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Workshop on IAEA Tools for Nuclear Energy System Assessment (NESA) for Long-Term Planning and Development

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Brazil Case Study Using INPRO Methodology:

ASSESSMENT OF TWO SMALL SIZED REACTORS (IRIS and FBNR) FOR ADDITIONAL ELECTRICITY GENERATION IN BRAZIL

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OUTLINE of the PRESENTATION

Background

- Formulation of the Assessment Study Proposal
- Objective, Scope, Rationale and Expectations

Logistics

- Effort and Expertise
- Documentation and Energy Planning Studies

Summary of the Results

- Long-term Energy Scenario and the Role of Nuclear Energy
- Brief description of the INS and of the Nuclear Power Plants
- Main Results of the Assessment Study

Lessons Learned

- Challenges/Limitations using the Methodology and their Underlying Causes
- Benefits in Performing the Assessment Study

Recommendations to INPRO and IAEA

Background – FORMULATION of the PROPOSAL

IAEA invitation letter to CNEN to participate in INPRO Phase 1B (2005)

- Propose a national assessment study, or
- Consider a regional assessment study together with Argentine

1st Meeting at CNEN's Directorate of R&D

- Opportunity for a mutually beneficial contribution to INPRO
- Concern about the amount of work involved and the availability of resources
- A national or regional study ?

  National Assessment Study of concrete interest (which INS ?)

Internal Seminar (Institute of Energetic and Nuclear Research - IPEN/SP)

- INS based on Closed Nuclear Fuel Cycle with Fast Reactors and ADS
- **Assessment of the reactor component only (IRIS) with regard to ALL INPRO areas**

Background – FORMULATION of the PROPOSAL

Invitation to external institutions to participate

- Navy Technological Center - CTMSP (SP)
- Army Technological Center - CTEx (RJ)
- Institute for Advanced Studies - IEAv (Aeronautics Technological Center)
- **Federal University of Rio Grande do Sul - UFRGS (FBNR)**

Workshop on Integral PWR reactors at Buenos Aires (November 2005)

- Brief announcement of Brazil's proposal of a national assessment study
- Discussion with INPRO reactor area coordinator (Mr. Ian Facer)

2nd Meeting at CNEN's Directorate of R&D

- Review and approval of the objective and scope of the assessment study
- Formal allocation of resources (human and material resources)
- Official response to IAEA and INPRO Secretariat
- Proposal presented at 8th INPRO Steering Committee Meeting (Dec. 2005)

Background – OBJECTIVE and SCOPE

Objective: **Screening** (not comparative) assessment of **IRIS** (International Reactor Innovative and Secure) and **FBNR** (Fixed Bed Nuclear Reactor) as alternative components of an INS completed with an open fuel cycle based on enriched uranium.

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Objective: **Screening** (not comparative) assessment of **IRIS** (International Reactor Innovative and Secure) and **FBNR** (Fixed Bed Nuclear Reactor) as alternative components of an INS completed with an open fuel cycle based on enriched uranium.

Scope: Limited to the **Reactor component** and to **TWO** INPRO areas/reactor:

Energy Planning	YES		
	Front- end	**Power Plants**	**Back- end**
Economics	NO	IRIS	NO
Safety	NO	IRIS / FBNR	NO
Environment	NO	NO	NO
Waste Management	NO	NO	NO
Proliferation Resistance	NO	FBNR	NO
Infrastructure	NO		

(Obs.: Energy Planning, Front and Back End were common for reactors)

Background – RATIONALE and EXPECTATIONS

Rationale

- The ongoing **review of Brazil's Nuclear Power Program** – Construction of new Units in the Southeast and Northeast regions and the expansion of nuclear fuel production for local use and future participation in the international fuel market.
- Brazil's **membership in IRIS International Consortium** – Led by Westinghouse and with participation of 21 organizations from 10 countries.
- The **development at the UFRGS (Brazil)** of the FBNR conceptual design.

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Expectations

- Get a **better understanding** of INPRO methodology by applying it to concrete cases
- Built a basic **suite of computer codes** and **reactor databases** to help performing more comprehensive and useful INS assessments with INPRO methodology
- Identify the **potential** of IRIS- and FBNR-based INSs (at least, in the methodological areas assessed) to contribute to sustainable energy development in Brazil;
- Identify the **technological gaps** and the **necessary RD&D** to fill these gaps in order that the IRIS- and/or FBNR-based INS can become sustainable in the areas assessed.

