ON BRAZIL’S PARTICIPATION IN THE INTERNATIONAL PROJECT ON INNOVATIVE NUCLEAR REACTORS AND FUEL CYCLES (INPRO)

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ABSTRACT

In response to a resolution of its 44th General Conference (GC(44)/RES/21) held in September 2000, the International Atomic Energy Agency launched in May 2001 the International Project on Innovative Nuclear Reactors and Fuels Cycles (INPRO) with the objective of supporting the safe, sustainable, economic and proliferation-resistant use of nuclear technology to meet the global energy needs of the 21st century. Brazil joined the project from its beginnings and in 2005 submitted a proposal for the screening assessment using INPRO methodology of two small-size light-water reactors as potential components of an innovative nuclear reactor system (INS) completed with a conventional open nuclear fuel cycle. The INS reactor components currently being assessed are the International Reactor Innovative and Secure (IRIS) that is being developed by an international consortium made of 21 organizations from 10 countries (Brazil included) led by the Westinghouse Company, and the Fixed Bed Nuclear Reactor (FBNR) that is being developed at the Federal University of Rio Grande do Sul. This paper gives an overview of Brazil’s participation in INPRO, highlighting the objective, scope and intermediate results of the assessment study being performed, and the possibilities for participation in one or two collaborative research projects under INPRO Phase 2 Action Plan for 2008-2009.

1. INTRODUCTION

The International Project on Innovative Nuclear Reactor and Fuel Cycles (INPRO) was launched in September 2000 in response to resolution 21 of the 44th IAEA General Conference (GC(44)/RES/21)[1]. The project, an initiative of the Russian Federation supported by a group of IAEA Members States has the objectives of: (1) helping to assure that nuclear energy is available to contribute in fulfilling, in a sustainable manner, the energy needs in the 21st century; (2) bringing together technology holders and technology users to consider jointly the international and national actions required to achieve the desired innovations in nuclear reactors and fuel cycles, and (3) creating a forum to include all stakeholders that will have an impact on, drawn from, and complement the ongoing activities at the national and international levels.

Innovative Nuclear Energy Systems (INS) encompasses all systems that will lead nuclear energy to a position of making a major contribution to global energy supply in the 21st century. In this context, future systems include evolutionary designs (an advanced design that achieves improvement over existing designs through small to moderate modifications) and innovative designs (an advanced design that incorporates radical conceptual changes in design approaches and or system configurations in comparison with existing practice); all fuel cycle components (mining, milling, conversion, enrichment, fuel fabrication, electricity
and co-generation, spent fuel storage, reprocessing, recycling): all industrial phases (site acquisition, design, construction, equipment manufacturing and installation, commissioning, operation, decommissioning, site release and closure), and also institutional and infrastructure measures (national and international legal framework, multilateral approach for assurance of fuel supply, harmonisation of regulations and industry standards, etc.).

To accomplish its objectives, INPRO has adopted a stepwise approach. In the first step, called Phase 1, a methodology, which must be fulfilled by any innovative nuclear energy system (INS) in order to meet the desirable target of sustainable energy supply, was developed, validated, and is being applied to the assessment of some potential INSs. INPRO methodology is comprised of Basic Principles, User’s Requirements and Criteria in the areas of economics, safety, environment, waste management, proliferation resistance, physical protection and infrastructure [2]. The methodology was further developed into a User’s Manual that provides guidance on how to apply these requirements in evaluating a given INS, taking into account local, regional and global boundary conditions that would apply to both developing and developed IAEA Member States. The assessment studies also help to identify the research and development needed to overcome the INS technological gaps and provide important feedback information for the continuous improvement of the methodology itself. Phase 1 was completed in July 2006. Its main outputs were the INPRO Methodology and User’s Manual, and the completion of the study Assessment of the DUPIC fuel cycle with respect to proliferation resistance by Republic of Korea. Eleven other studies, which initiated in Phase 1, are now proceeding in INPRO second step, called Phase 2.

