Enhancing interface between technology users and holders of innovative nuclear energy system, IAEA/INPRO bringing users'/Developing Countries' point of view, and GIF bringing potentially available innovative technologies. This may include an assessment of selected GIF system using INPRO methodology from user's point of view.

2) Enhancing interface in the areas of safety, security and safeguard for establishing technologies to meet expectation for innovative systems, which could include assessments of GIF systems against IAEA Safety Standards.

3) Joint discussion on future reference deployment scenario of Generation IV systems.

4) Subsequent joint consideration of institutional and infrastructure conditions to enable expanded use of GIF systems including closed fuel cycle.

Further cooperation with INPRO and IAEA could benefit GIF when it considers the use of Generation IV systems in countries not yet operating nuclear power as of today. Given the situation that currently more than 60 countries are considering embarking on nuclear power programme, [8] GIF may consider what is the role of GIF in it and if GIF needs to re-orient its direction to meet the needs of all including the newcomers. Although the priority of the new-comers will be, as can be observed from the CUC document, [4] to prepare nuclear infra-structure and install proven reactors, it may be worth to consider in the course of development of Generation IV systems:

- Use of Generation IV systems by the newcomers in years to come in safe, reliable, secure and proliferation-resistant manner.
- Conditions to enable expanded use of Generation IV systems by countries

including newcomers (This consideration includes infrastructure for the use of closed fuel cycle and establishing waste repository and what institutional systems may enable this expansion.).

- SMR (Small and Medium size Reactor) version of Generation IV systems.

INPRO has been working and further intends to enhance its cooperation with the emerging countries through their application of INPRO methodology to evaluate INS and through CUC. [4] IAEA has been facilitating network of SMR development through its CRP (Coordinated Research Programme) and various Technical Meetings on SMR designs.

V. CONCLUSION

INPRO has evolved to include activities other than methodology development. They are Collaborative Projects, Common User Considerations, vision/scenario analysis, and consideration of institutional arrangement necessary to enable global use of innovative nuclear energy system. Synergetic effect by the INPRO working together with GIF will be possible based on the unique value of INPRO and complementary relationship.

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