Logistics – EFFORT and EXPERTISE

Human resources

- IRIS - 8 (eight) engineers from CNEN (CDTN, IPEN and IEN)
- FBNR - 1 (one) senior researcher and co-workers from the Federal University of Rio Grande do Sul - UFRGS
- Working partial time for approximately two years

Expertise

- Most engineers and researchers from CNEN hold M.Sc.. and Ph.D. degrees and have experience in reactor safety analyses through participation in the licensing and operation of Angra 2 NPP and on-the-job training in Germany.

- The working group from the UFRGS was led by the main designer of the FBNR concept, who has a long research experience in reactor physics and reactor safety analysis.

- The economics and non-proliferation analyses, however, were carried out by non-specialists in these areas.

Logistics – DOCUMENTS and STUDIES

INPRO documents (Methodology)

- IAEA TECDOC 1362; IAEA TECDOC 1436 and IAEA TECDOC 1575
- Draft of INPRO Manual; and INPRO Case Studies (Phase 1A)

Energy Planning: Official documents - Ministry of Mines and Energy

- **NATIONAL PLAN OF ENERGY 2030** – Fundamental tool for the long term planning of the country's energy sector in the next few decades.
- NATIONAL PLAN OF ELECTRIC ENERGY 1993/2015 (PLAN 2015) – The reference instrument for planning of the national electric sector up to 2015.
- NATIONAL ENERGY BALANCE 2006 (BEN 2006) – Annual report of the national data related to the demand and supply of energy in the country.

IRIS and FBNR (INS components) – Several published documents

Angra 2 NPP (reference reactor for Safety and Proliferation Resistance) – FSAR

Angra 3 NPP (reference reactor for Economics) – Economic feasibility studies

Results – National Plan of Energy 2030 (PNE 2030)

Background

- Period of realisation: December 2005 to February 2007
- Personal involved: 36 experts from EPE/MME and 49 External Specialists
- 10 Thematic Seminars (Oil, Natural Gas, Biomass, Hydropower, ... and Nuclear)
- 3 World Scenarios and 6 National Scenarios - REFERENCE SCENARIO
- National software (UFRJ):

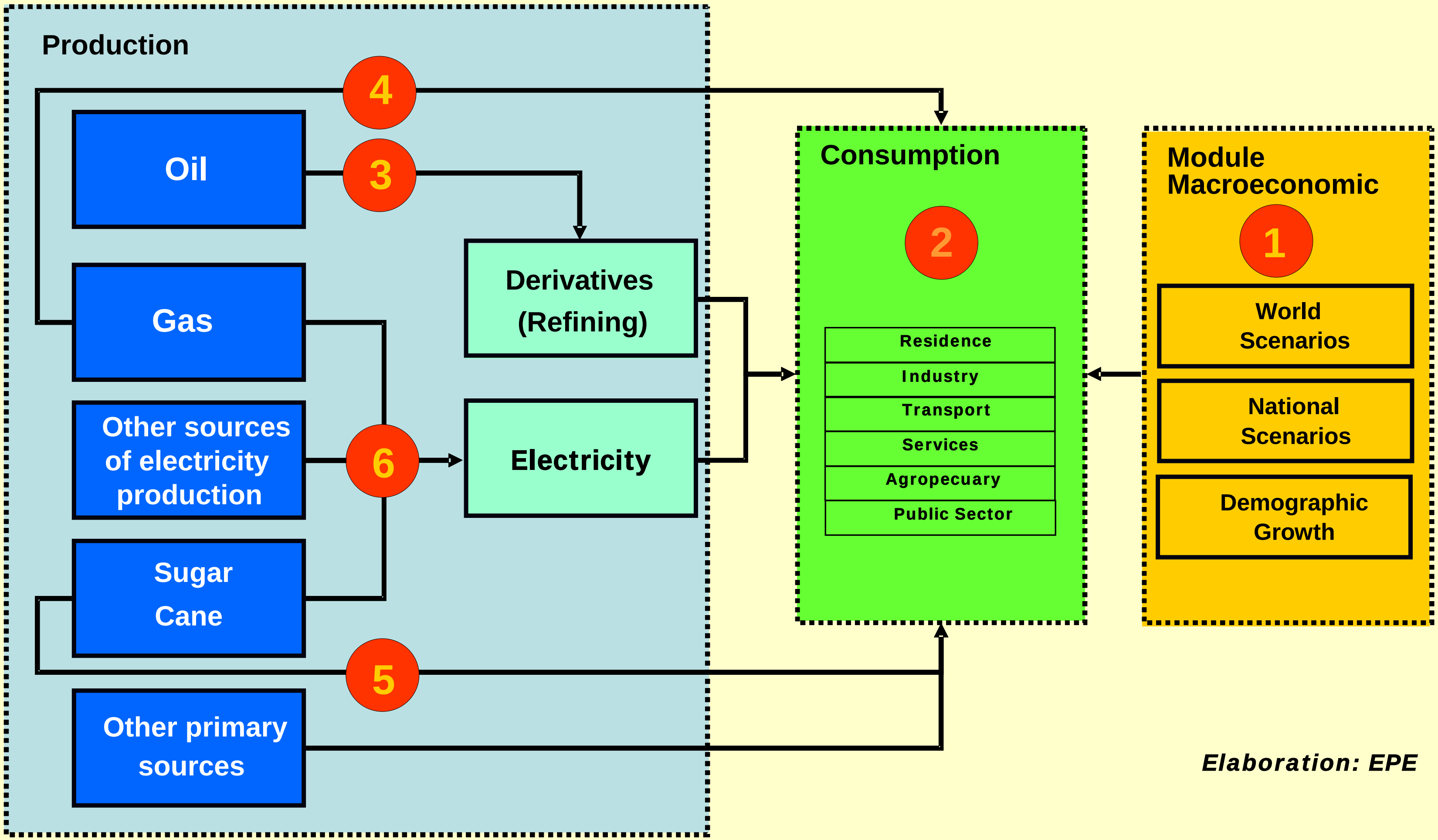
  MCMLP - model for long-term macroeconomic consistency analysis

