SIMPOSIUM
SITING OF NEW NUCLEAR
POWER PLANTS AND
IRRADIATED FUEL FACILITIES

Operation and Construction Experience
of Brazilian Nuclear Power Plants

ELETROBRAS ELETRONUCLEAR

(Fernando Henning)
(DT)
Contents

- Company Introduction
- Plants in Operation: Angra 1 and 2
- Opportunity for Nuclear in the Electricity Generation Matrix
- Angra 3
- New Buildings after Angra 3
Brazilian Nuclear Industry Organization

MINISTRY OF MINES AND ENERGY

ELETROBRAS (holding)

ELETROBRAS Atomic Energy

ELETROBRAS Nuclear

MINISTRY OF SCIENCE & TECHNOLOGY

BRAZILIAN NUCLEAR ENERGY COMMISSION

CNEN

NUCLEAR FUEL INDUSTRY

INB

NUCLEAR HEAVY EQUIPMENT

NUCLEP

RESEARCH INSTITUTES

IPEN, CDTN, IEN, IRD, CRCN

CONVENTIONAL UTILITIES

Furnas, Chesf, ...
Company Actuation in the Electrical Sector

Electricity Supply Chain

GENERATION | TRANSMISSION | DISTRIBUTION | CONSUMERS

• Industry
• Trade
• Residential
• Others

ELETRONUCLEAR: Production of electricity from nuclear source.
ELETRONUCLEAR Objectives

Design, build and operate nuclear power plants according to high standards of safety, efficiency and social and environmental responsibilities.

Develop the capability of Brazilian industry and engineering companies to provide supplies and services for nuclear power plants.
<table>
<thead>
<tr>
<th>Directorate</th>
<th>Staff Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rio</td>
</tr>
<tr>
<td></td>
<td>Engineers</td>
</tr>
<tr>
<td>DT</td>
<td>195</td>
</tr>
<tr>
<td>DO</td>
<td>11</td>
</tr>
<tr>
<td>DA</td>
<td>20</td>
</tr>
<tr>
<td>DG</td>
<td>42</td>
</tr>
<tr>
<td>DP</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>275</td>
</tr>
</tbody>
</table>

| Total        | 275          | 16          | 597     | 888    | 355       | 15         | 1427   | 1797  | 0        | 0          | 5        | 5      | 630   |

The table above represents the distribution of staff members across different directorates and locations within an organization. The columns represent the number of engineers, physicists, and others, and the rows are classified by directorate. The final row sums the staff numbers across all directorates, providing a total count for each category.
Admiral Álvaro Alberto Nuclear Power Station

ANGRA 2
Power: 1.350 MW
Technology: Siemens/KWU
Operation: January/2001

ANGRA 1
Power: 640 MW
Technology: Westinghouse
Operation: January/1985

ANGRA 3
1.405 MW
June 2018

Main Thermal Power Plant in Brazil

- São Paulo: 220km
- Belo Horizonte: 350km
- Rio de Janeiro: 130km
Safety and Environmental Protection

Safety and Environmental Protection

Angra 1 + 2

about 40 years
reactor operation

IAEA

inspection by international
institutions

IAEA

WANO

no radiological
impact to
environment

waste stored at
site according to
high safety and
environmental
standards

licensing and fiscalization

personnel training
- More than 200 million MWh produced
- Operation according to high safety and performance standards
- Continuous improvement of performance indexes
Operational Safety Record

Angra 1 + 2

Report of safety related events (according to CNEN-NE-1.14)

- No incidents, only deviations without safety relevance (INES scale level 0)

INES Scale - IAEA
Investments in the Operating Plants

- Upgrading and Replacement of Large Components
- Design Improvements
- I&C Modernization
- Safety Improvements (including Fukushima Response Plan)
- Ageing Management for Plant Lifetime Extension
- Extension and Improvement of Waste Management Center
- Spent Fuel Storage Facility Outside the Units

Investments

<table>
<thead>
<tr>
<th>Year</th>
<th>Angra 1 + 2 (R$ million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>110,0</td>
</tr>
<tr>
<td>2009</td>
<td>164,5</td>
</tr>
<tr>
<td>2010</td>
<td>172,8</td>
</tr>
<tr>
<td>2011</td>
<td>129,6</td>
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<tr>
<td>2012</td>
<td>131,1</td>
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</tbody>
</table>
Plant Life Cycle Management

1- Beginning of commercial operation (1985, design for 40 years)
2- License for 30 years (1994)
3- First PSR (2004)
4- License for 14 years (2010)
5- Second PSR (2014)
6- Recommended deadline for LR application (2019)
7- Third PSR (2024)
8- Expiration of current license (2024) and beginning of extended life - 20 years
9- Expiration of renewed license (2044)
Angra 1: Plant Life Cycle Management