Phase 2 started in July 2006 and its Action Plan 2006-2007 defined three working directions:

- The first direction contains methodology oriented activities, where the methodology will be continuously improved with feedback from 12 assessment studies being performed by INPRO Members. It also includes creation of a vision report on opportunities and challenges of large-scale nuclear energy development;
- The second direction contains institutional/infrastructure oriented activities, which will address the future infrastructure needs requiring innovation and infrastructure requirements for nuclear plants to be deployed in the future;
- The third direction contains collaborative project related activities, which were newly introduced in Phase 2. The collaborative projects will be performed by groups of interested INPRO Members on a variety of technological topics which were mainly (but not exclusively) identified during INPRO assessment studies and which are needed to improve the performance of existing INS components, or to develop new components of an optimum INS, in accordance with the needs of a given IAEA Member State.

All interested IAEA Member States are invited to perform assessments of INS of their choice using INPRO methodology and/or to propose or participate in collaborative projects for development and deployment of INS. As of July 2006, INPRO has 26 Member States. INPRO Members contribute to the project by providing funds, experts, assessment studies and by participating in collaborative R&D projects. Brazil joined INPRO from its beginnings and in 2005 submitted a proposal for participation in Phase 1 by performing the screening assessment using INPRO methodology of two small-size light-water reactors as potential components of an innovative nuclear reactor system (INS). Currently, the country is considering its participation in one or two collaborative projects already approved for INPRO Phase 2. An overview of Brazil’s participation in INPRO is presented in the next Sections.
2. BRAZIL’S PARTICIPATION IN INPRO PHASE 1B (2ND PART)

2.1. Background

In 2005 Brazil submitted for participation in INPRO Phase 1B (2nd part) the study: *Assessment of two innovative small and medium sized reactors for electricity generation in Brazil using INPRO methodology* [3]. Three major driven forces stood behind this proposal:

- First, the ongoing review of the Brazilian nuclear programme, which should include, in the highest scenario, the construction of new nuclear power stations in the country’s Southeast and Northeast regions, and the expansion of nuclear fuel production for local use and, possibly, future participation in the international nuclear fuel market;
- Second, Brazil’s membership in the international consortium for development of the IRIS reactor, which is led by Westinghouse Electric Company and includes 21 organisations from 10 countries. IRIS is a modular, integral type, pressurised, light water cooled, small power reactor (335 MWe per module) with a conventional refuelling scheme. Co-generation nuclear power plant (NPP) designs are also being developed for seawater desalination, district heating and process steam [4, 5]. Brazil primary responsibilities in the reference design are to perform transient and safety analyses, and to collaborate on the pressurizer design and in desalination application studies, and
- Third, the development of the FBNR reactor at the Federal University of Rio Grande do Sul (UFRGS), Brazil. FBNR is a modular, integral type, pressurised, light water cooled, factory (re)fuelled, small power reactor (40 MWe per module), which is currently being developed with international support including that of the IAEA Coordinated Research Project (CRP) on Small Reactors Without On-Site Refuelling (SRWOR) [6, 7].

2.2. Objective and scope

The objective of the work is to perform a screening (not comparative) assessment of the IRIS and FBNR reactors as components of a potential INS that includes a conventional open fuel cycle, using INPRO methodology. IRIS is a small reactor with a conventional refuelling scheme, while the FBNR is a small reactor without on-site refuelling scheme. A comparative assessment between these two components has not been attempted, not only because the INPRO methodology for this procedure is not formally available yet, but mainly because the two reactor designs are in a very different stage of development: preliminary licensing stage, for the IRIS design, and conceptual development stage, for the FBNR one.