  MIPE - integrated model of energy planning (demand analysis)

- IAEA software:

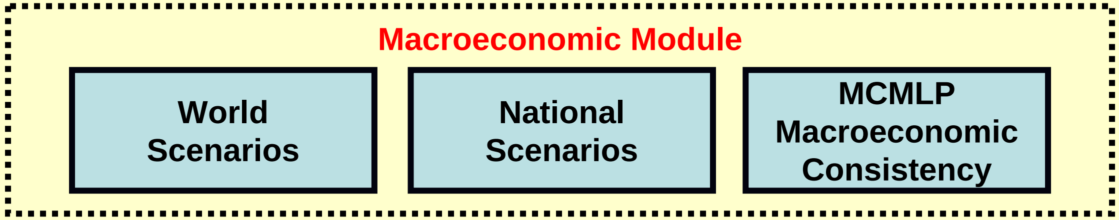
  MESSAGE - model for energy supply strategies alternatives and general environment impact

Results – PNE 2030 General Methodology



Elaboration: EPE

Results – PNE 2030 Models Employed



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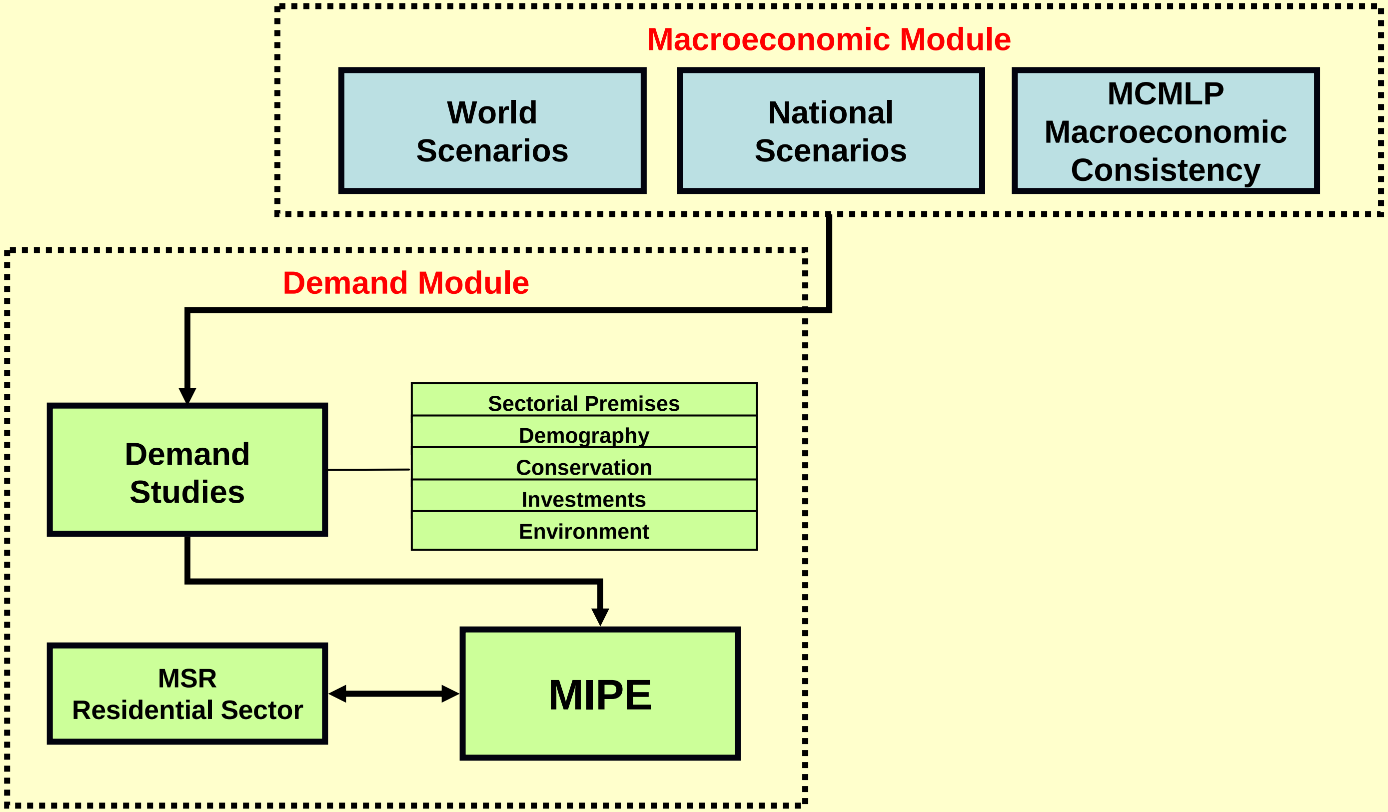