- **Keeping of Design Safety and Performance Levels**
  - Replacement of the RPV Closure Head and CRDM
  - Mitigation of PWSCC in Dissimilar Metal Welds in RPV Nozzles (MSIP)
  - Service Water System (Equipment and Piping Replacement)
  - Liquid Radioactive Waste System (Replacement of the Evaporator Package)
  - Replacement of the Main Transformers
  - Reactor Coolant Pump Shield Passive Thermal Shutdown Seal
  - Monitoring of Civil Structures
  - Assessments and Design Modifications for Severe Accidents
  - Fukushima Response Plan

- **Power Uprating and Reduction in Outage Duration**
  - Modifications in the Secondary Circuit
  - Replacement of Turbine Rotors and Upgrade of the Electrical Generator
  - Improvements in Electrical Equipment

- **Life Extension**
  - License Renewal Process (Implementation of LTO Concepts)
  - I&C Modernization
  - Replacement and Refurbishment of Aged Equipment
Plant Life Cycle Management

1. Beginning of commercial operation (2001, design for 40 years)
2. License for 30 years (2011)
3. First PSR (2012)
4. Second PSR (2022)
5. Third PSR (2032)
6. Recommended deadline for LR application (2036)
7. Expiration of current license (2041) and beginning of extended life - 20 years
8. Expiration of renewed license (2061)
Angra 2: Plant Life Cycle Management

- **Keeping of Design Safety and Performance Levels**
  - Replacement of Heat Exchangers of the Conventional Closed Cooling System
  - Improvement in Primary Circuit Bleed and Feed Capability
  - RPV Level Instrumentation System
  - Main Control Room Post Accident Filtering System
  - Service Water System (equipment and piping replacement)
  - Monitoring of Civil Structures
  - Assessments and Design Modifications for Severe Accidents
  - Fukushima Response Plan

- **Power Uprating and Reduction in Outage Duration**
  - Modifications in the Turbines and in the Secondary Circuit
  - Improvements in Electrical Equipment
  - Substitution of the Original Reactor Coolant Pumps Seals by Hydrodynamic Seals

- **Life Extension**
  - License Renewal Process
  - I&C Modernization
  - Replacement and Refurbishment of Aged Equipment
Brazil Electricity Generation (Jan to Dec 2012)

Total Generation

85.90%

0.62%
1.08%
1.72%
1.49%
6.08%
3.11%

Thermal Generation

23.09%
45.08%
11.04%
12.74%
8.05%

Source: ANEEL
In a world electric generation dominated by fossil fuels Brazil is a unique example of RENEWABILITY.
Top 15 World Hydropower Generators (2010)

Only Norway and Paraguay have a relative contribution of hydropower greater than Brazil.
Hydropower requires system integration

Brazil: continental dimensions comparable to Europe
Installed Hydropower

... but without a proportional increase in the water stock

Reduced Energy Storage Capability

Installed hydro capacity increasing ...
small reservoirs to avoid flooding large surfaces
Increasing Need of Thermal Regulation

This tendency will be amplified by new projects in Amazon Basin

- Current average hydro capacity factor: 55%
- Future average Amazon hydro capacity factor: 20-25%

Project AHE MADEIRA 6.500 MW
Project AHE BELO MONTE 11.000 MW
Minimum cost according capacity factor range

But costs are not the only decision factor:

- Price volatility
- Assurance of supply must be considered too
Angra 3
(under construction)
Angra 3: Start, Deferring and Resumption

- **Initial Phase of Project**
  - 1975: Agreement Brazil & Germany (Peaceful Use of Nuclear Energy)
  - Reactor Type: PWR-1.350 MW / Increased to 1.405 MW
  - Main Vendor: Siemens-KWU (today’s AREVA)
  - Original Reference Plant: Grafenrheinfeld
  - Start of Civil Works: July-1984
  - Interruption of Construction: June-1986 (Economic Crisis in Brazil)

- **Basis for Project Modernization**
  - German Plants of Konvoi Series: Emsland / Neckarwestheim 2 / Isar 2
  - Implementation of Improvements: Angra 2 & Angra 3

- **Current Reference Plant: Angra 2**
  - Base for PSAR of Angra 3: FSAR of Angra 2
  - Main Differences: Construction on sound rock / Digital I&C / Updated normative basis

- **Present Situation: Under Construction**
  - Governmental Planning: Ten Years Plan for Energy Expansion / Growth Acceleration Plan
**Angra 3: Licensing Process**

### Environmental Licensing: IBAMA
- 17 Public Meetings with communities
- 8 Official Public Hearings:
  - Angra dos Reis (2) / Paraty (2) / Rio Claro (2) / Ubatuba (1) / Rio de Janeiro (1)
- LP: Preliminary License: 23-Jul-2008
- LI: Installation License: 05-Mar-2009
- Social Compensations: MR$ 352
  - Education, Health, Environmental, Culture, etc.