The front and back-end technologies of the open fuel cycle option selected are not assessed, but the inflow and outflow of materials in the reactor component are considered, whenever possible. The scope of this assessment study is further limited to the areas which are of the country’s main interest – safety and economics, in the IRIS case – or areas in which the INS has an estimated greater potential - safety and proliferation resistance, in the FBNR case. In accordance with the INPRO methodology, however, to arrive at a proper judgement of the sustainability of any INS a holistic assessment covering all the areas defined by the methodology has to be performed. It is Brazil’s intention to pursue such goal with regard to both reactor designs in a future study. Finally it should be pointed out that the information and the intermediate results reported here should be completed and updated up to the issuance of the final assessment report.
2.3. Organisation

The assessment studies are being performed by two independent groups of experts. Assessment of the IRIS reactor is being performed by experts from the Centre for Development of Nuclear Technology (CDTN) at the State of Minas Gerais, from the Nuclear and Energetic Research Institute (IPEN), located at São Paulo, and the Nuclear Engineering Institute (IEN), at Rio de Janeiro. All three research institutes belong to the Research and Development Directorate (DPD) of the Brazilian Nuclear Energy Commission (CNEN). The FBNR is being assessed by experts from the UFRGS with the support of some international collaborators. General co-ordination work and financial support are provided by DPD/CNEN.

2.4. Intermediate Report

In August 2007, an intermediate report [12] was delivered to the International Coordinating Group of INPRO for review. The report is divided into five chapters. Following an introductory Chapter, the development of the national energy demand and supply scenarios is presented. It has drawn from the studies for the elaboration of the National Plan of Energy 2030 [8], from the documents National Plan of Electric Energy 1993/2015 (PLAN 2015) [9], Decennial Plan of Electricity Expansion 2006–2015 [10] and updated data from the National Energy Balance 2006 [11]. Chapter Three discusses the process of selection and identification of the INS chosen for study, including the associated fuel cycle option. Chapters Four and Five present the results of the assessments of the IRIS and FBNR designs with regard to the INPRO methodology area of reactor safety only. Chapter Six closes the work with two summary tables of the assessment results and some concluding remarks concerning the study follow-on activities.

The reactor safety area of INPRO methodology involves the judgment of the INS compliance with respect to the 38 Criteria that follow from 4 Basic Principles and 14 User Requirements. According to the methodology terminology if the value of an indicator is acceptable, the judgment is that the INS component (the reactor) complies with or has potential to fulfill the specific criterion considered. Otherwise, the judgment becomes non-compliant or no potential to fulfill this criterion. This judgment procedure is repeated likewise for all criteria of a user requirement, then for all user requirements of each basic principle and finally for all 4 basic principle of the reactor safety area. The rationale for each judgment on potential of the INS reactor component should be adequately documented in the report.

For the IRIS reactor, the numerical or logical values of 31 out of 38 indicators were found acceptable, and 4 others have potential to be acceptable. The high percentage of acceptable results in the performed judgment reflects the advanced stage of development of IRIS reactor design (preliminary licensing stage). Overall these assessment results indicate that the reference design of IRIS complies with most of the Basic Principles of the reactor safety area of INPRO methodology.

With regard to the FBNR reactor, the numerical or logical values of only 14 out of 38 indicators were found acceptable and 21 others have potential to be acceptable. The relatively low percentage of acceptable results in the performed judgment reflects the low level of maturity (conceptual stage) of the FBNR project. Nevertheless, the assessment results clearly indicate that the FBNR innovative design has potential to comply with most of the Basic Principles of the reactor safety area of INPRO methodology.
3. BRAZIL’S PARTICIPATION IN INPRO PHASE 2

In accordance with the scope of the Brazilian first assessment study, the next task involves the assessment of the IRIS and FBNR designs with regard to the INPRO methodology areas of economics and proliferation resistance, respectively. Its successful completion will conclude the study as originally proposed. However, to arrive at a proper judgement of the sustainability of any INS, a holistic assessment covering all the areas defined by the INPRO methodology has to be performed. It is Brazil’s intention to pursue such goal with regard to both reactor designs in a subsequent study which falls under direction one of INPRO Phase 2.

Concerning the collaborative projects related activities of the third direction of the Phase 2 Action Plan, 14 project proposals by different Member States have been approved by the INPRO Steering Committee at its 11th Ordinary Meeting in July 2007 to be performed as joint initiatives under the auspices of INPRO/IAEA (see Table 1). In that meeting Brazil showed potential interest in participating in France’s proposal (no. 6) Environmental Impact Benchmarking relative to an INS component, and in some topics of India’s Collaborative Project Proposal related to Advanced Water Cooled Reactors (no.9).