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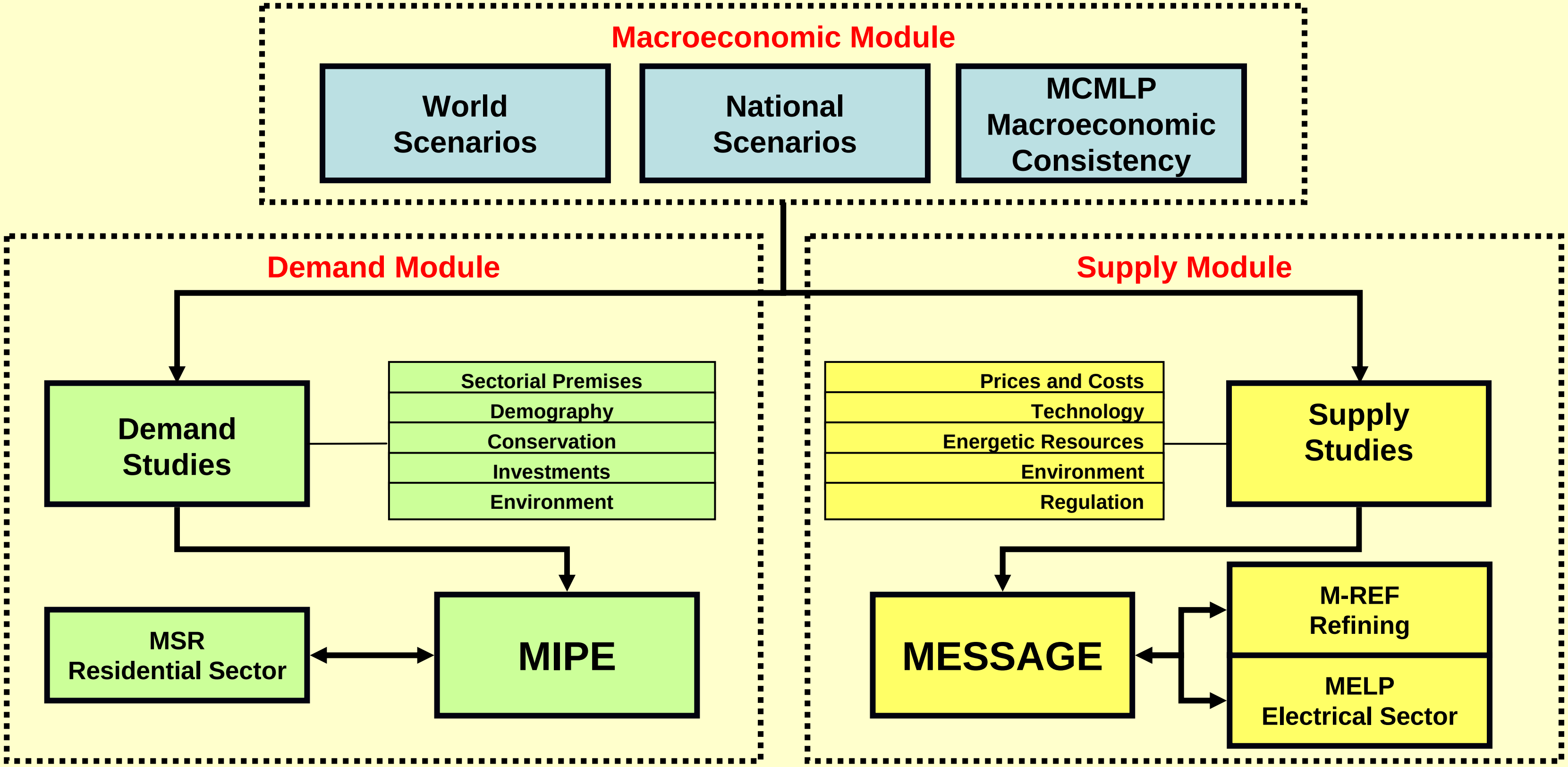