### Nuclear Licensing: CNEN
- 1\(^{st}\) Partial License: 09-Mar-2009
  - Cave levelling concrete
  - Waterproofing of nuclear buildings foundations
- 2\(^{nd}\) Partial License: 11-Mar-2010
  - Conventional Structures
- 3\(^{rd}\) Partial License: 29-Mar-2010
  - Turbine Building
- Construction License: 31-May-2010
  - Subject to gradual authorizations for concrete pouring

### Environmental Licensing:
- 38 releases already granted
  - Total volume authorized by CNEN: 77,926m\(^3\)
  - Total volume with pending authorization by CNEN: 23,103m\(^3\)
Angra 3: Upgrading of Normative Basis

- Angra 2 Design
  - "as built"
  - Reference Plant
  - Angra 2 Design Modification
  - 50 Project Modifications
- Angra 3 Design

Additional requirements !!!

- Licensing
  - Evaluation of the Angra 3 design considering the normative basis valid in 2003
  - Upgrading of the protection against external events

- modernization of all I&C systems;
- last generation man-machine interface;
Angra 3: Budget for Completion

<table>
<thead>
<tr>
<th>ITEM</th>
<th>JUNE-2010 (R$ x 10^6)</th>
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<tbody>
<tr>
<td>Licensing</td>
<td>10,0</td>
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<tr>
<td>Environmental Expenses</td>
<td>352,1</td>
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<tr>
<td>National Engineering</td>
<td>439,5</td>
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<td>Foreign Engineering</td>
<td>758,3</td>
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<td>National Supplies</td>
<td>1,612,3</td>
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<td>Imported Supplies</td>
<td>2,224,6</td>
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<tr>
<td>Civil Construction</td>
<td>1,514,8</td>
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<tr>
<td>Electromechanical Erection</td>
<td>1,447,4</td>
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<tr>
<td>Other Expenses</td>
<td>322,4</td>
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<tr>
<td>Contingency</td>
<td>606,3</td>
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<tr>
<td>First Fuel Charge</td>
<td>662,4</td>
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<tr>
<td><strong>TOTAL</strong></td>
<td><strong>9,950,1</strong></td>
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</table>

~ USD 5.4 B
USD/R$ = 1.85

- 7 Independent Budgetary Studies required by:
  - CNPE: National Council for Energy Policy
  - MME: Ministry of Mines and Energy
  - ELETROBRAS: Holding Company

**Reference to the Budget Estimate:**
FUSP (June-2002)
Monetary update for June-2010
Angra 3: Contractual Arrangement

- Existing Contracts to be negotiated (signed in the 80s)
- Main Contracts
- Biddings
  - Imported Goods and Services + Warranties
  - Civil Works
  - Civil Design Structures
    - Partial Scope
  - National Supplies
    - Existing Contracts
  - Engineering Services
  - Electromechanical Erection
  - National Supplies

Confab Bardella Nuclep

Andrade Gutierrez

Engenix

AREVA
Angra 3: Funding

**Domestic Market**

- **BNDES:** R$ 6.1 billion  
  MR$ 1,277 released

- **Eletrobras:** R$ 890 million  
  MR$ 594.3 released

**Foreign Market**

- **CAIXA:** R$ 3.8 billion
Angra 3: Main Activities at Site – Civil Works

- Reactor Building (UJB)
- Auxiliary Reactor Building (UKA)
- Control Building (UBA)
- Turbine Building (UMA)
Angra 3: Main Activities at Site - Erection

Steel Containment Erection

Zone 1

Zone 2

Zone 3

Zone 4

Zone 5

Simulation
Time schedule currently under reevaluation:
AREVA supplies and services:
• signature of amendments expected for May 2013;
• critical path: design and supply of safety digital I&C;
Bidding process for electromechanical erection:
• 2nd phase to be launched in April 2013;
• expectation to start at site in last quarter of 2013.
EXPLORATORY STUDY: SITE PE-1 (artistic view)
## Electricity Supply Expansion

<table>
<thead>
<tr>
<th>Fonte</th>
<th>CASO BASE</th>
<th></th>
<th>CASO 1</th>
<th>CASO 2</th>
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<tbody>
<tr>
<td></td>
<td>N</td>
<td>NE</td>
<td>SE/CO</td>
<td>S</td>
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<tr>
<td>Conservação</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td>?</td>
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<tr>
<td>Hidrelétrica</td>
<td>43.720</td>
<td>580</td>
<td>8.860</td>
<td>4.140</td>
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<td>Gás Natural</td>
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<td>3.500</td>
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<td>Carvão</td>
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<td>4.000</td>
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<td>Biomassa</td>
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<td>950</td>
<td>3.300</td>
<td>500</td>
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<td>Resíduos Urbanos</td>
<td>0</td>
<td>300</td>
<td>700</td>
<td>300</td>
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<tr>
<td>TOTAL</td>
<td>45.520</td>
<td>10.630</td>
<td>31.260</td>
<td>12.740</td>
</tr>
</tbody>
</table>

(1) 53 TWh (aprox. 16% do consumo atual) = Potência de cerca de 12.000 MW (hidrelétrica) ou 7.800 MW (nuclear)

Fonte: PNE 2030 / EPE-MME, Nov-2007 / Tabelas 8.27 (Pág.234) e 8.31 (Pág.239)
Sites for New Nuclear Power Plants

BRAZILIAN NUCLEAR POTENTIAL ATLAS

40 CANDIDATE AREAS
Thanks for the attention!!!