Table 1. Collaborative Project (CP) Proposals

<table>
<thead>
<tr>
<th>No.</th>
<th>Project title (leading country)</th>
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<tbody>
<tr>
<td>1</td>
<td>Investigation of options for management of spent nuclear fuel in a country with a small territory (Armenia)</td>
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<tr>
<td>2</td>
<td>Safety operation of INS in the power system of limited capacity (Armenia)</td>
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<tr>
<td>3</td>
<td>Meeting energy needs in the period of raw materials insufficiency during the 21st century (Czech Republic)</td>
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<tr>
<td>4</td>
<td>Further investigations of $^{233}$U/Th fuel cycle (India)</td>
</tr>
<tr>
<td>5</td>
<td>Performance assessment of passive gaseous provisions (France)</td>
</tr>
<tr>
<td>6</td>
<td>Environmental impact benchmarking relative to an INS component (France)</td>
</tr>
<tr>
<td>7</td>
<td>Investigations of safety issues for advanced HTR reactors and their combined operation with hydrogen producing plants (India)</td>
</tr>
<tr>
<td>8</td>
<td>Investigation of technological challenges related to removal of heat from reactor cores operating at temperatures of 600-100 °C with focus on liquid metals and molten salts for use in HTR, ADS, molten salt reactors and advanced fast reactors (India)</td>
</tr>
<tr>
<td>9</td>
<td>Collaborative project proposal related to Advanced water cooled reactors (India)</td>
</tr>
<tr>
<td>10</td>
<td>Integrated approach for the design of safety grade decay heat removal system for LMR (India)</td>
</tr>
<tr>
<td>11</td>
<td>Acquisition/diversion pathway analysis for the assessment of proliferation resistance (Republic of Korea)</td>
</tr>
<tr>
<td>12</td>
<td>A global architecture of INS based on thermal and fast reactors with the inclusion of a closed nuclear fuel cycle (Canada, China, France, India, Japan, Republic of Korea, Russia and Ukraine)</td>
</tr>
<tr>
<td>13</td>
<td>Assessment using INPRO methodology on the basis of general characteristics and input/output parameters of advanced and innovative nuclear fuel cycles within large scale INS based on closed nuclear fuel cycle concept to satisfy the principles of sustainability in the 21st century (Russia)</td>
</tr>
<tr>
<td>14</td>
<td>Legal, institutional and technical issues of development and introduction of non-stationary movable SM NPP in developing countries in accordance to the INPRO methodology (Russia)</td>
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4. CONCLUSIONS

This work presented an overview of Brazil’s participation in the International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO), launched (in 2001) and coordinated by International Atomic Energy Agency. INPRO objectives, the project-execution approach and the results of Phase 1 were first briefly introduced. Next, the objective, scope and organization of the national assessment study of two small-sized water-cooled reactors (IRIS and FBNR) proposed by Brazil for participation in INPRO Phase 1 were presented and the results obtained so far were briefly reported. Finally, potential contributions to the ongoing INPRO Phase 2, which include the completion of the IRIS and FBNR assessments with regard to the methodology areas not covered in the first study and participation in collaborative projects for the development and deployment of selected (components of) INS, were mentioned. These future contributions are currently being discussed in the Directorate of Research and Development of CNEN and an eventual participation shall be confirmed at the next ordinary meeting of INPRO Steering Committee scheduled to December 2007.

REFERENCES

1. 44th IAEA General Conference, Resolution 21 (GC (44)/RES/21), Vienna (2000).
3. “Brazilian proposal for participation in INPRO Phase 1B (2nd part): Assessment of two innovative small and medium sized reactors for electricity generation in Brazil using INPRO methodology”, Presentation at the 8th INPRO Steering Committee Meeting by Mr. Orlando J. A. Gonçalves Filho, IAEA, Vienna (2005).