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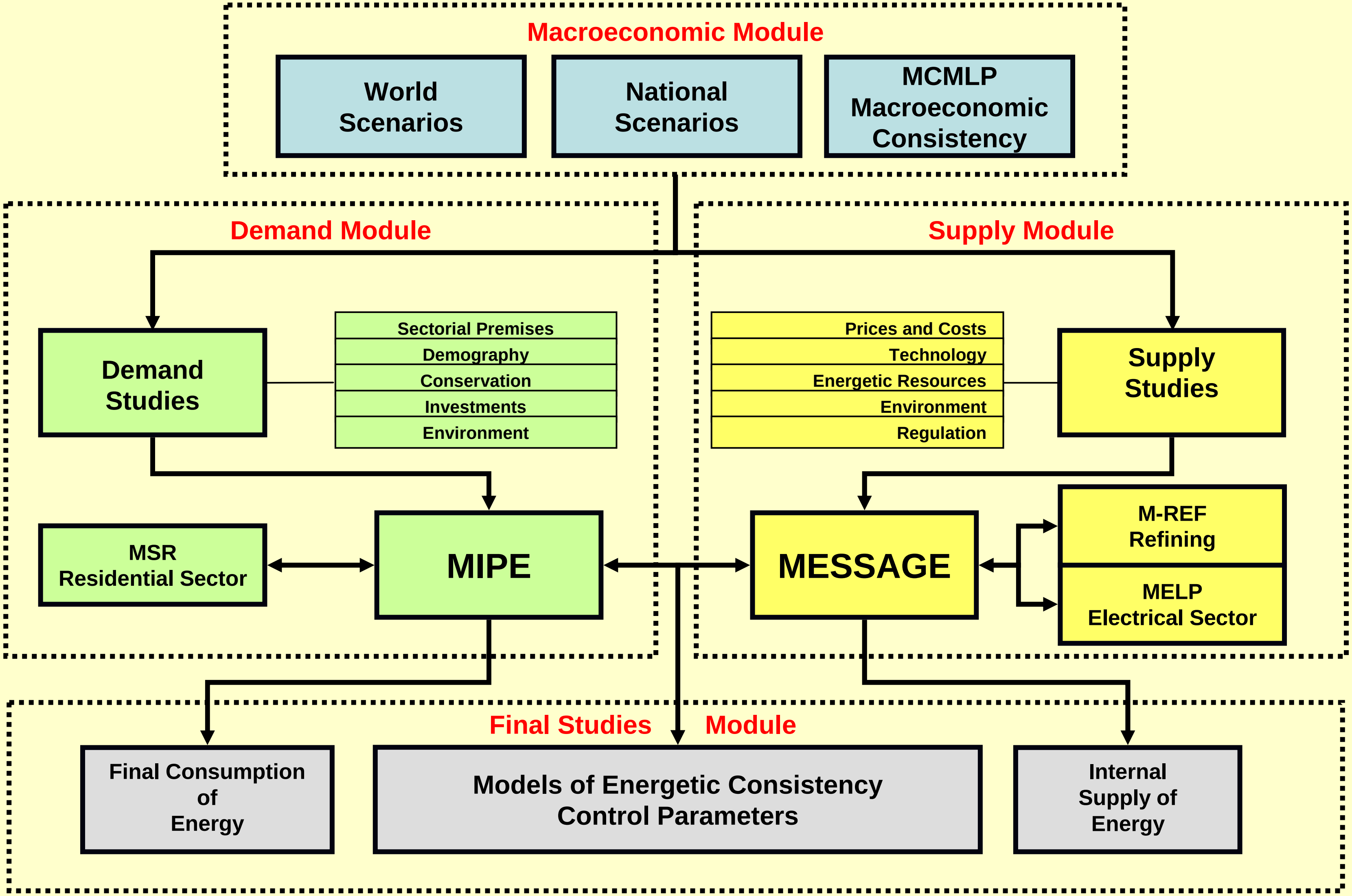


Results – ENERGY SCENARIO and ROLE of NE

National Plan of Energy 2030: Role of Nuclear Energy

• The reference scenario forecast an expansion of the installed electricity capacity of **130,100 MWe** until 2030. Nuclear shall contribute with **5,300 MWe**. The CNPE approved the restart of Angra 3 construction (1,350 MWe PWR Siemens design, twin to Angra 2 Unit). Expected operation date: 2013.

ELECTRICITY CAPACITY EXPANSION, GWe	2005	2015	2020	2025	2030	INCREASE 2005-2030
Installed capacity	86.9	128.8	151.7	181.7	217.0	130.1
Hydropower	68.6	99.0	116.1	137.4	156.3	87.7
Conventional thermal	14.9	21.0	22.5	25.0	32.5	17.6
NUCLEAR	**2.0**	**3.3**	**4.3**	**5.3**	**7.3**	**5.3**
Alternative sources (*)	1.4	5.5	8.8	14.0	20.9	19.5
Annual average increased		8.4	4.6	6.0	7.1	5.2

(*) Mostly from small hydropower plants, biomass plants, wind plants

Results – DESCRIPTION of INS

Technology and Systems selection

ADVANCED THERMAL REACTOR WITH OPEN FUEL CYCLE BASED ON ENRICHED URANIUM

For the nuclear reactor component:

ADVANCED PRESSURIZED WATER REACTOR TECHNOLOGY, with innovative features (IRIS and FBNR reactors)

For the nuclear fuel cycle component:

ALL INDIGENOUS NUCLEAR CAPACITY AND FACILITIES AVAILABLE, including uranium mining and milling, uranium conversion, uranium enrichment, nuclear fuel fabrication, electricity generation and waste management facilities (waste disposal facilities are not taken into account). Material resource is not a major concern since Brazil has large reserves of uranium sufficient to satisfy the demand considered in the reference scenario.

Location envisaged for INS installation

Southeast region: 1000 MWe NPP Units
Northeast region: 335 MWe NPP Units (seawater desalination option desirable).

Results – NUCLEAR POWER PLANTS

IRIS - International Reactor Innovative and Secure

Integral, modular and small sized PWR, which focused on innovative safety features (Safety-by-design™)

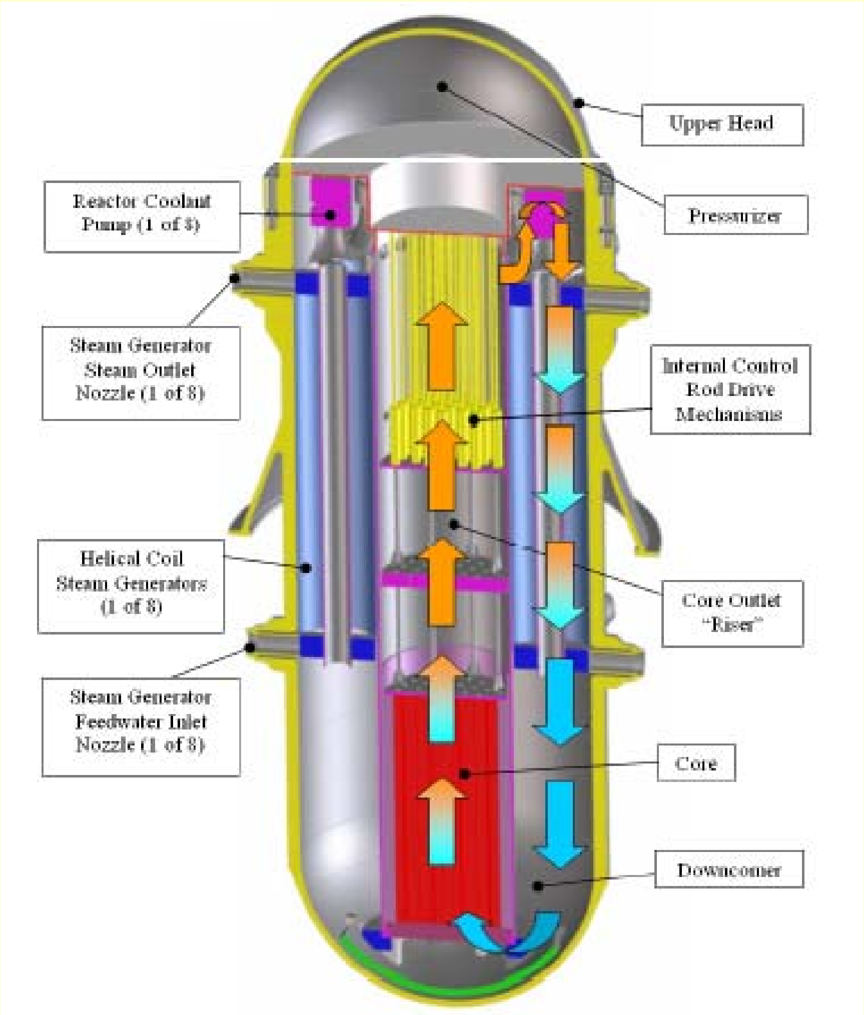
Some design parameters:

Power output 335 MWe/module
Fuel: UO_2, enriched to 4.95%
Core lifetime: ~ 4 years
Plant lifetime: ~ 60 years

Desalination option: 279 MWe

Advanced stage of development

(Preliminary licensing stage)



Results – NUCLEAR POWER PLANTS

FBNR - Fixed Bed Nuclear Reactor

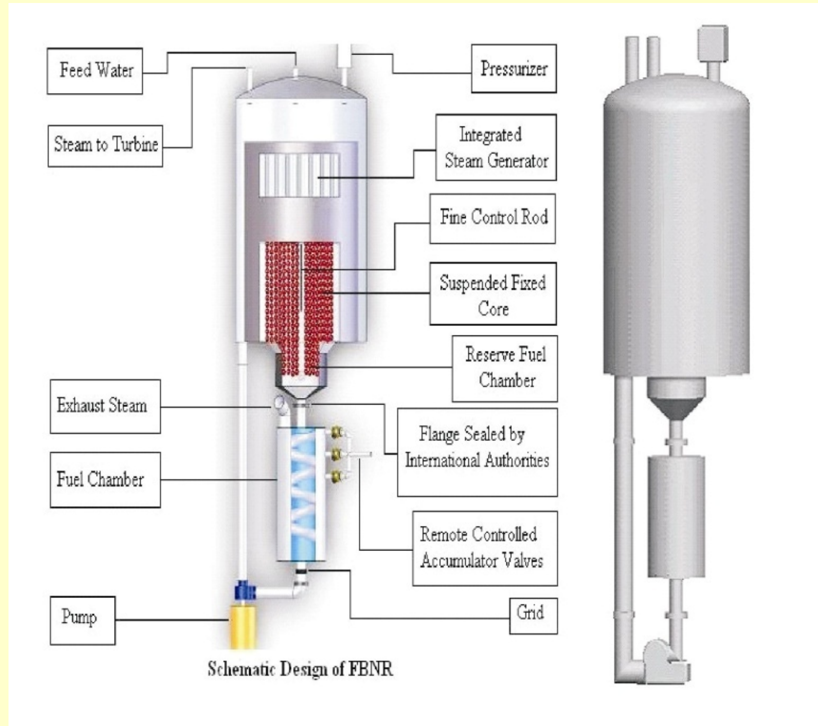
Integral, modular, small sized PWR, factory fabricated and fuelled.

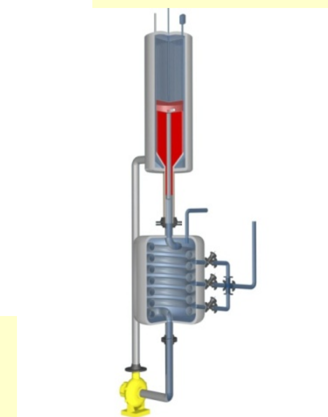
Some design parameters:

Power output: 70 MWe/module
Fuel: CERMET type spheres
15 mm diameter, Zircaloy cladded fuel element.

Desalination option

Conceptual stage of development





CERMET Fuel Element

15mm Diameter

Results – MAIN RESULTS

IRIS safety assessment results

- **31** out of **38** numerical or logical values indicators were assessed as **COMPLIANT (82%)**
- **04** indicators have **POTENTIAL** to be acceptable **(11%)**
- **01** indicator **TO BE JUDGED** (analyses and/or experiment have yet to be performed)
- **02** indicators were found **NON-APPLICABLE**

JUDGEMENT ON POTENTIAL: COMPLIES MOSTLY with the 4 BP of safety

IRIS economics assessment results

- **06** out of **08** numerical or logical values indicators were assessed as **COMPLIANT (75%)**
- **02** indicators have **POTENTIAL** to be acceptable **(25%)**

JUDGEMENT ON POTENTIAL: COMPLIES MOSTLY with the BP of economics.

Results – MAIN RESULTS

FBNR safety assessment results

- **29** out of **38** numerical or logical values indicators were assessed as **COMPLIANT (76 %)**
- **09** indicators have **POTENTIAL** to be acceptable **(24 %)**

JUDGEMENT ON POTENTIAL: COMPLIES MOSTLY with the 4 BP of safety

FBNR proliferation resistance assessment results

- **ALL** numerical or logical values indicators were assessed as **COMPLIANT (100 %)**

JUDGEMENT ON POTENTIAL: COMPLIES with the BP of PR

Lessons – CHALLENGES/LIMITATIONS and UNDERLYING CAUSES

Clarity of documentation

• The INPRO documentation was considered reasonably clear by the assessors. Nonetheless, there is still room for improvement, such as, for example, the preparation of a comprehensive case of a full scope NESA assessment (that is, an assessment study of a complete INS covering all INPRO areas) and the establishment of a set of minimum numerical values for the acceptance limits, whenever applicable.

Availability of data/information needed

• Despite CNEN being a member of IRIS consortium, the assessment team had difficult in obtaining complementary information from the IRIS project leaders. The main underlying cause was their lack of knowledge of INPRO methodology, which apparently hampered them in providing useful and timely information.

Support from Secretariat

• Although recourse to INPRO Secretariat to contact project designers had been considered at some point, a firm request for assistance was not actually placed. On the other hand, the effort of the Secretariat to make the various Chapters of INPRO Manual available in due time was appreciated by the assessors.

Lessons – CHALLENGES/LIMITATIONS and UNDERLYING CAUSES

Overview of proposed modifications to INPRO methodology

- The (numerical and logical) acceptance limits should be based, to the extend possible, on design data from evolutionary generation III reactors and from fuel cycle technologies already demonstrated (or at least in prototype scale) AND should be incorporated into INPRO methodology and Manual. The specification of acceptance limits for new indicators eventually introduced by assessors should obey the same criterion.

- The case examples inserted at the end of each Manual Chapter should refer to the same and complete INS.

- A minor error in equation 35 of Appendix A of INPRO Manual of Economics was identified. A correction formula was proposed.

Lessons – BENEFITS of performing the INPRO AS

Benefits versus expectations

- A better understanding of INPRO methodology;
- Trained a small group of reactor specialists in the methodology;
- A first judgement of the IRIS- and FBNR-based INSs potential to contribute to sustainable energy development in the country;
- Help disseminate the INPRO project and the INPRO methodology inside CNEN and in some external institutions.

Application of assessment results

- There is no immediate application planned for the assessment results but in the medium-term, they might influence the selection of the new NPPs to be considered for deployment after the start-up of operation of Angra 3 NPP. Nonetheless, the experience gained in carrying out this exercise shall be useful in future when assessing other reactors types of interest.

Results versus effort

- Results were commensurate with the effort employed. The overall effort was greatly reduced by the availability in just-in-time manner of the National Plan of Energy 2030.

RECOMMENDATIONS to INPRO and IAEA

Summary of key points

- IAEA and INPRO secretariat should assist interested assessors in obtaining complete technological and economic (non-sensible) data from the INS designers and technology suppliers necessary for their assessment studies;

- Training courses (workshops) in the application of INPRO methodology should be offered on a regular basis (every 2 to 3 years, for example);

- INPRO secretariat should develop a database containing information on innovative technologies (reactors and fuel cycles) useful for INPRO assessment studies;

- A first version of the so-called INPRO Portal should be completed and released as soon as possible. All relevant information (such as, INPRO methodology, Manual, Reports of Assessment Studies and Collaborative Projects, Technology Database, INPRO meetings, etc.) should be made available to all INPRO Member States.

RECOMMENDATIONS to INPRO and IAEA

Suggestions for updating the methodology and revising TECDOC-1575

• The (numerical and logical) acceptance limits should be based, to the extent possible, on design data from evolutionary generation III reactors and from fuel cycle technologies already demonstrated (or at least in prototype scale) AND should be incorporated into INPRO methodology and Manual. The specification of acceptance limits for new indicators eventually introduced by assessors should obey the same criterion.

• A full scope assessment study (covering a complete INS and all INPRO areas) should be performed and incorporated by areas at the end of the corresponding chapters of the INPRO Manual.

Timing

• A revised version of TECDOC-1575 incorporating the main points cited above should be available no later than 2012.

CONCLUDING REMARK

- **INPRO methodology (IAEA/TECDOC-1575) is an useful methodological tool that can be used for judging the potential of a nuclear energy system to contribute for sustainable energy development.**

Thank you for your attention

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